Using Mobile Devices as Experimental Tools in Physics Lessons

An empirical study of the effects on learning and motivation at secondary school level

THÈSE

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par

Maria Alice GASPARINI

de

Rougemont (VD)

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Résumé

Aperçu et axes de recherche

Les tablettes numériques et les smartphones sont des appareils faciles à manipuler et largement répandus parmi toutes les générations, l'utilisation de ces dispositifs mobiles comme instruments de mesure dans les expériences (en anglais « Mobile Devices as Experimental Tools » – MDETs) dans les cours de sciences est aujourd'hui une réalité: les capteurs intégrés les rendent des vrais instruments de laboratoire compactes et relativement peu coûteux, capables d'effectuer des mesures pour un grand nombre de phénomènes tels que la mécanique, l'électricité, l'acoustique, l'optique et la radioactivité (entre autres). Un premier avantage de l'utilisation des MDETs dans l'enseignement des sciences est la possibilité d'effectuer des mesures précises et – par rapport aux instruments de classe traditionnels – relativement sans effort, tout en permettant une interprétation en temps réel des données, et ce à l'intérieur et à l'extérieur de la salle de classe. Cela donne aux élèves la possibilité d'apprendre les sciences dans de nouveaux contextes, pouvant être perçus comme plus authentiques par rapport aux cours de sciences traditionnels (*contexte situationnel*). De plus, puisqu'il s'agit d'appareils familiers, faisant partie de la vie quotidienne des élèves, les smartphones et les tablettes sont perçus comme des instruments authentiques en soi, en constituant ainsi un *contexte matériel*. Cette double authenticité correspond au cadre théorique de l'enseignement des sciences basé sur le contexte (« Context Based Science Education »): des observations empiriques ont indiqué qu'en fournissant de la pertinence dans les cours par des contextes authentiques il est possible d'avoir un impact positif sur la motivation et l'apprentissage des élèves.

En dépit de la croyance répandue selon laquelle un effet positif sur la motivation peut entraîner des effets positifs considérables sur les résultats d'apprentissage, les méta-analyses indiquent plutôt que seulement une corrélation modérée existe entre la motivation et l'apprentissage. En outre, les preuves empiriques des effets *directs* des MDETs sur les résultats d'apprentissage ne semblent pas concluantes à l'heure actuelle. D'une part, les MDETs représentent des instruments à grand potentiel, dont les applications peuvent produire aisément et rapidement des tableaux, des schémas et bien d'autres fonctions qui, dans un cours traditionnel, doivent être produites par les élèves eux-mêmes. En conséquence, les élèves qui maîtrisent déjà ces fonctionnalités peuvent idéalement bénéficier d'une réduction de la charge cognitive étrangère au cours des expériences, résultant en une capacité d'apprentissage accrue. Cet effet a d'ailleurs déjà été observé pour l'utilisation d'autres technologies de l'information et des communications (TIC) dans le contexte l'apprentissage des sciences. Par ailleurs, d'autres études ont également indiqué des effets négatifs des TIC sur l'apprentissage, par exemple des effets distrayants entravant l'apprentissage.

Bien que de nombreuses expériences utilisant les MDETs aient été proposées au cours de la dernière décennie, il n'existe que peu d'études empiriques évaluant leurs effets en didactique. Des études récentes ont été menées au niveau secondaire II, remplaçant uniquement les instruments de mesure par des MDETs (fournissant donc uniquement le *contexte matériel*), lors d'une seule session de laboratoire de mécanique. Des effets ont été ainsi observés

- Sur l'intérêt et la curiosité – mais pas sur l'apprentissage – pour les élèves des classes non spécialisées en physique ;

- Sur l'apprentissage de la physique – mais pas sur les variables affectives – chez les élèves des classes spécialisés en physique.

Une autre étude concernant des étudiants universitaires en physique, où des exercices d'analyse vidéo utilisant les MDETs ont été ajoutés aux exercices des séances hebdomadaires, a montré des effets positifs à la fois sur l'apprentissage du cours et sur plusieurs variables de motivation.

<u>Objectifs et conception de l'étude</u>

La principale différence entre cette recherche et les investigations précédentes réside dans son intégration systématique dans toute une séquence d'enseignement dans de classes ordinaires de physique, la durée de l'intervention, le niveau scolaire et le profil des élèves (non spécialisés en physique). En effet, d'une part les effets bénéfiques sur l'apprentissage peuvent être amplifiés lorsqu'ils sont mis en œuvre de manière systématique sur le long terme. D'autre part, le niveau d'intérêt plus élevé observé suite à une intervention de courte durée pourrait être dû à un effet de nouveauté, ou uniquement à l'intérêt des élèves pour les dispositifs eux-mêmes (contexte matériel), sans que cela puisse se traduite en réel intérêt pour les sujets étudiés : dans ce cas, l'effet ne serait que temporaire. Le but de cette recherche a donc été d'exploiter pleinement le potentiel des MDETs afin d'évaluer leurs effets au niveau du secondaire II sur le long terme (plusieurs mois), non seulement sur l'apprentissage de la mécanique, mais aussi des mathématiques sous-jacentes, de plus que sur la motivation, en tenant compte et en complétant les résultats précédents.

Dans cette perspective, plusieurs activités MDETs ont été conçues, de sorte qu'elles puissent convenablement remplacer les activités de laboratoire traditionnelles pendant tout un semestre pour le groupe de traitement, tout en conservant les mêmes objectifs pédagogiques et dans les mêmes délais que pour le groupe de contrôle. Cela a été possible grâce à la praticité et la versatilité des MDETs: en effet, contrairement à d'autres façons de mettre en œuvre un enseignement des sciences basé sur un contexte authentique, et au-delà des effets sur les élèves, l'utilisation de ces instruments peut facilement être intégrée dans le cours sans changements majeurs à l'environnement didactique déjà existant. Ainsi, dans le choix des activités des MDETs, la priorité a été donnée aux objectifs pédagogiques dans les délais fixés par le programme scolaire, par rapport à la seule introduction d'activités avec des situations ou des instruments perçus comme authentiques. De plus, au moins le contexte matériel a été présent pour le groupe de traitement dans toutes les activités, et le contexte situationnel a été présent lorsque les conditions le permettaient. Afin d'évaluer l'avantage réel de l'utilisation des MDETs par rapport au même cours sans leur utilisation, les approches didactiques et la planification de l’enseignement ont été maintenues les mêmes dans le groupe de contrôle et dans le groupe de traitement. En particulier, le même contexte situationnel a été créé dans les deux groupes. Lorsque, pour des raisons pratiques, les conditions n'ont pas permis au groupe de contrôle de réaliser une expérience (ayant les mêmes objectifs d'apprentissage que le groupe de traitement) avec le même contexte situationnel que le groupe de traitement, ce même contexte situationnel a été créé sous la forme d’exercice sans prise de mesures. De plus, au final le nombre total d'expériences réalisées au cours de l'étude a été le même pour les deux groupes.

L'étude a été construite sur des comparaisons multiples entre le groupe de contrôle et le groupe de traitement (sans ou avec MDETs), sur des élèves du lycée genevois (« collège »), qui n'ont pas choisi la physique et les mathématiques comme option spécifique pour leur maturité. Au cours de l'année scolaire 2018-2019, 105 élèves ont participé à l'étude pilote, appartenant à 7 classes de 2$^{\text{ème}}$ année, reparties entre 3 enseignants dans 2 collèges genevois. En 2019-2020, l'étude principale a été réalisée sur 8 classes encadrées par 4 enseignants de 3 collèges. Il s’agissait de trois classes de 2$^{\text{ème}}$ année et une classe de 3$^{\text{ème}}$ année. Pour l'étude pilote et l'étude principale, chaque enseignant avait au moins une classe appartenant au groupe de contrôle et une classe appartenant au groupe de traitement (classes parallèles). Nous remarquons que les post-tests des classes d’un des enseignants ont été effectués lors du premier confinement de la pandémie de Covid19. Les interventions ont duré à chaque fois un semestre entier. Le programme couvrait la cinématique et la dynamique de base: position, vitesse moyenne et instantanée, vitesse, accélération, mouvement rectiligne uniforme, mouvement rectiligne uniformément accéléré, les trois lois de Newton, la gravitation et la chute libre. Dans le groupe de traitement, cinq à six activités basées sur l'analyse vidéo ont remplacé les expériences traditionnelles et/ou certains exercices. Hormis cette différence, le plan de cours et le contenu d'apprentissage des travaux pratiques ont été identiques pour les deux groupes ayant les mêmes enseignants.

L'apprentissage conceptuel a été mesuré avant et après le l’instruction par un questionnaire à choix multiple développé à partir de tests conceptuels existants ainsi que de quelques nouvelles questions, afin d’adapter l’instrument aux contenus spécifiques de la séquence didactique. En sus des questionnaires conceptuels, les résultats des évaluations habituelles faites par les enseignants ont été considérés. Une série de variables dépendantes affectives ont été mesurées (*intérêt*, *relation à la réalité*, *conception de soi* et *curiosité* par rapport au cours de physique) et, en outre, plusieurs co-variables potentiellement pertinentes ont été prises en compte (par exemple les capacités non verbales, les connaissances préalables, la familiarité avec les TIC ou la charge cognitive). Tous les tests sont basés sur des instruments précédemment publiés et ont été traduits en français et revalidés avant le début de l'étude pilote.

Sélection de résultats et implications

Le questionnaire d'apprentissage conceptuel développé, adapté au contenu d'apprentissage spécifique de l'intervention, présente des propriétés psychométriques satisfaisantes à très bonnes (difficulté des items, discrimination, cohérence interne), comparables aux autres tests conceptuels et aux normes actuelles. Il en va de même pour les instruments utilisés pour les variables affectives et les co-variables (par exemple pour l'*intérêt* pour la physique, la *conception de soi* et la *curiosité* $\alpha_C \approx 0.7 - 0.8$). Dans l'étude pilote et dans l'étude principale, un fort gain d'apprentissage global dans la compréhension conceptuelle de la mécanique a été observée à la fois dans le groupe de traitement et dans le groupe de contrôle, y compris les élèves qui ont passé le post-test pendant la première semaine de confinement dû à la pandémie de Covid19. Au total, pour la taille de l'effet pré/post (Cohen *d*), la plus petite valeur tourne autour de 1, indiquant un effet entre le « grand » et le « très grand ». L'effet s'est produit également dans les groupes de chaque enseignant pris séparément, montrant que l'enseignement a été efficace pour toutes les classes prises individuellement, qu'elles aient été de traitement ou de contrôle. Cependant, les résultats de l'analyse ANCOVA de l'étude principale ont confirmé ce qui ressortait également de l'étude pilote, c'est-à-dire qu'aucun effet de l'utilisation des MDETs sur l'apprentissage de la physique n'est présent: ni sur la note globale du semestre, ni sur les résultats de la compréhension conceptuelle de la mécanique (tests conceptuels). Par ailleurs, nous remarquons que les MDETs n'ont pas d'effet significatif sur la charge cognitive lors des expérimentations, indiquant qu'aucun effet distrayant de ces dispositifs ne se produit lorsque leur utilisation est suffisamment encadrée.

L'étude a également confirmé le lien existant entre l'apprentissage de la physique et des mathématiques, notamment par l'observation d'un possible effet de petite taille de l'utilisation des MDETs sur l'évolution des résultats en mathématiques. En effet, les élèves du groupe de traitement ont obtenu en moyenne une meilleure note en mathématiques que ceux du groupe de contrôle. Aussi petit soit-il, cet effet hypothétique peut s'expliquer en considérant le programme parallèle de mathématiques suivi par les élèves dans le même semestre inclut l'algèbre, les polynômes et les fonctions, dont l'apprentissage pourrait en effet être amélioré par les représentations multiples fournies par les applications d'analyse vidéo dans le cours de physique. Cette possibilité est confirmée par l'impression générale des enseignants participant à l'étude. Ainsi, au-delà du fait qu'aucun effet global n'a pu être observé au cours de cette étude, nous avons des indices qui laissent penser que l'effet de l'utilisation des MDETs dans les cours de physique sur l'apprentissage des mathématiques pourrait être étudié plus en profondeur dans le futur. Bien que la présence d'un tel effet soit hypothétique, cette relation est en ligne avec le cadre théorique indiquant un fort lien entre l'apprentissage de la physique et celui des mathématiques, et mérite d'être pris en compte dans la planification de futures recherches.

De manière similaire à ce qui a été observé pour l'apprentissage, l'enseignement était globalement équitable entre le groupe de traitement et le groupe de contrôle pour ce qui concerne les variables dépendantes affectives. Les variations pré/post de *relation à la réalité*, *conception de soi*, *intérêt* et *curiosité* par rapport au cours de physique ont été similaires pour les deux groupes, et les variations temporelles (pré/post) de ces variables affectives ont toutes été

- légèrement négatives sauf pour la *relation à la réalité* dans l'étude pilote, bien que de manière non significative ;
- toutes légèrement positives sauf image de soi dans l'étude principale. Pour la *relation à la réalité* et *l'intérêt*, cette amélioration est significative à la fois pour le groupe de traitement et le groupe de contrôle, avec un effet de petite taille (d entre 0,28 et 0,30 pour la *relation à la réalité*, et entre 0,19 et 0,23 pour l'*intérêt*).

De plus, aucune différence significative, due à l'utilisation des MDETs, concernant l'évolution des variables affectives n'a été observée. Ceci confirme que l'éventuelle première phase d'intérêt des élèves pour l'utilisation des MDETs (contexte matériel) finit par s'estomper au cours du semestre.

Au-delà des effets des MDETs en tant que tels, cette étude a reproduit certains résultats précédemment connus dans la recherche en enseignement des sciences, tels que l'influence du genre dans l'apprentissage de la physique, ainsi que l'impact important des connaissances antérieures sur la réussite.

Conclusion

En conclusion, bien que l'intervention ait été globalement aussi bonne mais pas meilleure qu'un apprentissage conventionnel assez efficace en physique, de nouvelles perspectives s'ouvrent quant à l'utilité des MDETs pour un meilleur apprentissage des mathématiques sous-jacentes à la physique. En particulier, des perspectives restent ouvertes quant à l'utilisation de ces dispositifs pour créer des situations authentiques dans l'apprentissage de la physique, par exemple lors de travaux à domicile ou dans le cadre extrascolaire.

Outre l'impact sur les élèves, l'utilisation des MDETs offre des perspectives intéressantes pour l'enseignement de la physique dans les classes de lycée pour diverses raisons. Tout d'abord, la facilité et la praticité de la préparation des expériences par les enseignants constitue un avantage certain: pour le même contenu qu'une activité classique, les activités avec les MDETs permettent une mise en œuvre plus rapide, et un gain de temps précieux pour d'autres moments pédagogiques. Les élèves ont également la possibilité de d'économiser de la charge cognitive et du temps, lors de la prise de données et lors de la production de représentations (graphiques, tableaux, régressions), à condition qu'ils soient familiarisés avec les différentes formes de représentations fournies par les applications. Le facteur le plus limitant pour une utilisation prolongée des MDETs dans les écoles reste la capacité de fournir ces appareils dans le cadre strictement scolaire et de les entretenir dans le temps, car les tablettes doivent être régulièrement mises à jour ou changées, et leur disponibilité et celle des applications nécessaires pour tous les élèves n'est pas évidente.

Summary

Overview of research

Tablets and smartphones are easy to handle and widespread among people of all generations, and the use of these Mobile Devices as Experimental Tools (MDETs) in science classes is nowadays a reality: the built-in sensors provide a new kind of compact and relatively inexpensive instruments measuring a wide number of phenomena such as mechanics, electricity, acoustics, optics and radioactivity, among others. A first advantage of using MDETs in science education is the possibility to perform relatively – with respect to traditional classroom instruments – effortless and, in the same time, precise measurements, supporting a real time interpretation of the data, both inside and outside the classroom. This makes it possible for pupils to learn science in new contexts that can be perceived as more authentic than traditional sciences courses (situational context). Moreover, as these are familiar devices, part of everyday life of pupils, they are perceived as authentic instruments in themselves (material context). This double authenticity matches the theoretical framework of Context Based Science Education, and the empirical evidence shows that providing relevance by certain authentic contexts can have a positive impact on pupils' motivation and learning.

Despite the widespread belief that a positive effect on motivation can lead to strong positive effects on learning achievement, meta-analyses show only a moderate correlation between motivation and learning. Furthermore, the empirical evidence of the direct effects of MDETs on learning achievement seems to be inconclusive at present. On the one hand, they represent powerful instruments whose applications can easily and straightforwardly produce tables, diagrams, and many other functions that – in a traditional course – have to be produced by the pupils themselves. As a consequence, pupils that already know to handle those functions could benefit from a reduction of the extraneous cognitive load during the experiment, resulting in increased capacity for learning. This has already shown for other Information and Communications Technology (ICT) applications to science learning. Yet other studies indicated also negative effects of ICT on learning, e.g. distracting effects, impeding learning.

Even though many experiments using MDETs have been proposed in the last decade, only few empirical studies about their educational impact exist. Recent studies were carried out at the secondary II level, replacing only the measuring instruments of a single mechanics' classroom laboratory by MDETs (providing only the material context). Effects were observed

- On interest and curiosity – but not on learning achievement – for pupils of non-specialized physics classes;
- On learning – but not on affective outcomes – on pupils of specialized physics courses.

Another study concerning undergraduate physics' students, where video analysis exercises using MDETs have been added to the exercises in the weekly tutorial sessions, showed positive effects both on learning and on affective outcomes.

Purpose and design of this study

The main difference of this study with respect to previous investigations is its systematic integration in a whole learning sequence in regular physics classroom, the duration of the study, the school level and the profile of the students, not specialized in physics. On the one hand, the effects of a beneficial approach on learning can be larger, when implemented in a systematic and longer-lasting way. On the other hand, for an intervention of short duration the observed higher level of interest could be due to a novelty effect or to the pupils' interest in the devices themselves (material context), but not a real interest in the studied topics. If this is the case, this effect might only be temporary. The aim of this research is thus to fully exploit the potential of MDETs to assess their effects at the level of the secondary school on the long term (several months) not only on the learning of mechanics, but also of the related mathematics, more than on the motivation, taking into account and completing the previous results.

With this aim, we produced several MDETs activities, which suitably replace the traditional laboratory activities in the treatment group during a whole semester, while maintaining the same educational objectives and within the same deadlines as the control group. This has been possible thanks to the practicality of MDETs: unlike other ways of implementing context-based science education, and beyond the effects they can have on students, the use of these devices can easily be integrated into the course without major changes in existing pedagogical environment. Thus, in the choice of MDETs activities priority has been given to educational objectives within the time limits fixed by the school program, before the sole introduction of activities with authentic instruments or situations. Furthermore, at least the material context was present in all the activities; the situational context has been added when conditions allowed it. In addition, in order to assess the actual advantage of using MDETs with respect to the same course without their use, the planning and teaching approaches have been kept the same in the control group and in the treatment group. In particular, the same topical context has been privileged in both groups. When, for practical reasons, the conditions did not allow the control group to carry out an experiment (having the same learning objectives as the treatment group), with the same topical context as treatment group, this topical context was as well present as an exercise sheet. Eventually, the total number of experiments done during the study was the same for both groups.

Thus, the design was a repeated measurement control-treatment group comparison (without vs. with MDETs) on pupils of the Geneva high school, which did not choose physics and mathematics as specific option for they maturity. During the school year 2018-2019, 105 pupils participated in the pilot study, belonging to 7 class-groups of the 2nd year taught by 3 teachers. In 2019-2020, the main study was carried out on 8 class-groups taught by 4 teachers: three 2nd year class-groups and one 3rd year class-group. For both pilot study and main study, each teacher had at least one control and one treatment class (parallel classes). We notice that the post-tests of the class groups of one of the teachers were done during the first lock down of the Covid19 pandemic. The interventions lasted each time a whole semester. The curriculum covered basic kinematics and dynamics: position, average and instant velocity, speed, acceleration, uniform liner motion, uniformly accelerated linear motion, the three Newton's laws, gravitation and free fall. In the treatment group, five to six activities based on the video analysis replaced traditional experiments and/or some exercises. Up to this difference, the lesson plan and learning content of the labwork were identical for both groups, and the same teacher taught them.

Conceptual learning was measured with pre- and post-test by a multiple-choice questionnaire developed from existing concept tests as well as a few new items in order to fit the specific learning content of the sequence. In addition to the conceptual questionnaires, scores in two usual teacher-made learning assessments are recorded. A series of affective dependent variables were measured (physics interest, relation to reality, situational self-concept, curiosity) and, moreover, several potentially relevant covariates were taken in to account (e.g. non-verbal abilities, prior knowledge, familiarity with ICT, cognitive load). All the tests are based on published instruments and have been translated to French and re-validated before the beginning of the pilot study.

Selected results and implications

The newly developed conceptual learning questionnaire, adapted to the specific learning content of the intervention, shows satisfactory to very good psychometric properties (item difficulty, discrimination, internal consistency), comparable to other concept tests and to current standards. The same holds for the instruments used for the affective variables and the covariates (e.g. for physics interest, self-concept and curiosity $\alpha_C \approx 0.7 - 0.8$).

In the pilot and in the main study, an overall strong learning gain of conceptual understanding of mechanics was observed both in treatment and control group, including the pupils who took the post-test during the Covid19 pandemic shutdown. In total, the pre/post smallest effect size (Cohen *d*) is about 1, indicating a large to very large effect. The effect also occurred in the groups of each teacher taken separately, showing that the instruction was effective for all individual class-groups, whether treatment or control. However, the results of the ANCOVA analysis of the main study confirmed what also emerged from the pilot study, i.e. that no effect of the use of MDETs on the learning of physics is present: neither on the overall grade during the semester, nor on the global conceptual understanding of mechanics (conceptual tests). One the other hand, we also notice that the MDETs do not have a significant effect on the *cognitive load* during the experiments, indicating that no distracting effect of these devices occurs when their use is sufficiently scaffolded.

The study also confirmed the link existing between the learning of physics and mathematics, in particular by the possibility of a small size effect of the use of MDETs on the evolution of results in mathematics. Indeed, the pupils of the treatment group obtained a higher average *mathematics grade* than those of the control group. However small, this effect can be explained considering the parallel mathematics program in the same semester, which contains algebra, polynomials and functions, whose learning could indeed be ameliorated by the multiple representations of video analysis in physics. This possibility is confirmed by the general impression of the teachers participating to the study. Thus, beyond the fact that no overall effect could be observed during this study, we have clues that lead to think that the effect of the use of MDETs in physics classes on the learning of mathematics could be investigated more in depth in the future. Although the presence of such an effect is hypothetical, this connection would be in line with the theoretical framework of the strong interactions between physics and mathematics learning, and deserves to be considered in future research.

Similarly to what observed for learning, the instruction was overall fair between the treatment group and the control group for the affective dependent variables: the pre/post variations of the situational *relation to reality, self-concept*, *interest* and *curiosity state* in physics were similar for both groups, and the time variations (pre/post) of these affective variables were

- all slightly negative except *relation to reality* in the pilot study, although not significant;
- all slightly positive except *self-concept* in the main study. For *relation to reality* and *interest,* this improvement was significant for the both treatment and control group, with a small size effect (*d* between 0.28 and 0.30 for *relation to reality,* and between 0.19 and 0.23 for *interest*).

In addition, no significant difference by the use of MDETs for any affective output has been observed. This confirms that the possible first phase of interest of students for the use of MDETs (material context) eventually fades away during the semester.

Beyond the effects of MDETs as such, this study replicated some previously known results in science education research, such as the impact of gender in learning physics, and the important influence of prior knowledge on achievement.

Conclusion

In conclusion, although the intervention was overall as good but not better than a quite effective conventional learning in physics, new perspectives open as to the possible usefulness of MDETs for a better learning of the mathematics underlying to physics. In particular, perspectives remain open as to the use of these devices to create authentic situation contexts, for example for homework tasks or in extra-curricular settings.

Besides the impact on pupils, the use of MDETs offers interesting prospects for physics teaching in high school classes for various reasons. First, the easiness and practicality of the preparation of the experiences by the teachers constitutes a clear advantage: for the same content as a conventional activity, MDETs activities allow a faster implementation, saving precious time for other teaching moments. Pupils have the possibility to save cognitive load and time as well, when taking data and when producing representations (graphs, tables, regressions), provided that they are familiar with the different forms of representations provided by the apps. The most limiting factor for prolonged use of MDETs in schools is rather the ability to provide these devices and maintain them over time, as tablets need to be regularly updated or changed, and their availability for all the students and that of the necessary apps is not obvious.

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1. INTRODUCTION

1.1 The Geneva high school

The study presented in this document took place between 2017 and 2020 in the Geneva secondary high school ("Collège de Genève"). Geneva is the Swiss town of international organizations, where several cultures and nationalities mix in everyday life, including in public schools, and hosts CERN, the world-renowned center of physics, where the Higgs boson has been detected for the first time in the last decade. Yet, the pupils who attend secondary schools in this town do not exception concerning the youths' disaffection towards the physical sciences.

In the canton of Geneva, the pupils going to the high school (which is one among many possible choices of secondary II schools existing in Switzerland) can obtain their maturity with a four-years formation, between 15 and 19 years old, after having attended secondary I school over three years, when they are between 12 and 15 years old. When registering for high school, the pupils must choose a discipline as a specific option – in French "Option Spécifique" (OS) i. e. a discipline that is studied in more depth – among the following possibilities: Latin, Greek, a 3rd Swiss national language (that is German or Italian), English, Spanish, Physics and Mathematical Applications (PYMAP), Biology and Chemistry (BICH), Economics and Law, Visual Arts or Music. The disciplines which are not studied as specific option, are followed like "Fundamental Discipline" (DF), that is with a minimum hourly allocation and a minimum level. For example, a pupil choosing the OS PYMAP, in his 1st-2nd-3rd-4th year timetable, follows respectively 1-2-6-6 hours per week of physics (PY) and mathematical applications to physics (MAP), and he takes 4-4-6-6 hours of mathematics (MAT) per week, as shown in figure 1.1, on the left side[1]. Thus, in Geneva the high school timetable contains between 27% (all the OS but PYMAP) and 30% (only the OS PYMAP) teaching of disciplines in the "experimental sciences" family, including mathematics, which represent the lowest percentage in Switzerland.

Pupils leaving secondary I do not yet know physics and mathematical modeling, most choose non-scientific OS, around 25% prefer the "Biology and Chemistry" option (therefore the majority of students with a scientific profile) and less than 10% prefer the "Physics and Mathematical Applications" option. Indeed, the gender ratio (number of girls / number of boys) is of about 1,2 for the OS BICH and 0,3 for the OS PYMAP[2], this ratio keeps the same as observed for registrations in the same respective university faculties in the Swiss Universities (see annexed document n. 1).

[1] Source : https://edu.ge.ch/co/sites/default/files/atoms/files/grille_horaire_co_2019.pdf
[2] See https://www.ge.ch/document/annuaire-statistique-enseignement-public-prive-geneve. This ratio is of1,3 in the Geneva high school, 1,0 for the OS EL, 1,7 for the OS MU and 2,7 for the languages. These are the data of the school year 2019-2020 and they do not vary much over the years.

OS PYMAP	**1st**	**2nd**	**3rd**	**4th**
MAT 2	4h	4h	6h	6h
PY OS	2h	4h	4h	4h
MAP OS	-	-	2h	2h
BI DF	-	2h	2h	-
CH DF	2h	2h	-	-

OS BICH	**1st**	**2nd**	**3rd**	**4th**
MAT 1	4h	4h	4h	4h
PY DF	1h	2h	2h	-
MAP DF	-	-	-	-
BI OS	2h	3h	3h	3h
CH OS	2h	2h	3h	3h

Figure 1.1: Hours per week of scientific disciplines for a pupil choosing PYMAP (left) of BICH (right) as specific option (OS). The disciplines, which are not studied as specific option, are followed like “Fundamental Discipline” (DF).

Pupils following the “Biology and Chemistry” specific option have a good general learning in sciences such as biology and chemistry, but little training in mathematics and physics. Moreover, as shown in the right side of figure 1.1, the hours of physics, followed as “fundamental discipline”, are placed at the beginning of the high-school formation, which implies that these students must learn the notions of physics curriculum without having the necessary mathematical prerequisites. For example mechanics is learned without knowing the bases on the study of functions (taught in the 2nd and 3rd year), trigonometry (taught from the 2nd year), vectors (taught in the 3rd year), derivatives or integrals (taught in the 3rd and 4th year)[3]. De facto, these pupils learn first mathematics in the context of the physics class. Physics teachers are well aware of this difficulty, faced by pupils in their approach to physics and the increased disaffection toward physics and mathematics applications that results. Unfortunately, many students with a scientific profile entering high school, including a large proportion of girls, make the choice of their specific option without knowing these difficulties and find misguided and with a false impression of what mathematical language in science is.

The study of this thesis specifically concerns these pupils, learning physics as fundamental discipline, i.e. pupils who did not choose as “Physics and Mathematical Applications” as specific option, but all the other possibilities among the remaining choices: some pupils are in the “Biology and Chemistry” option, but the majority are from the other options in humanities, languages, law or arts, then they are less attracted to science at the outset. Students from all the different options other than physics are grouped together in physics’ laboratory class-groups of 14 to 16 pupils; they have in common the difficulties mentioned above, due to the incoherence in the actual structure of the Geneva timetable[4].

[3] The detailed curriculum of the « Collège de Genève » is available in the annexed document n. 2.

[4] This system with options entered into force in Switzerland since 1998. Before 1998, instead of 9 different specific options, there were 4 "profiles", whose one scientific with 2-2-3-5 hours of physics per week, 6-5-5-6

1.2 Motivation and purposes of the study

In this context, the question of the motivation in studying physics of high school pupils and of offering better conditions for learning this discipline, more than its interaction with the learning of mathematics, is central and of great importance. The challenge of finding new tools in this direction has, among other things, particularly motivated this research.

Moreover, the use of tablets and Smartphones as a learning instrument is topical in the Geneva school: since few years there is the political will to introduce digital culture across all levels of education, and a debate on this subject has started in same time as the beginning of this research. This novelty will have an impact on the pupils' timetable, as many hours of "digital culture" will be introduced in the high school's schedule starting from the fall 2021, while also sacrificing hours devoted to experimental sciences. Furthermore, the groups of teachers from all disciplines are in the process of modifying their curriculums to integrate the IT tool transversally in the learning of all branches. Therefore, the hope is that the results and the teaching material developed during this research can be taken into consideration and useful in the development of the new curriculum and the way IT will be integrated to science learning.

This study aims to establish the effects of regular use of Mobile Devices as Experimental Tools (MDETs) on motivation and learning of students of the course of physics as fundamental discipline. Its originality is firstly the innovative and stimulating technology that is examined (video analysis by tablet apps) for which there are many proposals for classroom activities but few studies in physics research about the real impact on pupils learning. With this aim, some classic laboratory sessions are replaced by MDETs activities, so that the treatment group and the control group benefit from the same proportion of time devoted to manipulation for experiments and the same level and situation of exercises or activities. Secondly, the targeted public is high school pupils who have not chosen physics as an option for their maturity, therefore a sample quite representative of the population. The duration of the experiment, which extends over an entire semester, is also unprecedented and differs from the studies on this subject that have been carried out before.

The 2017-2018 school year was devoted to the definition research questions (chapter 2) and the construction of the teaching sequence and of the questionnaires instruments (chapter 3). Many MDETs activities perfectly adapted to the particular curriculum targeted were created and tested in the classes, before making a selection for the pilot study. Likewise, the instruments for evaluating the dependent variables and the important predictors were constructed and validated on the basis of the planned teaching, the existing literature and the results of the validation tests carried out before the summer of 2018.

During the year 2018-2019, 102 pupils participated in the pilot study (N_{TG} = 59; N_{CG} = 43), belonging to 7 physics class-groups taught by 3 different teachers. The results and discussion

hours of mathematics and 2-5-5-3 of biology and/or chemistry, and 3 non-scientific profiles (classic, modern and artistic) with 0-0-2-3 hours of physics per week, 4-4-4-4 hours of mathematics and 2-2-1-3 in biology and/or chemistry (see annexed document n. 1).

of this phase of our research, as well as modifications for the main study design are set out in chapter 4. As for chapter 5, it details the course and results of the main study, in which 111 pupils participated (N_{TG} = 55; N_{CG} = 56), divided into 8 groups-classes and taught by 4 teachers: the same as in the pilot study plus a new one. In the chapter 6 we discuss the results of the study and draw the conclusions, the limitations and the future possibilities, whether for teaching or for research. The concluding chapter (chapter 7) is devoted to a final assessment and the perspectives for future.

2. STATE OF RESEARCH IN PHYSICS EDUCATION AND RESEARCH QUESTIONS

2.1. Teaching possibilities of Mobile Devices used as Experimental Tools

Tablets and Smartphones are relatively easy to handle and widespread among people of all generations and teens in particular. Their use as learning tools in science classes has nowadays become very popular: the built-in sensors provide a new kind of compact and relatively inexpensive instruments measuring a wide number of phenomena such as radioactivity, electricity, acoustics, optics and mechanics, among others. Many experiments traditionally performed in science courses can easily be carried out with these devices and new proposals for educational experiments arise: the journal *Physics Teacher* has created a section devoted to this subject since 2012 [Kuhn & Vogt, 2012]. In physics education, tablets and Smartphones have for example been used as experimental tools in mechanics (see e.g. [Chevrier *et al*., 2013; Gabriel & Backhaus, 2013; Darmendrail & Müller, 2020; Hochberg *et al*. 2016; Koleza & Pappas, 2008; Kuhn & Vogt, 2013; Monteiro *et al*., 2014; Shakur & Sinatra, 2013]), waves and acoustics (see e.g. [Castro-Palacio & Velázquez-Abad, 2013; Parolin & Pezzi, 2013; Sans *et al*., 2013; Forinash & Wisman, 2012; Greenslade, 2016; Hirth *et al*., 2016; Vogt *et al*., 2015]), optics ([Klein, *et al*., 2014; Thoms, *et al*., 2013]), or electromagnetism and radioactivity (see e.g. [Forinash & Wisman, 2012; Silva, 2012; Kuhn *et al*., 2014; Keller *et al*., 2019]). Some examples of possible setups, using Mobile Devices as Experimental Tools (MDETs) are shown in figure 2.1.

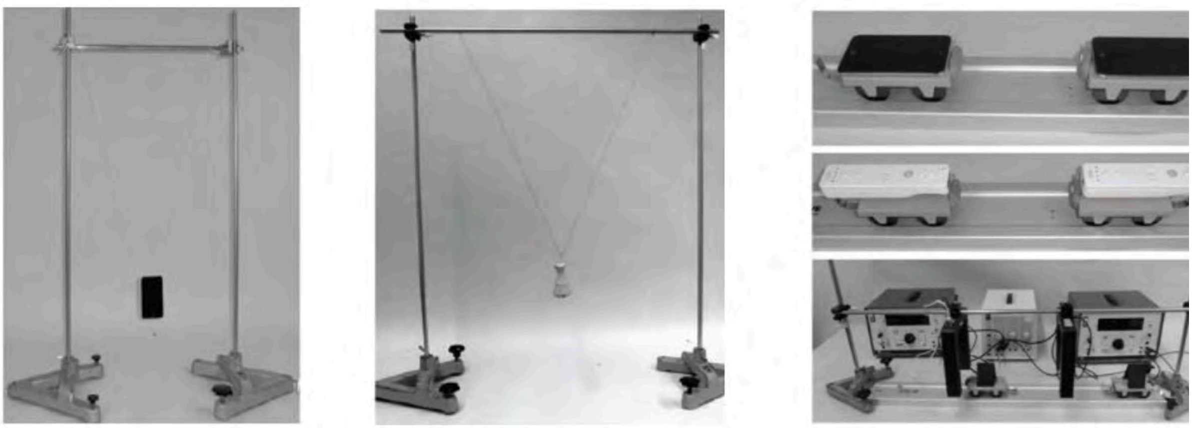


Fig 2.1: Examples of the use of MDETs replacing the traditional setup in mechanics courses: a simple pendulum with a Smartphone measuring the amplitude of oscillations (left) versus a conventional version (centre). On the right: one-dimensional collision testing the momentum conservation: with a couple of Smartphones (right-top), of WiiMote (right-centre) and conventional (right-bottom) [Hochberg, 2016].

Besides the already important role of these devices for the transmission and processing of information, the integrated sensors of tablets and Smartphones make them real laboratory devices, compact and mobile, opening the possibility to carry out experimental measurements giving real-time data accessible to all audiences [Darmendrail *et al*., 2021]. Furthermore, the existing applications (apps) can easily generate many representations of the recorded data: tables, graphics, animations or other formats, as well as the combinations of these representations. The main advantage of these Mobile Devices used as Experimental Tools (MDETs) is therefore not so much of having high precision, but rather the possibility to carry out experiments easily accessible to a large audience, whether inside or outside of the classroom or the laboratory. From the point of view of science education – and in particular of physics education – many advantages open up when implementing MDETs activities, with both educational and practical benefits, both for pupils and teachers.

Firstly, practical advantages already exist by simply using MDETs for many traditional classroom experiments, just replacing the instruments for data collection (we will see some examples of this kind of activities in this research). For example:

- For the same experimental task in the classroom, less time is generally needed to prepare a MDETs manipulation and to take measurements with respect a traditional setup, thanks to the *easiness* and the *practicality in the implementation* of the laboratory sessions on the part of the teachers, but also *in the handling* of the material on the part of the pupils.

- The flexibility of MDETs allows the creation of new classroom activities and/or experimental situations, which would simply not be possible with traditional setups, such as the vertical jump experiment [Darmendrail & Müller, 2020] (also present in this study). The classroom use of MDETs leads to generally shorter lab sessions (i.e. typical durations of problems based on fictive data), freeing up more time for better focus on the conceptual contents or other activities, and allowing more flexibility in planning teaching sequences.

- Moreover, students work on real data: MDETs activities can therefore be considered as intermediaries between problems with fictive data and lab experiences, going beyond the limit of the long-established contrast between theoretical exercises and experimental laboratories.

Secondly, the *mobility* of these devices makes possible to take the measurements and activities remotely, which on one hand can be advantageous in the situations of distance teaching, as it has been necessary during the last months in many schools, following the pandemic situation of 2020). On the other hand, the measures can be taken straight outside the physics course, whether in the school setting during a course in another discipline (gymnastics, arts, music, etc.), by promoting the interdisciplinary nature of learning, or even as part of many other activities of daily living and/or assigning homework tasks.

2.2. Context-based science learning

2.2.1. Context-Based and Science-Technology-Society teaching approaches

As we have highlighted above, a remarkable advantage of using MDETs in science classes is the possibility to perform new types of activities, creating new situations that would simply not be possible using a traditional lab setup, whether inside or outside the classroom. Thus, new contexts for the science learning can be conceived, closer to the everyday life of the students and to their real interest. This matches the theoretical framework of Context Based Science Education (CBSE) [Bennett *et al.,* 2007], whose positive impact on pupils' motivation (with large effect sizes) and learning (with medium effect sizes) has been revealed in certain empirical studies [Bennett *et al.*, 2007; Gilbert *et al.*, 2011; Müller *et al.*, 2014]. With the aim to foster affective attitudes (i.e. feelings toward science learning and its contents) and learning in scientific branches, CBSE recommends the promotion of learning contexts which are perceived as authentic by students, that is to say that they "reflect how [scientific] disciplines build, organize and assess the knowledge of the world that learners encounter" [Warkins *et al.*, 2012]. In their review, Bennet *et al*. (2007) take into consideration 17 studies out of 60 in different countries, where traditional education is compared to that based on Context-Based (CB) or Science-Technology-Society (STS) approaches, namely where contexts and applications of sciences, linked to the everyday life or to the current society or technology questions, are used as starting point for the development of scientific contents. These studies were carried out over periods of more than one year and they show that CB or STS approaches lead to a general better attitude (motivation, interest) to sciences, while maintaining a level of learning comparable to that of traditional teaching. This approach is beneficial for both boys and girls, and the positive effect is stronger for girls, resulting indeed in a reduction of the gender gap. Furthermore, the PISA 2006 study (Organization for Economic Co-operation and Development [OCDE, 2007]) repeatedly states the importance of the inclusion, in the science courses, of activities "that could be part of the actual experience or practice of the participant in some real-world setting [and] place most value on tasks that could be encountered in a variety of real-world situations", in order to improve the motivation of young people for scientific branches [OCDE, 2007, p. 81].

Despite the encouraging empirical evidence and the recommendations in favor of context-based science learning, an obstacle to the widespread introduction of CBSE in science courses mainly comes from the difficulties encountered to prepare such courses on the long term, which normally requires a profound adaptation of the existing pedagogical means in relation to the actual curricula [Ratcliffe & Millar, 2009]. In other words, it is often difficult for teachers to reconcile the efficiency in terms of the amount of content to be taught and the pedagogical instruments available with a CBSE approach on the long-term. This is why Swarat *et al.* (2012) propose the implementation of rather point-wise and episodic context interventions, which can be more in line with the constraints and the teaching material already existing. This format turns out to be more flexible and feasible, as it combines the advantages of a context-based teaching without upsetting the existing methodological or organizational conditions. An example of this practice is the introduction of context tasks based on the analysis of newspaper articles, whose authenticity and links with everyday life are straightforward. In this case, the beneficial effects on motivation and on learning, compared to a traditional teaching, is observed with effect sizes between medium and large (Cohen's d = 1.52 for learning, $\omega^2 = 0.5$ for motivation, $\omega^2 = 0.2$ for learning[1]), [Kuhn & Müller, 2014].

2.2.2. Material context and topical context

MDETs constitute a new educational support intended to reconcile the practice of context-based activities with existing educational approaches, because these devices can easily be introduced in the classical sciences classes. At the same time, provide a learning context in two different and related ways:

- Firstly, as Smartphones and tablets are widely widespread (all the pupils participating in this research owned a Smartphone or a tablet), they are familiar objects, and often have an important emotional value to young people: therefore, the simple use of these "hands-on" and attractive devices as measuring instruments during the physics lessons is an element of authenticity in itself, constituting what is called a *material context* (an instrument) [Hochberg *et al.*, 2018]. Moreover, the material context exploits the attractiveness of new technologies to strengthen the interest of students in the discipline studied, by putting them in direct contact with the real and authentic data collected [Swarat *et al.*, 2012]. However, the interest focused only on the measuring instrument needs to be maintained in order to be transferred to the discipline on a long-term basis, which is unlikely in the context of one-off activities, but rather requires a prolonged use of MDETs.

- Secondly, as seen previously, the flexibility and the "hands-on" format of the MDETs activities opens up the possibility of new contexts for science learning, perceived as relevant to the everyday life of pupils, whether inside or outside the school. For example activities whose context is a sport (as the study of the motion of a tennis ball or the body of a gymnaste) or a hobby practiced by the student: this is called a *topical context*. Topical contexts are known to be able to foster interest and learning in science [Bennett *et al.*, 2007].

Between the two types of context possible with MDETs, the topical context is likely to promote a positive attitude towards sciences in a more direct way, because it is based on a more explicit link between the studied discipline and the center of interest of pupils. Nevertheless, the effect of the topical context is reinforced if the material context is also present. Carrying out activities that combine both contexts, material and topical, is a

[1] The definition of the effect size measure *d* is given in section 3.2, and ω^2 is a biased alternative similar to η^2 (also defined in section 3.2), often used for small size samples.

promising approach to make the most of the potential of MDETs in sciences lessons [Hochberg *et al.*, 2018].

2.2.3. Focus on affective outcomes

In the next paragraphs, we will mainly develop the variables of interest, relation to reality curiosity and self-concept with regard to the subjects studied.

Following what is explained previously, two important sub-dimensions of motivation might be directly impacted by the use of MDETs in the physics lessons and will be object of our investigation: the pupils' *perception of the relation to reality* as well as the *interest in relation to the subjects of learning*. *Relation to reality* reflects the extent to which the subjects treated in the course appear relevant and linked to the daily life of the learners and therefore it corresponds also to a measure of the perceived authenticity. *Interest* is defined as "a psychological state of engaging or predisposition to reengage that occurs and develops during interactions between persons and their environment as objects, topics, contents or ideas; interest is characterized by focused attention and an affective reaction, such as enjoyment" [Hidi & Baird, 1986; Hidi & Renninger, 2006; Krapp, 2002].

Another key internal state of motivation in our investigation is the construct of *curiosity as a state*, that is the curiosity toward the subject of learning. Arnone, Small, and Chauncey define curiosity as "a desire for new information or experience that includes a trigger, a reaction to that trigger, and a resolution, which can be satisfactory or unsatisfactory" [Arnone *et al*. (2011), p.185]. Indeed, the initial trigger can be for example an authentic situation of an activity in the physics course. If the learner perceives a first resolution as satisfactory, this can be the source of her or his interest or motivation to seek new information and to engage in a new learning, renewing in turn the initial state of curiosity. For this virtuous circle to be maintained, it is however necessary that the learner keeps on feeling that she or he has the skills to seek new information and easily reach this satisfactory resolution. On the contrary, if the dominant feeling of the learner is not being able to satisfy his curiosity in a relatively short time and/or with limited effort, the virtuous circle is interrupted.

In this mechanism, "contextual" or "personal factors" may impact the perception of possibility of success in finding a satisfactory resolution. The "contextual factors" belong to the learning environment: for example the teacher, the learned subject or the context of an activity. In this perspective, the creation of topical or material contexts using MDETs, can turn out to be an important "contextual factor", which favor the virtuous circle involving the curiosity towards physics, the interest carried for this branch and the motivation to its learning. In addition, the relative ease of access to the data and their representations makes it possible to minimize the effort of the learner, provided that she or he masters the functionalities of the apps (as we will explain in section 2.3). Thus, the perceived competence of a pupil to quickly, easily and successfully conduct MDETs activities is increased and this, in turn, can increase her or his confidence in the possibility of finding a satisfactory solution, thus fostering the *curiosity as a state* regarding physics subjects.

Among the "personal factors" that can influence the perceptions of value and expectancy for success in the result, we mention

- the cognitive capacities of the individual,
- her or his *curiosity as a personality trait* and
- the *situational self-concept*, intended as "a mental representation of oneself, including a collection of cognitive beliefs about oneself formed through experience and feedback from the environment" [Gutman & Schoon, 2013; Valentine *et al.,* 2004].

Although *curiosity as a trait* is a stable component of personality, the *situational self-concept* regarding physics' course is typically associated with interest and, as interest, can evolve depending on the context of learning. This is why we will consider *situational self-concept* as a fourth dependent variable of our study. Moreover, a set of predictors of relevance known from the literature will be taken into account, based on existing research in the field (previous knowledge, gender, …; see section 3.4).

2.3. General background from educational science

2.3.1. Conceptual understanding

The difficulty of the conceptual understanding in physics, and particularly in mechanics, has been a known topic in educational research since the 1970s (see e.g. [Linke & Venz, 1978 and 1979]; [Hammer, 1996]; [Leonard *et al*., 2014]). Since then, researchers have been observing that common pre-existing wrong conceptions constitute a major obstacle in the good comprehension for an adequate understanding of the basics concepts. This understanding is in turn fundamental for problem solving, experiments and other scientific competencies ([Helm & Novak, 1983]; [Novak, 1987]; [Abrams, 1997]). Those wrong pre-existing ideas, collectively referred to as *misconceptions*, are originally explained as the result of "naive theories" that, although scientifically incorrect, allow students to give coherent interpretations of the phenomena they observe in their lives ([Clement, 1982], [McDermott, 1984] and [Megalakaki & Labrell, 2009]). An example of this first view is the idea that a more massive body falls faster than a lighter one arises from the observation of motions in everyday life without taking friction into account. Similarly, the erroneous belief that a non-vanishing resultant force is necessary to keep an object moving with a constant velocity not only is a deeply ingrained misconception in learning mechanics, but it has also been the dominant thought of humanity for millennia by Aristotelian thought. Indeed, misconceptions are recognized to persist even after instruction and this is all the more striking considering that observations of the areas of activation of the brain by functional magnetic resonance (fMRI) indicate that misconceptions may remain in memory even after learning the correct conceptual description of a phenomenon [Dunbar *et al*., 2007].

Complementary to the first view that misconceptions arise from pre-built naive theories, a second view is considering students' knowledge in terms of "units" or "pieces of knowledge", which are unorganized large conceptual structures: misconceptions would derive from the application of these "pieces" of knowledge to inappropriate situations [DiSessa & Sherin, 1998], [Hammer, 1996]. The most common example is the explanation of the hotter or colder seasons by the distance between the Earth and the Sun, which is a wrong explanation coming from the application of the "piece" of knowledge that the distance from a heat source has an effect on the perceived temperature (which is correct in itself) and the neglect of the obliquity of the ecliptic. In mechanics, we cite the false idea, also tested in this study (see section 3.5 on the construction of the conceptual instrument), that the average speed during a round trip (twice the same distance) is the arithmetic average between the speed on the outward journey and back. According to the study of Reed *et al*. (1985 and 1986), 85% of the students give this answer and only 5% of the students give the right answer (harmonic average) and this proportion changes by few units of percent even after instruction on the subject, although conceptual changes may have taken place. Here the idea of applying the arithmetic mean of the two speeds, which may be correct in other contexts, is used inappropriately in the situation where the two journeys do not have the same duration: this error is attributed to what is also called “availability heuristic”, i.e. “a mental shortcut that relies on immediate examples that come to a given person's mind when evaluating a specific topic, concept, method or decision. The “availability heuristic” operates on the notion that if something can be recalled, it must be important, or at least more important than alternative solutions, which are not as readily recalled.” [Esgate & Groome, 2005].

A further theoretical framework explains many of most common and robust misconceptions through *category mistakes*, that is the attribution of experiences and/or concepts to inappropriate ontological categories, represented by a given class of objects or entities (see [Chi, 2008] and references therein). For example, the category of the “material objects” (things that have a mass) forms a different category than the set of "events" (things that happen over times), or the set of "processes" (transformations over time). According to this view, the knowledge of the learner is classified into distinct and stable ontological categories and the main obstacle to a correct learning of mechanics comes from the wrong categorization of the physical quantities: for example the pupils tend to consider forces as material objects rather than interactions, and this is at the origin of the idea that in a collision between two objects of different masses, the more massive object acts with a greater force. Similarly, when a student classifies the "velocity" (a vector) in the category "scalar quantities" (a number), she or he is lead to consider that a movement at constant speed has no acceleration.

Each of the three theoretical views described above can only give clues to understand the complicated process of learning concepts (and unlearning misconceptions) and they should be considered in a complementary manner.

For decades, many studies have been carried out investigating the role of misconceptions in the construction of scientific knowledge, and several inventories exist to assess conceptual understanding in many physics chapters included those of mechanics, to which we will refer in this research [Beichner, 1994], [Hestenses & Wells, 1992], [Hestenses *et al*., 1992], [Reed & Saavedra, 1986] and [Thornton & Sokoloff, 1998]. The aim of this strand of research is to provide is to provide the most efficient instructional strategies to overcome learners' difficulties by engaging students in a process called *conceptual change* [Strike & Posner, 1982]. For this purpose, students are made to become aware of the cognitive conflicts created by the confrontation of their ideas with different situations and reshape their reasoning to accommodate scientific concepts; among the most efficient approaches in mechanics, we cite the use of interactive lectures and the real-time display of physical quantities [Sokoloff & Thornton, 1997], or the integration of concept mapping techniques into the instruction [Romance & Vitale, 1997].

Thanks to their functionalities, we suppose that a well-structured use of MDETs in mechanics lessons may have direct beneficial effects on learning. First, if interpreted correctly and easily, the multiple representations (see section 2.3.4) provided by the apps of video analysis lead to a reduction of the cognitive load (see section 2.3.3) of the learner, allowing the working memory to focus on the learning of the physics concepts. Secondly, their interactive learning, and possibility of working with real-time representations of the studied motions (see section 2.4), is also supposed to promote awareness on the part of the pupils of their misconceptions. Through the various activities carried out throughout the months, to allow them to engage in a conceptual change process improving their mechanics understanding. Indeed, dislodging the deeply rooted misconceptions is often a non-linear, lengthy and painstaking process. Thus, by its extent over time, our study will intend to observe the evolution of the conceptual changes of the participating students (both in the control and treatment group) and also the differences between the students who used MDETs and those who have had the same course without these devices. We will also individually analyze the typical misconceptions encountered in the targeted program and link them, one by one, to the MDETs activities in section 3.5 about the construction of the activities and of the instrument to measure the conceptual knowledge of the students.

2.3.2. Mathematics and physics learning

Mathematics is considered as the language of nature and, especially in physics, knowing how to manipulate this language is an essential skill, not only for solving problems, but also for an in-depth conceptual learning of physics ([Sanjay Rebello *et al*., 2007]; [Nilsen *et al*., 2013]). The intricate relationship between the understanding of physics and of mathematics goes far beyond considering the latter as a mere tool of calculation for the former, or that of physics as just a possible frame for applications of mathematics. These two disciplines have historically leveraged on each other to advance, and the progresses of the one are inexorably linked to those of the other [Karam, 2015]. This strong interdependence can also be found in the context of educational research: the learning of these two disciplines is interconnected in complex and inextricable ways [Pospiech *et al*., 2019].

A better knowledge of the mathematical language allows to learn physics better, as it has been known empirically for decades, starting from the first classical works (as [Thorndike, 1946], r ≈ 0.8), to more recent research studies, reporting effect sizes ranging between medium and large (see e.g. [Meltzer, 2002] or [Karam, 2015]), or other studies concerning specific topics and confirming the previous results ([Torigoe & Gladding, 2007 and 2011; Pepper *et al*., 2012; Uhden *et al*., 2012; Wilcox *et al*., 2013; Bollen *et al*., 2015]).

Reciprocally, the application of mathematical notions to different contexts of physics gives the possibility of understanding more deeply the abstract meaning of the equations and symbolism, bringing to a better mastery of the mathematics notions behind, and setting off a virtuous circle for the benefit of learning both disciplines. As Sherin says (2001) "(…) successful students learn to understand what equations say in a fundamental sense; they have a feel for expressions, and this guides their work. More specifically, students learn to understand physics equations in terms of a vocabulary of elements that I call symbolic forms. Each symbolic form associates a simple conceptual schema with a pattern of symbols in an equation. (…) Physics expertise involves this more flexible and generative understanding of equations".

Indeed, contrarily to the pure, application-free mathematical language, the expressions used in physics take a "substantial" meaning: here symbols correspond to physical quantities, have units, and the equations translate conceptual relationships between these "substantial" quantities [Tuminaro & Redish, 2007]. "Filling" (conceptually) symbols with units and knowing how to use the different meanings of the abstract mathematical language should be considered a learning task in itself for students, which requires an effort. Furthermore, this competence opens to the capacity of abstraction and generalization characterizing the mathematical language applied to nature and, at the same time, it allows a deeper understanding of the relationships between quantities and of the underlying mechanisms. However, this overlap, taking place when learning mathematics and physics, is often underestimated by the separate teaching of one discipline or the other.

Indeed, previous studies indicate that often, even if students have the mathematical knowledge necessary for solving problems, they do not attempt to apply it in the context of a physics course, and vice versa [Bassok, & Holyoak, 1989; Sabella & Redish 2007; Meredith & Marrongelle, 2008]. They rather need encouragement and guidance to establish the links between their knowledge of mathematics and physics [Cui *et al*., 2008]. This shows that the ability to mobilize resources is strongly linked to the context in which the knowledge has been acquired and to the learner's perception of the appropriate knowledge to activate in a particular situation, which is called *epistemological framing* [Bing & Redish 2009].

Based on previous research, we will therefore come up with two learning variables in this study, which are explained in the following.

First, we will study the evolution of the mechanics' learning (both conceptual and global) among high school students, which will be our first learning outcome. As many (although largely not all, unfortunately[2]) notions of the mathematics course, studied by pupils at the same time, are underlying and essential to the understanding of the targeted physics contents (such as algebra manipulations, solving equations and inequalities, representations and graphic interpretations of linear and polynomial functions or trigonometry), we will take into account the role of mathematical prior knowledge in the learning of physics, together with several predictors of relevance known from the literature (see section 3.4 on control variables).

Secondly, as the mathematics notions studied are also used by the representations given by the video analysis apps (see section 2.3.4 and in particular the figures 2.2 and 2.3), we hypothesize that the use of MDETs can also have a positive effect on the learning of the contents of the mathematics studied in parallel by pupils. This is why we will consider the results in mathematics as an additional independent learning variable.

2.3.3. Cognitive load theory

In section 2.2, we explained how the creation of a context in science learning, whether material (an authentic instrument) or topical (an authentic situation), could foster the motivation in the disciplines concerned. Despite the widespread belief that a positive effect on motivation can lead to a positive effect on learning achievement (see for example [Bennett *et al.,* 2007]), meta-analyses have only shown a moderate correlation (0.3-0.4) between motivation and learning [Uguroglu & Walberg, 1979; Wild *et al.*, 2001]. These values are lower than expected when considering that an increased motivation and therefore an increased engagement might lead to a better learning of a discipline. As a consequence, based solely on the effects that MDETs can have on motivation, we can only hope to observe moderate <u>indirect</u> effects on physics learning. Nevertheless, arguments and empirical observations exist, regarding possible <u>direct</u> effects of MDETs on learning, and this within a theoretical framework other than the CB/STS approach: the *cognitive-load-theory* (CLT) and the *cognitive-affective theory of learning with media* (CATLM, see section 2.3.4).

Cognitive load theory, developed by Sweller, Van Merrienboer and Paas (1998), is based on the model of the *working memory* and in particular on the idea that its capacity is limited [Miller, 1956; Baddeley & Hitch, 1974]. In this model, the amount of cognitive load of a task is rated by the level of “element interactivity”, where an “element” is a concept or a procedure to be learned and the “elements interactivity” represent different links between the elements of a given learning task. Learning separate elements with only a few connections (as simply memorizing the three Newton's laws) is considered a “low element interactivity” task. In contrast, a task has a “strong element interactivity” when there are many connections between

[2] Essential notions in mechanics as those of vector, derivative or integral, are not studied until the 3rd or 4th year of the general formation Geneva high school (while mechanics is only studied in the 2nd year).

the different elements (for example solving complex problems or carrying out physics experiments, where the links between the observations and the theory have to be established).

According to CLT, there exist three kinds of cognitive load occupying the working memory:

- The *intrinsic cognitive load* is generated by the nature of the learning content and then it is inherent (intrinsic) to the complexity of the learning subject itself. This load is the result of the interactivity between the elements of a learning task; it will be all the richer, as the elements and their connections are numerous. The intrinsic load is the basis of learning and therefore cannot be reduced, but its level depends on the level of expertise of each learner, as a better mastering of the prerequisites to the learning content can reduce the cognitive effort required to process new information.

- The *extraneous cognitive load* arises from the presentation of the content to be taught and does not contribute to learning. In every learning task, the extraneous load should be reduced as much as possible by limiting the superfluous interactivity between the elements of a given educational content, for example by removing any useless information in a statement or any purely decorative image.

- The *germane cognitive load* constitutes the essential part of the learning process; it describes the proportion of working memory devoted to the construction and automation of the information by interpreting, classifying, differentiating and organizing the links between the elements. An effective teaching should stimulate students to engage in such learning processes and thus increase the proportion of germane cognitive load.

Since its inception, cognitive load theory has played a central role in educational research. However, it has practical limitations, since for example it is not easy to empirically differentiate between the different types of cognitive load[3]. High values of cognitive load perceived by a pupil can be either positive or negative for learning achievement, depending on the proportion of extraneous and germane cognitive load [De Jong, 2010; Schnotz & Kürschner, 2007]. In addition, the amount of cognitive load does not depend of the accuracy of the content learned [De Jong, 2010]: for example a pupil may perceive a high level of cognitive load while reinforcing pre existing misconceptions. For this reason the empirical estimate of the perceived cognitive load should always be interpreted taking into account the details of the learning process of a task.

[3] Possibilities for empirically differentiating the kinds of cognitive load exist [DeLeeuw & Mayer, 2008], but they are beyond the scope of our research.

2.3.4. Cognitive-affective theory of multimedia learning

The cognitive-affective theory of multimedia-learning (CTML) [Mayer 1999, 2003 and 2005] combines CLT with several further assumptions, suggested by research in educational science. First, CTML is based on the idea that the learner's working memory has limited capacity and virtually unlimited capacity of the long-term memory. In addition, it postulates that two independent channels convey the transmission and the processing of information in working memory – the verbal (texts, explanations) and the visual-pictorial channels (images, videos) – and that the information is processed through two main representation codes: verbal and nonverbal (dual coding theory [Clark & Paivio, 1991]). Another important assumption at the basis of CTML is that a conscious effort from the learner in the cognitive process is needed for her/his meaningful learning.

In order to create an effective multimedia-learning environment, Mayer and Moreno (2003) derived a series of main principles from the empirical research on CTLM, including:

- The *multimedia principle*: students learn better when processing both channels (verbal and visual-pictorial) are exploited and connected, because when words and images are both present in an explanation, they have the possibility to build two different mental representations – a verbal model and a visual model – and therefore can build connections between them;

- The *temporal contiguity principle*: when giving a multimedia explanation, words and corresponding pictures should be presented contiguously in time rather than separately: when the verbal and visual channels are solicited simultaneously, the mental representations of both channels are kept at the same time in working memory and, therefore, mental connections between the verbal and visual representations are favored;

- The *spatial contiguity principle*: the corresponding information, as the representations concerning the same motion in mechanics, should also be presented spatially close together, in order to prevent the students from dissipating in the visual search processes that contribute to an increase in the extraneous cognitive load;

- The *split-attention principle*: words should be presented in an auditory way rather than visually, as presenting both text and images on the screen can overload the visual information processing system more than if the narration is processed in the verbal information processing system and the animation is processed in the visual information processing system. This principle connects with the multimedia principle in its recommendation to optimally exploit both the processing channels;

- The c*oherence principle*: any extraneous material should be excluded, as any superfluous information for cognitive resources in working memory competes with the information important for learning, while a shorter presentation leads the learner to select relevant information and organize it productively. The learning environment should “reduce extraneous processing, manage essential processing, and fostering generative processing”;

- The *interactivity principle*: the students should be given the opportunity to actively participate to learning, by interacting with the teaching material rather than receiving instructions passively. Interactivity fosters the processing of new information by engaging the learner in an active search for meaningful learning.

In this context, MDET represent powerful instruments with the potential to reduce the extraneous cognitive load during mechanics’ experiments, as the apps can easily and straightforwardly produce multiple representations as tables, diagrams, and many other functions that – in a traditional course – have to be produced by the pupils themselves. An example of multiple representations of the motion of a bouncing toy given by the apps of video analysis (which, in addition, is also an example of activity with a topical context – see section 2.2) is shown in figure 2.2. These representations can be used for example to calculate the elastic potential energy stored by a “jumper popper toy” before bouncing off the ground, either from the difference between its initial and final gravitational potential energy (thanks to the position data), or from the difference between its initial potential energy and its maximum kinetic energy, immediately after the rebound (thanks to the speed data). A second example of the same kind multiple representations for a harmonic oscillation motion of a pendulum is shown in figure 2.3.

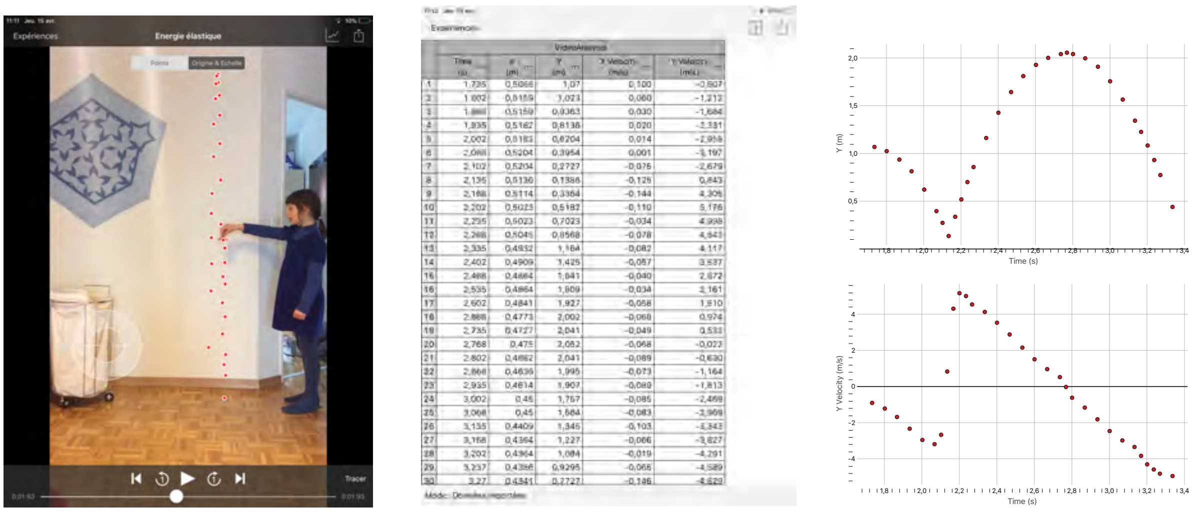


Figure 2.2: Multiple representations of the motion of a jumping popper toy dropped from a given height, and releasing elastic potential energy as it bounces on the ground (the toy pops and changes its shape when bouncing), given by the apps of video analysis of a Smartphone. The energy released allows the object to reach a higher height than the starting one. From the left to the right: the chronophotography of the trajectory (the points of the tracing are the positions at regular intervals of time), the table giving the x and y components of position and velocity at the beginning of the motion, and the graphs of the y kinematic quantities as functions of time.

In both examples a considerable amount of data on motion experiments can be easily stored and exploited within the mobile device, depending on the targeted learning and the level of the learner. This possibility frees up more time and attention to interpret, classify and organize the useful information and to consolidate the element interactivity, resulting in increased germane cognitive load and therefore capacity for learning. Nevertheless, it is important to note that this benefit is only possible for pupils who already are able to handle these functions, failing which their use may turn out to be counterproductive and, on the contrary, overload the working memory and prevent pupils from focusing on the content to be learned, resulting on a negative effect on learning. In fact, gaining empirical evidence on this interplay of positive and negative effects is a main research objective of the present thesis.

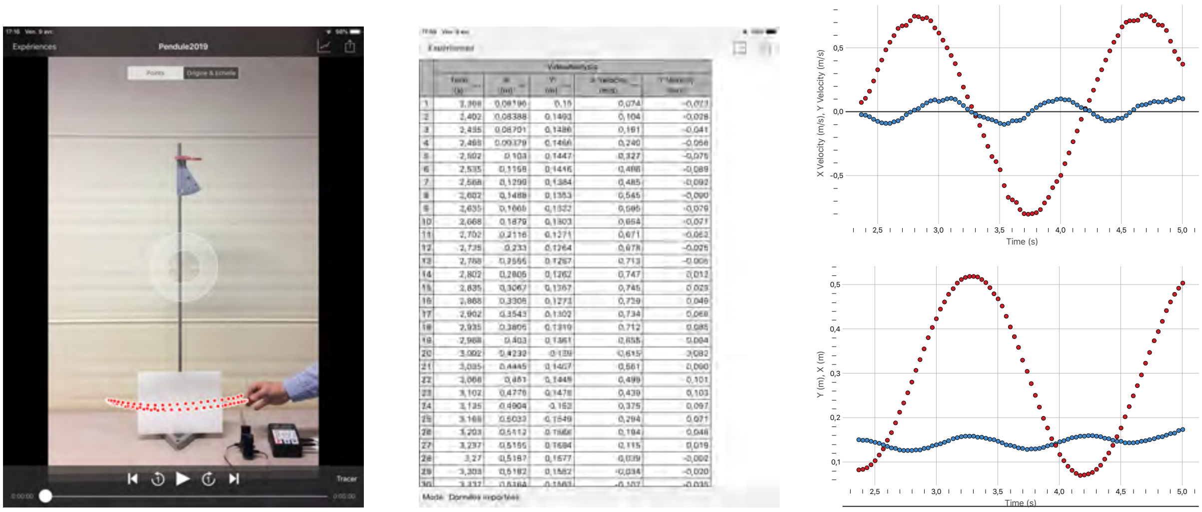


Figure 2.3: Same representations as in figure 2.2, but for the harmonic oscillation of a pendulum. From the left to the right: the chronophotography of the trajectory (the points of the tracing are the positions at regular intervals of time), the table giving the x and y components of position and velocity at the beginning of the motion, and the graphs of these kinematic quantities as functions of time.

These considerations fall within the more general framework of Information and Communications Technology (ICT)-enhanced learning research, which was developed since the 1990s with the introduction of computerized approaches to science teaching as a replacement of traditional means (e.g. [Thornton & Sokoloff, 1990] or [Tho *et al.*, 2015]). Here, the same arguments of reduction of extraneous cognitive load are suggested to explain the possible advantages of Information and Communications Technology (ICT) approaches for learning but also for motivation, which can be enhanced by the new media [Moreno, 2005]. In fact, in order to explain the positive effect on learning, there is firstly the possibility for ICT and in particular MDETs, to easily provide multiple representations of the data (tables, graphics, chronophotography, ...), recognized as capable of improving learning in science and in mathematics (see for example [Aisworth, 2006] or [Scheid *et al.*, 2019] and citations thereby). However a solid understanding lies above all in the ability to make connections between the different representations and to create coherent connections within each representational format, that is to say to create "intrarepresentational connections"

[Seufert, 2003; Mayer, 2005 (pp. 31-38); Mayer, 1989]. According to Mayer (1989 and 2002), these connections and the consistency between them are essential for effective learning. This is the reason why caution is necessary when introducing these multiple representations into science learning sequences: learners must have the necessary prerequisites for handling all the representations provided. On the contrary, understanding how to interpret the different representations is often a learning process in itself for pupils, which can lead to a cognitive overload on their working memory. Indeed, empirical evidences also exist of negative effects of the use of ICT on learning, due in particular to the cognitive overload of the pupils when they have to integrate, interpret and coordinate several representations during learning [Van Bruggen *et al*., 2002]. These findings can be applied in particular to MDETs approaches in physics learning.

2.4. Technology-based learning

2.4.1. Real-time data representations

A specific kind of multiple representation learning and an important feature common to ICTs and MDETs with potentially positive effects on learning, is that of being able to provide data in real-time during the experiment. Regarding the use of MDETs in kinematics, the apps of video analysis provide time diagrams (position and velocity as a function of time, see right side of figures 2.2 and 2.3) and its chronophotography (left side of figures 2.2 and 2.3) only a few seconds after the visualization of the motion. Thus, this linking in time of an observed motion with its simultaneous graphic representations can facilitate the equivalent linking in the pupils' memory and promote their germane cognitive load. In other words, this "quasi simultaneity" functions act as a "facilitator" for the creation of links between the different representations of the studied motion [Mokros, 1987; Thornton, 1986].

The empirical evidence of such a positive effect on kinematics learning is given in a study using a Microcomputer-Based Laboratory (MBL) approach over a short period [Brassel, 1987]: here the combined effect of the real-time kinematic representations (delay less than 20 seconds) and the use of ICT (MBL) is present. Nevertheless, by removing the kinesthetic feedback, but maintaining only the juxtaposition of a video and the simultaneous graphic representation of a movement, the positive effect on learning disappears [Beichner, 1990]. Beichener explains that the positive effect observed by Brassel is mainly due to the immediate control over the physical event and its graphic representation, present in the MBL approach, but also in the functionalities of the MDETs apps.

2.4.2. Mobile, interactive learning

The use of MDETs in science learning is also in line with the definition of *mobile and technology learning*, intended as "the processes of coming to know through conversations across multiple contexts among people and personal interactive technologies" [Sharples *et al*., 2007, p. 224]. Theoretical arguments in favor of mobile learning highlight over all the possibilities of personalizing and contextualizing learning by overcoming temporal or environmental limitations known in traditional learning [Crompton et al., 2016].

Arguments and empirical evidence exist, showing that mobile technology can improve the attitudes and perceptions of the learner towards the discipline studied [Wu *et al*., 2012; Swarat *et al*., 2012].

In addition, Haßler, Major and Hennessy (2016) argue how technological and mobile approaches are likely to improve learning in various ways. Firstly, the interactive, flexible and adaptive properties of these approaches support a learning environment that builds up with pupils' reactions and feedback, creating a personalized, not predetermined teaching; indeed, the possibility of new meaningful and authentic situations matches with the CBSE and its potential benefits on motivation, engagement and learning, which we mentioned above. Moreover, the learning advantages of mobile and technology approaches are further discussed in recent reviews and meta-analyzes in terms of critical success factors [Alrasheedi *et al*., 2015], of general learning theories [Crompton *et al*., 2016] and other features [Hwang & Tsai, 2011; Wu *et al*., 2012; Pimmer *et al*., 2016]. So far, the majority of the research developed on mobile learning does not concern physics learning but is rather within the framework of other sciences. For this reason, efforts still have to be made to expand the information in this direction.

2.4.3. Distracting effects

Despite the many advantages of MDETs in science classes, their distracting effect is often mentioned, as is the case for ICT in general (see e.g. [Fried, 2008] for laptops).

On the one hand, regarding learning, a study found that banning Smartphones in the school allowed pupils to achieve significantly better results than when these devices were enabled. In particular, this effect was greater for lower performing pupils and the authors attribute these results to the distracting effect of Smartphones [Beland and Murphy, 2015]. In another study, Smartphones were given to pupils who had never used them before during a whole school year. Although initially most of the pupils believed that the Smartphone would have helped them enhancing their learning goals, and they could actually use these devices for informal learning, their initial enthusiasm faded away and finally the general feeling among the pupils was that Smartphones were rather distracting and that, on the contrary, they contributed to worse results [Tossell *et al*. 2014]. This feeling can be explained to the extent that, if the use of Smartphones is not sufficiently structured, the pupils can make an inappropriate use of these devices: for example by processing information which is not correctly connected to targeted learning, which is likely to lead to an increased extraneous cognitive load and therefore a resultant negative effect on learning.

On the other hand, three more recent studies (which will be discussed in more detail in the next section), where MDETs were provided in order to assess their impact on motivation and learning in physics, did not highlight any distracting effect of these devices and they rather reported positive effects [Hochberg *et al.* 2018 and 2020; Klein *et al.*, 2018]. This suggests that the distracting effect is possible especially when the tablets or Smartphones used belong to the pupils.

The possible effects of MDETs in physics education, which are discussed in the previous paragraphs, are summarized in Figure 2.4. Based on these results we will formulate the research questions of this study.

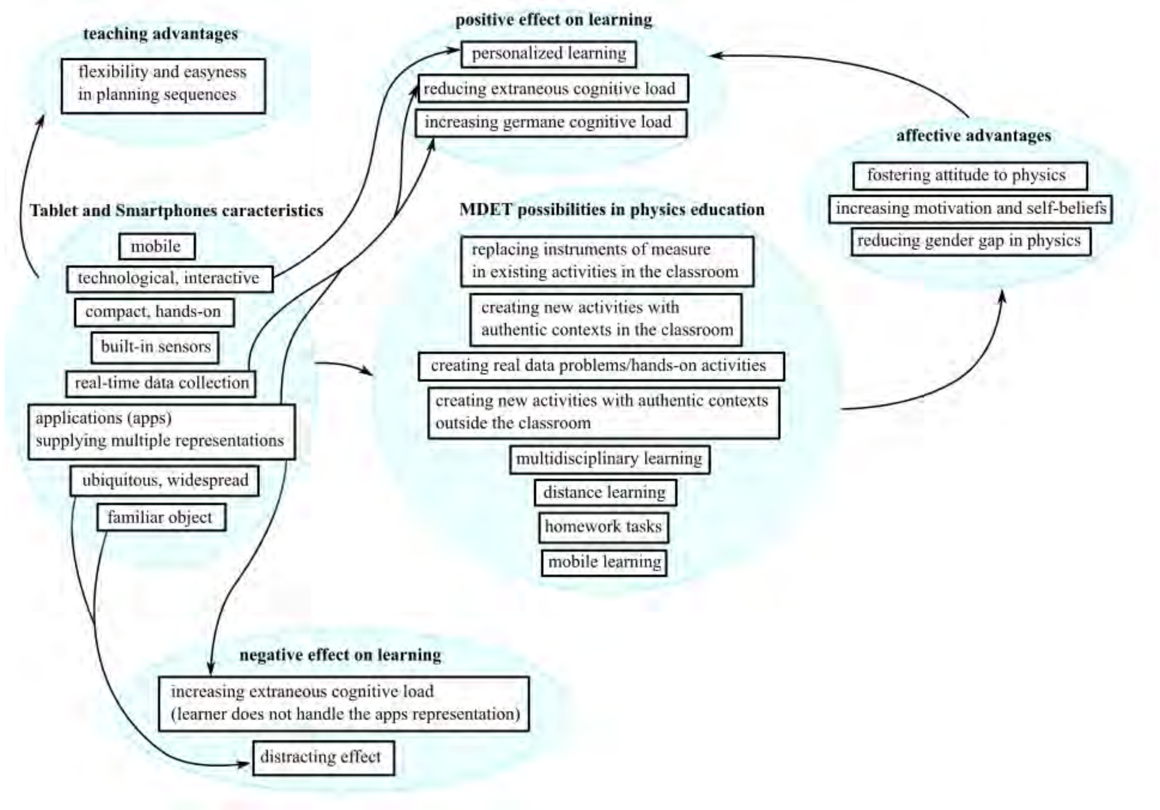


Figure 2.4: Recap chart of the possible effects of the use of MDETs during the physics courses.

2.5. Research questions

In section 2.2, we have seen that the creation of a *topical context* using MDETs can have a positive impact on motivation, more than on learning, in sciences and in particular in physics classes. Furthermore, the mere use of mobile devices as instruments for the experiments, even in the classroom, creates a *material context*, which can also improve both attitude and learning towards physics, because the instrument itself is perceived by students as a familiar object, linked to their daily life. Insofar as both the familiar instrument and an authentic experiential task are present simultaneously, they combine in a double context (topical and material) whose positive effects can be expected to be greater than the sum of each one, because they reinforce each other by interacting [Hochberg *et al.*, 2018].

In addition, in sections 2.3 and 2.4 we have seen that learning through MDETs involves new technologies, which have been shown fostering pupils' motivation, as these devices allow them to learn with real and therefore more authentic data. This is in addition to the reasons related to their “hands-on” and mobile properties [Swarat *et al.*, 2012].

Even though many experiments using MDETs have been proposed in the last decade (see for example references in the section 2.1 and references cited therein), only few empirical studies about their educational impact exist. Hochberg *et al.* (2018 and 2020) replaced traditional measuring instruments with mobiles devices (Smartphones in the first study and tablets in the second one) during a traditional mechanics’ experiment on oscillations, therefore only keeping a material context. The results of the first investigation (published in 2018) have shown higher interest levels in pupils of the treatment group (with a small to medium effect size), as well as a better curiosity related to the studied subjects (small effect size). No differences in learning of mechanics were observed. In contrast, the second pilot study reports significantly higher levels of learning achievement in the treatment group (with medium effect size) and no differences have been observed for affective outputs and cognitive load. The difference between these two point-wise interventions was mainly in the sample: although in both cases the participating students attended secondary II, in the latter they had in specialized physics classes, then originally more motivated than the sample of the former research, having a more general background. These second results might thus only concern a selection of students already good in physics.

Furthermore, Klein *et al.* (2018) have shown medium to large positive effects on kinematic representations, conceptual understanding, relation to reality, curiosity, disciplinary authenticity, self-concept, interest and autonomy. Contrarily to the studies of Hochberg *et al.* (2018 and 2020) this investigation was on the long term and concerned undergraduate physics students; here the video based tasks replaced part of the exercises in the weekly sessions of the treatment group and they did not replace traditional laboratory sessions. The table 2.1 summarizes the main characteristics of these previous studies.

- On the one hand, the effects of a beneficial approach on learning can be larger, when implemented in a systematic and longer-lasting way and indeed, the intervention by Klein *et al.* (2018) was performed over the medium term. However the students of this study were a selection of a relatively high level: academic, and students of physics; these two factors suggest that the measured effects might be only valid for this specific target group. Besides, the fact of limiting the comparison only within the framework of exercises sheets, without experimental manipulation, suggests that part of the potential of MDETs for mechanics learning (as real time representation of an observed motion, or the ownership of the data collection) remains to be tested.

- On the other hand, in the case of an intervention of short duration (as in Hochberg *et al*., 2018) the observed higher level of interest of the treatment group could be due to a novelty effect or to the pupils' interest in the devices themselves (material context), but not a real lasting interest in the studied topics. If this is the case, this effect might only be temporary. In addition, in the studies by Hochberg *et al*. (2018 and 2020) only the material context was deployed, which leaves unanswered questions regarding the effects of using MDETs when exploiting its full potential, i.e. combining the topical and the material context. And this, on the middle-to-long term on an audience not originally motivated by learning physics.

Table 2.1: Summary of the main features of recent studies on the effects of MDETs in mechanics classes.

Study	**School level**	**Specialized physics course**	**Duration of the intervention**	**Topic context**	**Material context**
Hochberg *et al*. (2018)	Secondary II	No	One lab session	No	Yes
Hochberg *et al*. (2020)	Secondary II	Yes	One lab session	No	Yes
Klein *et al*. (2018)	Undergraduate	Yes	Several months	Yes	Yes
This study	Secondary II	No	One semester (4-6 lab sessions)	Yes	Yes

The aim of our investigation is thus to fully exploit the potential of MDETs to assess their effects in mechanics learning at the level of the secondary school and on the long term (several months), taking into account of and complementing previous research. In this perspective, we will produce several MDETs activities, which will suitably replace the traditional laboratory activities in the treatment group during a whole semester, while maintaining the same educational objectives and within the same deadlines as the control group. This is possible thanks to the practicality of MDETs: unlike other ways of implementing context-based science education, and beyond the effects they can have on students, the use of these devices can easily be integrated into the course without major changes in existing pedagogical environment.

Thus, as wee will see in more detail in chapter 3, in the choice of MDETs activities priority has been given to educational objectives within the time limits fixed by the school program, before the sole introduction of activities with authentic instruments or situations. Furthermore, at least the material context will be present in all the activities, and the topical context will be added when conditions allow it. In addition, in order to assess the actual advantage of using MDETs with respect to the same course without their use, the planning and teaching approaches will be kept the same in the control group and in the treatment group. In particular, the same topical context will be privileged in both groups. When, for practical reasons, the conditions will not allow the control group to carry out an experiment (having the same learning objectives as the treatment group), with the same topical context as treatment group, this topical context will be as well present as an exercise sheet. Eventually, the total number of experiments done during the study will be the same for both groups.

Note that our study is about learners at high school and, as explained in chapter 1 and more detail in the next section, they have not chosen physics at an advanced level. Moreover, the teaching experiments take place in a regular classroom setting (quasi-experiment), comprising a whole teaching sequence matched to the official study plan. The present study thus goes beyond existing research by its quasi-experimental character within regular high school mechanics courses.

In light of the above argumentation, based on previous research on the potential effects of MDETs on learning mechanics, mathematics, and affective outcomes, our research questions are as follows:

1. Does the long-term use of MDETs improve the learning of mechanics among high school pupils?
2. Does the long-term use of MDETs improve the learning of the related mathematics content among high school pupils?
3. Does the long-term use of MDETs improve levels of interest, perceived relation to reality, self-concept and curiosity related to the studied topics, among high school pupils?

3. MATERIAL AND METHODS

3.1. Study Framework

3.1.1. Setting

The study was carried out on 16 to 17 years old pupils of the Geneva high-school (Collège de Genève), in French. Those pupils have chosen a gymnasium orientation, which in Switzerland is done in 4 years between the age of 15 and 19. It consists of a basic generic formation, where many disciplines are studied at minima in "fundamental discipline" courses (DF). In addition, pupils choose one "specific option" (OS), a discipline that is studied in more depth, between: Latin (LA), Greek (GR), German (GE), Italian (IT), English (EN), Spanish (ES), Physics and Mathematical Applications (PYMAP), Biology and Chemistry (BICH), Economics and Law (EL) or Visual Arts (VA) or Music (MU). The pupils who participated in the study did not choose the specialized OS PYMAP and therefore attended the DF physics course (see section 1). The OS of the pupils participating in the study were AN, BICH, EL, ES, LA or VA. Physics lesson class-groups in Geneva have a maximum size of 16 pupils.

3.1.2. Sample

The project included one pilot study and one main study.

<u>Pilot study</u>

The pilot study (PS) was carried out from September 2018 to February 2019 (winter semester). The participants took the pre-test at the end of August or at the beginning of September 2018 (1^{st} or 2^{nd} physics lesson, depending on the course) and the post-tests in February 2019. In total 102 pupils participated in the pilot study. The participants were 2^{nd} year pupils from 7 different physics class-groups, taught by 3 different teachers (referred respectively as T1, T2, and T3), following the common curriculum of kinematics and dynamics of the “Collège de Genève” (see Annex 2). Furthermore, the author of this thesis was one of the participating teachers (teacher T1). Each of the 7 DF class-groups had between 14 and 16 pupils, and, as shown in table 3.1, teachers T1 and T3 taught one treatment class-group and one control class-group (parallel classes), and teacher T2 taught two treatment class-groups and one control class-groups. Thus, groups 1, 2 or 3 are composed of at least one control and one treatment class-group, taught respectively by the teachers 1, 2 or 3, and belong to two different schools of comparable socio-economic and educational background. Indeed, in Geneva public schools there is a great social and cultural mix in all classes on average. The acronyms CG and TG respectively refer to the control group and the treatment group, independent of the teacher.

Table 3.1: Seven class-groups taught by three teachers compose sample of the pilot study.

Group	Group 1 (taught by T1)	Group 2 (taught by T2)	Group 3 (taught by T3)
TG	TG1 (1 class-group; N=16)	TG2 (2 class-groups; N=29)	TG3 (1 class-group; N=16)
CG	CG1 (1 class-group; N=14)	CG2 (1 class-group; N=14)	CG3 (1 class-group; N=14)

Main study

The main study (MS) was conducted on the same model as the pilot study, from September 2019 to February-March 2020. In total, 111 pupils participated in the main study, belonging to 6 physics DF class-groups of the 2nd year, taught by the same teachers who participated in the pilot study (teachers T1, T2, and T3), following the same common curriculum (kinematics and dynamics), plus two more physics DF class-groups of the 3rd year of another school, taught by a fourth teacher (teacher T4), following the same curriculum as the other participants (there are possible variations in the order of the studied, and the same chapters could be done in different years, depending on the school). As for pilot study, each class-group had between 14 and 16 pupils, and each teacher taught one treatment class-group and one control class-group (CG) (parallel classes).

Table 3.2: Sample of the main study, composed by eight class-groups taught by three teachers. Each group (1, 2, 3 and 4) is taught by a different teacher and is composed by one treatment and one control group.

Group	Group 1 (taught by T1)	Group 2 (taught by T2)	Group 3 (taught by T3)	Group 3 (taught by T4)
TG	TG1 (1 class-group; N=13)	TG2 (1 class-group; N=14)	TG3 (1 class-group; N=13)	TG4 (1 class-group; N=15)
CG	CG1 (1 class-group; N=14)	CG2 (1 class-group; N=12)	CG3 (1 class-group; N=14)	CG4 (1 class-group; N=16)

3.1.3. Design

Control/treatment group design

The study is based on a repeated measurement control-treatment group comparison, i.e. without *vs*. with Mobile Devices as Experimental Tools (MDETs) using the apps of video analysis (see section 3.3). During the pilot study a total of 59 pupils were in the treatment group and 43 in the control group, while during the main study a total of 55 pupils were in the treatment group and 56 in the control group.

Timeline

Both interventions (pilot study and main study) lasted a whole semester: about 18 weeks, from September until February, as shown in table 3.3. The curriculum covers basic kinematics and dynamics. In the treatment group, 5 or 6 activities (depending on the teacher choices) based on the video analysis on iPads replaced traditional experiments and/or exercises. Up to this difference, the lesson plan and learning content of the labwork were identical for both groups.

Table 3.3: Timeline of the sequence and tests. Standard tests refer to the assessment tests made by the teachers, independently on the study; they contribute to the final average grade of physics.

Week	TG	CG
1	Pre-tests	
2 to 5	MDETs activities sessions and exercises	Conventional lab sessions and exercises
6	Standard test	
7 to 10	MDETs activities sessions and exercises	Conventional lab sessions and exercises
11	Standard test	
12	MDETs activities sessions and exercises	Conventional lab sessions and exercises
13 and 14	Exam session	
15 to 18	MDETs activities sessions and exercises	Conventional lab sessions and exercises
19	Post-tests	

In both pilot and main studies, the first and the last lessons of the semester were devoted to the administration of the pre- and post-test, respectively.

Instruments

The goal of the pilot study and the main study was to analyze the effects of the MDETs on pupils' learning and affective outcomes. Conceptual learning was measured with a pre- and a post-test by a multiple-choice questionnaire developed from existing concept tests as well as a few new items, in order to fit specific learning content of the sequence, as developed in section 3.5. Moreover, a series of variables were measured including the pre- and post- values of the affective independent variables (*interest*, *relation to reality*, *curiosity state* and *self-concept*, see section 2.5) plus many other variables likely to have an influence on the outcomes (as perceived *cognitive load* during the experiments, see section 3.4). The scales of these variables are based on well working published instruments and translated to French and re-validated before the beginning of the pilot study (see section 3.6). For each statement of the affective dimensions, pupils expressed themselves with a rating ranging from 1 (I totally disagree with this statement) to 6 (I totally agree with this statement).

Thus, at the beginning and at the end of the pilot and of the main study, the participant pupils took a pre-test resp. a post-test session, each lasting one teaching period (45’). At the beginning of the study (pre-test) pupils answered:

- One affective pre-test of 15’;
- One conceptual pre-test of 20’);
- The non-verbal abilities test of 6’ ([Elkstrom *et al*., 1976], pp. 176).

At the end of the study (post-test), they completed:

- One affective post-test of 15’, where the scale of *assessment of the teacher* was answered anonymously, and the scale *cognitive load due to the smartphones apps* was answered only for the pupils of the treatment group (see section 3.4);
- One conceptual post-test of 30’ (physics QCM).

All the tests were individual and paper based, except the post-tests of two class-groups in the main study, which were computer-based, because of the improvised confinement following the covid19 pandemic (March 2020).

The development of the conceptual and affective instruments and the choice of items and variables will be discussed in detail later in this chapter. Furthermore, at the beginning of chapter 4 (results of the pilot study) and of chapter 5 (results of the main study), a summary of the specificities of the instruments respectively used for each study will be given. The affective and conceptual tests used in the pilot study are the outcome of the analysis and the validation described in sections 3.4, 3.5 and 3.6, and all the tests administered can be found in appendix 3. We will present successively, in section 4.6, the improvements of these instruments, following the results of the pilot study.

The result of the conceptual post-test counted in the average of the final physics grade, which was not the case for the result of the conceptual pre-test. In order to motivate pupils to apply themselves to sincerely answer the pre-test questions it was explained that the results of these tests would be important to assess their progress in the course in view of a better implementation of teaching. Few pupils who did not complete some items on the day scheduled for the affective test (<1%) were systematically asked to fill these items in the following week, so eventually all the pupils answered all the items.

3.2. Data analyses methods

In this section, we describe the standard methods used to analyze items’ and tests’ properties according to classical test theory [Kline, 2005], which provide several items and test criteria to evaluate the quality of the tests by comparing them with recommended thresholds values. The standard criteria of significance and effect sizes used in the framework of this research are as well summarized below. The analyses were carried out using the R software [R Core Team, 2014] and the Excel application.

3.2.1. Descriptive statistics

Item mean and standard deviation

The answer of each item is associated with a score, and the *arithmetic mean* of an item is defined as the average score of all participants to a given item. The *standard deviation* quantifies the variability of the sample score for a given item around the sample mean. Psychometric scales for affective variables formed by six-level items typically produce mean values between 1 (“disagree completely”) and 6 (“agree completely”). Those values are transformed linearly to the interval between 0 and 1 to simplify their interpretation. In this case, the standard deviation of the sample is transformed in the same way. The same transformation is done for the respective scales of the cognitive tests (conceptual and spatial abilities).

Item difficulty and learning gain

For the multiple-choice items of conceptual tests, the mean score corresponds to the *item difficulty* P, and refers to the proportion of the sample that answered a given item correctly. This parameter is rather and more appropriately called *item easiness* by many authors (see for example [Ding & Beichner, 2009]), as varies between 0 and 1 and the higher it is for a given item, the easiest it is. Ding and Beichner (2009) recommend values in the interval between 0.3 and 0.9, because the items that are too easy or too difficult cannot make the distinction between high and low understanding of a student, since almost all students get these items right or wrong (ceiling effect). Besides, values of P outside this range typically results in poor values of other psychometric indices.

For the conceptual tests, the *learning gain* is defined as the difference between the pre and post difficulties divided by the difference between the maximum P and the initial difficulty [Hake, 2002]:

$$\text{gain} = \frac{P_{post} - P_{pre}}{1 - P_{pre}}$$

The average value of the P of all the individuals in a group is noted $<P>$. For the global results of a test, *gain of the average* $(<P_{post}> - <P_{pre}>) : (1 - <P_{pre}>)$ is not equivalent to *average of gain* $\left\langle (P_{post} - P_{pre}) : (1 - P_{pre}) \right\rangle$. However they are close if the correlation between the gain and the difficulty of the pre-test P_{pre} is low [Hake, 2002]. Moreover, they coincide for delta distributions. The usual definition of gain correspond to the gain of average $(<P_{post}> - <P_{pre}>)$ / $(1 - <P_{pre}>)$ [Hake 1998], excluding P_{pre}= 100% or close to 100% which can introduce skewing [Hake, 2002].

Item discrimination and point-biserial correlation coefficient

The *item discrimination* index D measures the difference between high and low achievers for a given item. D is generally computed according to the difference score on an item between the upper and the lower quartile [Ding & Beichner, 2009]. Therefore, the discrimination index is a measure of the discriminatory power that an item possesses, relative to others in a given test. We followed the criterion of Ding and Beichner (2009), that values of D greater than 0.3 are considered as acceptable, and the greater D is the better the quality of the item.

Related to the discrimination index D, the item *point-biserial correlation*, r_{it} is defined as the measure of the correlation between the average score of an item and the total average score of the test [Ding & Beichner, 2009]. Its value indicates how well each item correlates with the other items. Ding & Beichner suggest that *point-biserial correlation* below 0.2 indicates that an item might not measure the same construct as the other items and as a result should be discarded.

Cronbach's alpha

The Cronbach's alpha α_C or simply α [Cronbach, 1951] is an appreciation of the internal consistency of a one-dimensional scale or test [Kaplan & Saccuzzo, 2009 ; Kline, 2005]. If the items are strongly correlated with each other, they measure the same factor, resulting in higher values for Cronbach's alpha. However, Cronbach's alpha should be used with caution, because it tends to increase with a greater number of items in a scale and it does not allow any conclusion about the dimensionality of a scale [Cortina, 1993]. In our study, we followed the indications of Mallery and George (2003) usuallyaccepted by the research community for the interpretation of Cronbach's alpha values:

$\alpha_C > 0.9$	Very Good
$0.9 > \alpha_C > 0.7$	Good
$0.7 > \alpha_C > 0.6$	Acceptable
$0.6 > \alpha_C > 0.5$	Poor
$\alpha_C < 0.5$	Unacceptable

However it is important to note that, as highlighted by Taber (2017), these intervals have to be considered with caution, as their interpretation can depend on the context of the test. For instance, conceptual tests generally give lower values of Cronbach's alpha, especially when they assess a wide range of concepts or notions. This is the case in our study, for which many pedagogical factors contribute to the construction of the conceptual test.

Taking into account its limitations, the Cronbach's alpha can be useful for scale purification procedures, as it allows one to assess the variance specific to an element, the uniqueness of an element [Cortina, 1993]. Besides, for a given scale, it can be useful calculating a series of

Cronbach's α removing only one item at the time. In this way, we obtain a new alpha value associated with each item, noted α^*. If the omission of the item-specific variance decreases the alpha of the scale with all the items (i.e. $\alpha - \alpha^* > 0$), then the item in question contributes to a better consistency of the scale, and vice-versa.

Ferguson's delta

As with Cronbach's α, Ferguson's delta δ is a parameter that relates to a test as a whole and gives an appreciation of the discriminating power of the entire test [Ding and Beichner, 2009]. In particular, this index tells us about the distribution of learners' results on the possible values of the test. Good values for the delta are those around or greater than 0.9, which correspond to a normal distribution.

3.2.2. Statistical models

Factor Analysis and Principal Component Analysis

When a test measures a psychometric quantity, whether cognitive or affective, it consists of several items targeting potentially different psychological components. For example, learning mechanics includes several separate but related notions, such as interpreting one-dimensional or two-dimensional graphs of motion, understanding the laws of Newton, free fall, etc. When doing a *factor analysis*, one investigates whether a learner gives consistent answers to a group of items related to the same concept (or set of concepts).

More generally, factor analysis is a statistical method that considers the variability of several observed variables correlated in a single test, and aims to reduce this variability by using a reduced number of variables - called factors - which are not observed but are underlying and independent from each other [Tabachnick & Fidell, 2013]. The variables thus observed result in a linear combination of the underlying factors, each one taken with coefficients called *factor loadings*. Indeed, the square of each factor loading is the percentage of variance of an observed variable, which is associated with the corresponding factor. Thus, the factor analysis is a useful tool to develop consistent measurement instruments for abstract concepts, by evaluating the properties of individual items with respect to their factor adjustment.

When the number of factors underlying a test is known, from theoretical arguments or from previous empirical results, the analysis can be performed with a fixed number of factors and, in this case, the factor analysis is called *confirmatory*. On the contrary, if the factors are not known in advance, the analysis is performed without a fixed number of factors and the factor analysis is *exploratory*. This second type of analysis was preferred for the conceptual tests in our study, in view of the complexity of the concepts' interdependence in the targeted physics curriculum, and the absence of empirical previous evidence. In this case, the number of factors is generally estimated by considering only the factors with eigenvalues greater than 1 [Tabachnick & Fidell, 2013]. Alternatively, we can also determine the number of factors by plotting the loadings in decreasing order - the "scree plot" - and only considering the factors above (to the left) of the "scree" observed in the shape of the graphic [Cattell, 1966]. Moreover, it is often useful to compare the results of several factor analyses with different number of factors, to choose the solution that best matches with the theoretical and/or educational considerations, depending on a series of "goodness of fit" indices [Schermelleh-Engel *et al*., 2003]. In this research, we consider that an item belongs to a given factor when its loading is greater than 0.3, according to Stevens' recommendations (2002).

Regarding the extraction of the factors, there are two ways of proceeding: the factorization according to the *principal axis* and that according to the *principal components*. These two techniques lead to quite comparable loadings and a number of factors [Russell, 2002]. Nevertheless the theoretical framework that justifies the use of one technique rather than the other, as well as the mathematical procedure behind, is different. On the one hand, the principal component analysis models the correlated variables taking into account all the variance of each variable, without assuming *a priori* that a correlation between certain variables already exists. On the other hand, the principal axis factorizing only takes into account the covariance of the variables, by presupposing an underlying theoretical framework which already links certain variables [Tabachnick and Fidell, 2013]: principal axis factor analysis aims to maximize the modeled variance and thus the same item can more easily belong to several factors at the same time. This is why, for this type of factorization, rotation methods can be useful in interpreting the result.

In order to produce a stable factor solution, factor analysis requires at least three items per factor [Russell, 2002; Tabachnick & Fidell, 2013]. Moreover, factor analysis is sensitive to the ratio between the number of items of the initial item pool (k) and to the number of students answering those items (N), called the *subject-to-item ratio*. This value is typically between few units and hundred; the larger it is the more stable the factor analysis: an analysis of 303 subject-to-item ratios reports that around 63% of them have a subject-to-item ratio above 5:1 [Osborne *et al*., 2008].

In order to estimate the adequacy of factor analyses, the Kaiser-Meyer-Olkin (KMO) test measure of sample adequacy is commonly used to indicate the share of variance of the variables attributed to the underlying factors. Conventionally, KMO indices lower than 0.5 characterize data that are not suitable for factor analysis. The following values on the results are conventionally followed [Cerny and Kaiser, 1977]:

$$\text{unacceptable} < 0.5 < \text{mediocre} < 0.7 < \text{good} < 0.8 < \text{very good} < 0.9 < \text{superb}$$

In our work, we tried several types of factorizations and possible rotations in order to find a stable interpretation of the results of the conceptual physics tests. Nevertheless one knows that for this kind of conceptual tests a clear separation of the variables (factors) is not always possible, as often items can be considered as belonging to more than one conceptual dimension. Difficulties in elucidating the structure of concept tests through factor analysis are well known in the literature [Jorion *et al*.. 2015]. For few tests there an attempt of this kind is published (a review article from 2012 lists only 4 attempts of factor analysis out of 15 tests [Liu, 2012]. For the Force Concept Inventory test ([Hestenes *et al.,* 1992]) an interpretable factor structure was the subject of intense discussion [Lasry *et al*., 2011, Scott *et al*., 12].

In addition, performing a standard factor analysis on dichotomous data can be problematic when interpreting the results, as the data violates the assumption of a continuous distribution, (although this can be repaired by using the tetrachoric correlation - see [Woithe, 2020] “Factor analysis on binary data”]). For example, factor loadings can cause a downward bias, or additional factors without conceptual interpretation can be produced [Galbraith *et al*., 2008; Lorenzo-Seva & Ferrando, 2012; StataCorp, 2019]. In the case of physics conceptual multiple choices tests, the simplification of answers of the type "true or false" leads to a loss of information on the conceptions of the pupils, resulting in lower correlations and therefore a worse fit of the analysis, since the false answers and misconceptions are considered as equivalent (see in this regard the reference [Semak *et al*., 2017]). Caution is therefore required for interpreting the results of factor analyzes in the case of conceptual tests.

For each analysis of this work (pre- and post-tests), the number of factors was determined by the scree criterion or choosing the factors with eigenvalues >1. Then, in order to identify the most suitable factor structure, we compared several solutions with a different number of factors and rotated through oblique rotation for simplifying the data structure [Osborne *et al*., 2008]. We also placed a cutoff for loadings less than 0.30 and omitted the negative loadings, indicating anticorrelation between the results, unless a theoretical argument supports its presence.

<u>ANCOVA Analysis</u>

In order to determine if an independent categorical variable has an effect on a dependent categorical variable in a regression study, the *analysis of variance* or ANOVA can be performed as a first step [Ding & Liu, 2012]. For example, this analysis can be carried out to determinate whether the variable *group* (treatment or control) has an effect on the variable *interest in physics*, or on the result of the conceptual post-test. This is a statistics analysis’ tool that splits an observed aggregate variability found inside a data set into two parts: variability due to systematic factors, given by the experimental manipulation (treatment group or control group) and variability due to random unexplained factors. The former has a statistical influence on the given data set, while the latter does not.

Nevertheless, many other variables (categorical and continuous) may have an influence on the dependent variables (for example in our investigation the *prior knowledge of physics* or *self concept in physics*, as we will discuss in the section 3.4). This is the reason why the ANOVA analysis can be performed, where the effect of one or more other continuous variables that predict the outcomes are taken into account: those variables are called *covariates*. The aim is to establish what is the effect only due to the independent variable, i.e. whether or not the pupils using MDETs (treatment group or control group). Thus, the statistics *analysis of covariance*, also known as ANCOVA [Ding & Liu, 2012] is rather carried out. If the covariates can be measured, then including them in the model can control the influence that they have on the outcome, by carrying out a hierarchical regression in which the dependent variable is the outcome, and the covariates occupy a first place. In this way, the effect of the independent variable on the outcome is obtained *after* the effect of the covariates is taken into account.

The main advantage of including covariates in the ANOVA model is reducing the error variance within the group, because the random (therefore unexplained) part of the variance in the ANOVA can be attributed to the covariates, and therefore the error variance can be reduced and the effect of the experimental manipulation is better evaluated.

However, before performing an ANCOVA analysis, we must ensure that the assumptions underlying this method are respected [Field, 2012]:

(1) The independence between the covariates and the independent variable (the treatment), i.e. the covariates should be comparable across different groups of the experiment manipulation.

(2) The homogeneity of regression slopes: basically this condition means that the relation (positive or negative) between the outcome of a group of students and a covariate must be the same for all the groups of the experience (treatment group or control group). For example, if having a greater interest in physics implies a better post-test concept score for the treatment group, so must be the control group.

(3) The outcome variable should be approximately normally distributed. This can be checked using the Shapiro-Wilk test of normality on the model residuals.

(4) All groups of treatment should have the homogeneity of residuals variance; i.e. the residuals should have a constant variance.

<u>Multiple testing analysis</u>

When looking for the effects of a variable (the treatment) on a set of interrelated outcomes (for example the results of a set of individual items of the concept test), it is necessary to take into account the probability of finding false positives and to compare this probability with the number of “effects” found, to ensure that they are statistically significant. The aim of the false discovery rate (FDR) procedures is thus to estimate the rate of type I errors in null hypothesis testing when conducting multiple comparisons and then to control the expected proportion of false “effects” observed. In particular, in our investigation we will use the Benjamini–

Hochberg method, based on a step-down sequential Bonferroni-type procedure [Benjamini & Hochberg, 1995].

3.2.3. Effect sizes

Coefficient of determination or r-squared

The Pearson's r measures the linear correlation between two quantitative variables and can vary from −1, indicating a perfect negative linear relation, to +1 indicating a perfect positive linear relation (r = 0 means that no linear relation exists between two variables). The square of the Pearson correlation r^2 is named coefficient of determination and its size measures the proportion of variance shared by two variables, without giving any information about the direction of their correlation: thus the r^2 is always positive and varies between 0 and 1.
The descriptors for size of r^2 are [Cohen, 1988]:

$$0.01 < \text{small } r^2 < 0.09 < \text{medium } r^2 < 0.25 < \text{large } r^2.$$

Cohen’s d

When we want to compare the progression of a variable before and after the instruction (for example the normalized result of a concept test or the mean of an affective variable) or the statistical significance between a treatment group and a control group at any given time, we can calculate the effect size using Cohen's index d. This index takes into account the correlation between two measurements (1 and 2) measuring the impact of an intervention in units of standard deviations of the sample under consideration. When the compared sample are the same size (as is often the case for the pre / post comparisons of the same group), given the means and the respective variances pre and post for a given quantity *x*, the Cohen’s d is defined as the difference between two means divided by a standard deviation for the data [Cohen, 1988]:

$$\text{Cohen's d} = \frac{x_{mean\,1} - x_{mean\,2}}{\sqrt{\dfrac{\sigma_1^2 + \sigma_2^2}{2}}}$$

When the two samples are of different sizes, say N_1 and N_2, this definition generalizes as follows:

$$\text{Cohen's d} = \frac{x_{mean\,1} - x_{mean\,2}}{\sqrt{\dfrac{(N_1 - 1)\sigma_1^2 + (N_2 - 1)\sigma_2^2}{N_1 + N_2 - 2}}}$$

The descriptors of the Cohen d values commonly used are [Cohen, 1988; Sawilowsky, 2009]

$$0.20 < \text{Small d} < 0.50 < \text{Medium d} < 0.80 < \text{Large d} < 1.20 < \text{Very Large d}.$$

The conversion between the size effect of r^2 and Cohen's d is possible according to the formulas given by Fritz *et al*. (2012) or Lipsey & Wilson (2003):

$$\mathrm{d} = \frac{2 \cdot \mathrm{r}}{\sqrt{1 - \mathrm{r}^2}} \quad \Leftrightarrow \quad r^2 = \frac{d^2}{d^2 + 4}.$$

<u>Total eta squared</u>

When an effect of the independent variable is present after performing the ANCOVA analysis including all the covariates, the size effect is commonly measured by the *total eta squared*, η_t^2, which measures the proportion of variance associated with each main effect and interaction effect in the model, while controlling for other covariates, each additional variable will automatically increase the value of η_t^2:

$$\eta_t^2 = \frac{\text{sum squared of the considered effect}}{\text{sum of squares of all effects}}$$

The value for η_t^2 ranges from 0 to 1, where values closer to 1 indicate a higher proportion of variance that can be explained by a given variable in the model. The values criteria for η_t^2 are [Cohen, 1988]:

$$0.01 < \text{Small } \eta_t^2 < 0.06 < \text{Medium } \eta_t^2 < 0.14 < \text{Large } \eta_t^2.$$

The conversion between the η_t^2 and Cohen's d is possible by the following conversion [Fritz *et al*., 2012]:

$$\mathrm{d} = \frac{\sqrt{4 \cdot \eta_t^2}}{\sqrt{1 - \eta_t^2}} \quad \Leftrightarrow \quad \eta_t^2 = \frac{d^2}{d^2 + 4}.$$

3.3. Teaching Sequence

The teaching sequence of the whole semester (from September to February of the following year) was designed from the official program of the "Collège de Genève" (see annex n. 2). The contents are:

1) The kinematic quantities: position vector, displacement, trajectory, velocity vector (average and instantaneous), speed (average and instantaneous), acceleration vector (mean and instantaneous);

2) Linear motion: uniform linear motion and uniformly accelerated linear motion and their applications;

3) Dynamics: Newton's laws 1, 2, 3, the law of universal gravitation and free fall.

On this basis, the teachers constructed the sequence replacing a selection of laboratory and exercises sessions by 5 or 6 MDETs activities of video analysis for the treatment group, while keeping the traditional laboratory sessions in the control group classes. The activities were done using 8 iPads provided to each treatment class-group. Since there were a maximum of 16 pupils in each class-group, there was always at least one tablet for a couple pupils during the activity sessions. The activities focused on kinematics and dynamics, thus the "Video Physics" and "Graphical Analysis" applications by Vernier were used[1].

During the year 2017-2018, a set of activities were designed and carried out by the physics education researchers and the teachers. Some of these activities were tested by groups of pupils from the previous year to the pilot study. The table A.1 in the appendix 1 summarizes the activities that were considered, linking them to the targeted part of the curriculum (i.e. to the concepts worked on) and to the items of the conceptual test in its validation phase (see section 3.5.2). The activities that were tested during the year 2018-19 and eventually selected for the pilot study and the reasons for the selection are indicated in the last column of the table A.1. The teachers and the researchers selected 6 activities among a list of 14, according to the educational objectives, the level of the pupils and the constraints linked to the curriculum and the school. Moreover, the selected activities had to be consistent with the concepts tested by the selection of conceptual items validated during the year 2017-18 (see section 3.5). Then, for each selected activity, the corresponding protocol was created.

Each MDETs activity has been designed to replace an experimental activity or an existing exercise in the traditional course, therefore each MDETs protocol targets the same notions as the traditional equivalent activity/exercise, so as to ensure the same quality of teaching in all groups of pupils taught by the same teacher. When possible, whether for treatment group or control group, the activities/exercises had a situation-context.

In this section we will give a description of each of the six MDETs activities selected for the pilot study, plus a 7th activity, which was added in the main study (see chapter 5). For each one of them, the detailed working documents that have been submitted to the pupils are available in appendix 2.

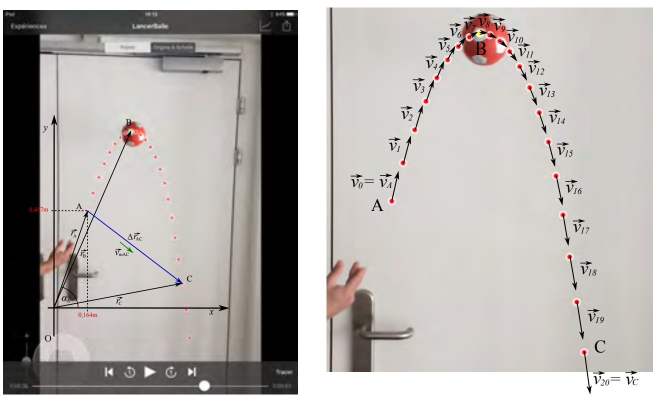
The MDETs activities used were :

[1] https://www.vernier.com/product/video-physics-for-ios/

1) Ball throw
2) Return trip
3) Uniform Linear Motion (ULM)
4) Average Acceleration in a Ball Throw
5) Uniformly Accelerated Linear Motion (UALM)
6) Standing Vertical Jump

MDET Activity n. 1: Ball Throw

The first activity introduces pupils to vector and scalar quantities in kinematics. That is on one hand vectors displacement, average velocity and instantaneous velocity; on the other hand the scalar quantities as the traveled distance, the average and instantaneous speed. It is therefore not yet an activity on the parabolic motion, even though the situation is that of the projectile in free fall, but rather on an introduction to quantities, as shown in the figure 3.1. In particular, items 7 and 8 of the conceptual validation test (see section 3.5 and table A.3 in the appendix 1) target these concepts. In the worksheet of the activity, the pupils of the treatment group are asked to calculate and draw the scalar quantities and vectors' magnitudes starting from the table of the measures given by the app. Since this was the first MDETs activity of the pilot study, the choice was made to let the pupils work on a video already recorded, to let them get familiar with the apps (tracing, presentation of data, graphics, ...). Thus, the treatment group pupils worked on common data (shown in figure 3.1) and begun taking their own data starting from the 2nd activity.



	Time (s)	X (m)	Y (m)	Vx (m/s)	Vy (m/s)
A →	2.101667	0.164113	0.486723	0.821477	2.61152
	2.135	0.191017	0.57753	0.834162	2.440874
	2.168333	0.219861	0.657233	0.836641	2.179557
	2.201667	0.247614	0.724845	0.818791	1.857887
	2.235	0.274281	0.781373	0.803716	1.50007
	2.268333	0.300858	0.824796	0.796213	1.14388
	2.301667	0.327359	0.857128	0.788792	0.799453
	2.335	0.353782	0.87837	0.772083	0.448369
	2.368333	0.379114	0.887521	0.747731	0.085574
	2.401667	0.403348	0.883573	0.731034	-0.26383
	2.435	0.427511	0.869543	0.724488	-0.603222
	2.468333	0.451591	0.843415	0.720457	-0.943472
	2.501667	0.475601	0.807204	0.713812	-1.297147
	2.535	0.499514	0.75688	0.693742	-1.648208
	2.568333	0.522349	0.69648	0.654512	-1.975611
	2.601667	0.544099	0.624998	0.58762	-2.293582
	2.635	0.561747	0.543461	0.516591	-2.602281
	2.668333	0.577302	0.450849	0.482663	-2.891913
	2.701667	0.592801	0.350171	0.485782	-3.170038
	2.735	0.609246	0.240412	0.50554	-3.472118
C →	2.768333	0.626622	0.119557	0.521792	-3.795179
	2.801667	0.644922	-0.013404	0.513653	-4.073268
	2.835	0.661148	-0.154794	0.497063	-4.27334
	2.868333	0.677319	-0.304124	0.489049	-4.399681

Figure 3.1: Example of situation and data for the MDETs activity n.1.

In parallel, the pupils of the control group carried out an exercise involving the same kinematic notions, but whose context was a trip in a surrounding area (between the cities of Nyon and Montreux), from a map and information available on Google Maps, as shown in figure 3.2.

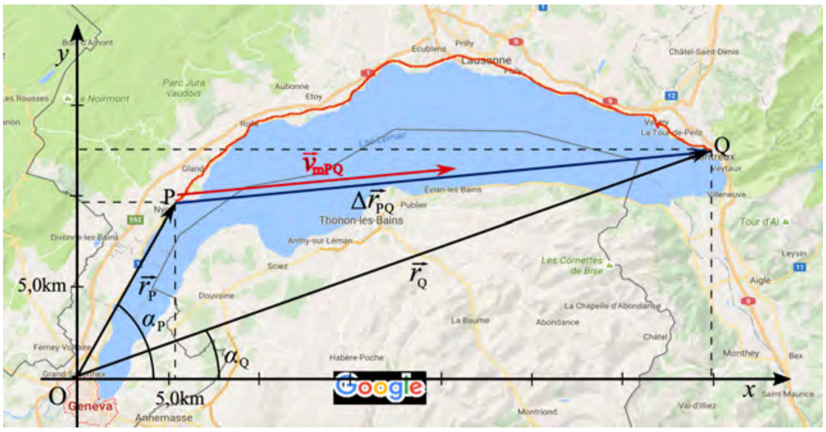


Figure 3.2: Example of situation of the activity of the control group, targeting the same notions as MDETs activity n.1 of the treatment group (vectors and scalars quantities in kinematics).

MDET Activity n. 2: Return Trip

The second activity consists of analyzing a hypothetical return trip movement of a pupil. Each trip covers the same distance but is made at a faster speed on the outward journey than on the return. The pupils have to calculate the velocity vector and the speed for the outward journey, for the return, and for the entire trip, after having made their prediction of the total average speed. This activity therefore allows the pupils to confront the misconception that the total average speed is equal to the mathematical average of the speeds in each of the journeys of the same distance: according to the study of Reed *et al*. (1985 and 1986), 85% of the students give this answer and only 5% of the students give the right answer. For this activity, it was possible to keep the same related-to-reality situation for the treatment group and the control group: the pupils of the control group could do the exact same activity, but measuring times and distances with traditional instruments, such as stopwatches or meters.

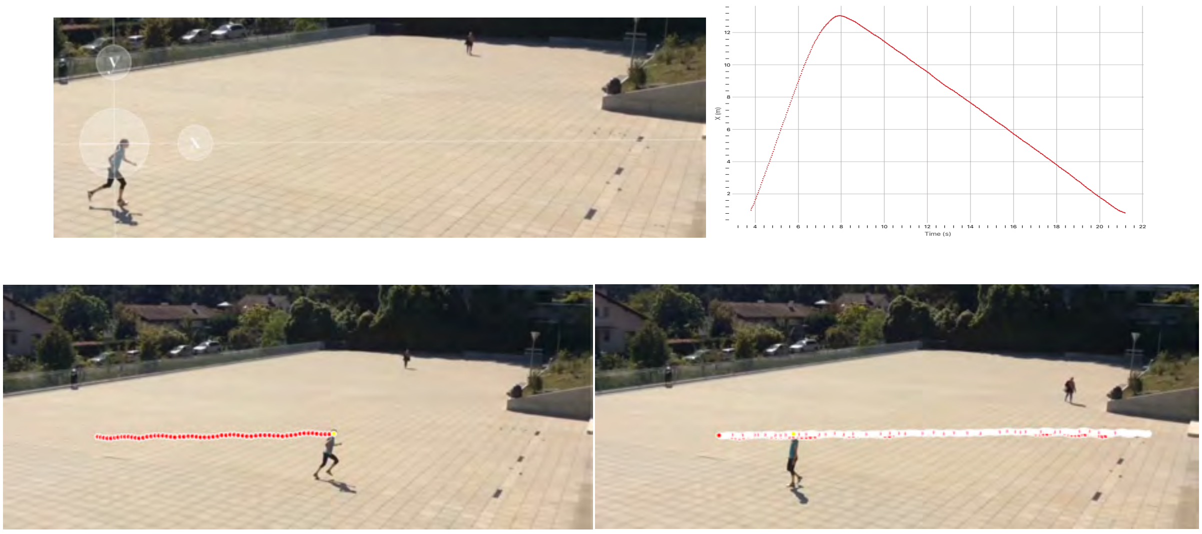


Figure 3.3: Example of situation of the second MDETs activity: fixing the reference frame, time diagram and tracing the movement.

MDET Activity n. 3: Uniform Linear Motion (ULM)

To analyze the uniform and linear motion, the control group pupils performed an experiment using a traditional setup, which varied according to the teacher and the school: for example, the motion of a ball over a short distance, of a marble or a cart on a rail (air rail or slightly inclined rail, to compensate for friction). The pupils of the control group had to create the motion's time diagram from the data collected with traditional instruments like a chronometer and a measuring tape. The pupils of treatment group analyzed the movement of a projector roller on a table (see the figure 3.4), starting from the data table provided by the app: as for the control group, they calculated the slope and the intercept, and they found that the diagram of velocity is a plateau. Indeed, they also got the graphics directly available by the app and thus didn't have to draw it.

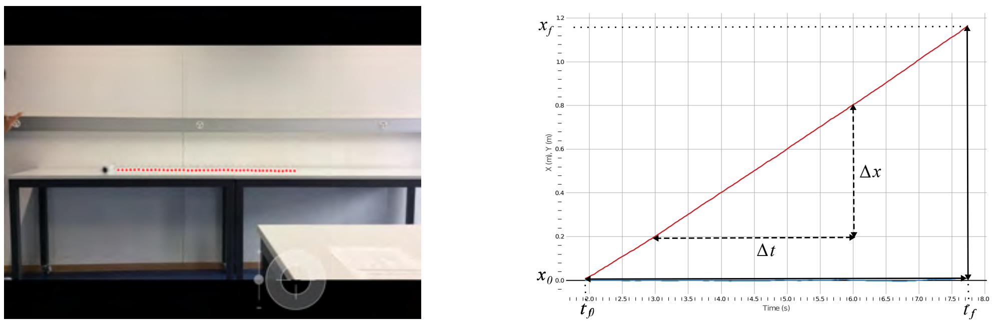


Figure 3.4: The ULM of a projector roll motion tracing, the time diagram of this motion in the MDETs activity n. 3. Pupils calculated the slope and the intercept with the data of the app. Graphical Analysis.

As one of the pedagogical objectives of this activity is that pupils are able to construct a time-diagram of a motion, pupils of the treatment group did not use the option "add a regression" to the graph here initially. They were shown this function only at the end of their analysis, to compare with their results for the slope and the intercept.

For both groups, this activity was the first allowing the pupils work on the notion of function, dependent and independent variables; and to associate, for the first time, these abstract notions with the corresponding physical quantities. Although pupils have seen these notions separately from physics (in math class), this application turns out to be a challenge for them.

MDET Activity n. 4: Average Acceleration in a Ball Throw

This activity takes up the situation and the data of the MDETs activity n.1, but after the pupils have been introduced to the notion of average acceleration vector. Here, the pupils of treatment group had to calculate the intensity of this vector from the instant velocities and

duration of the ball's flight, and then draw it on the diagram with a given acceleration scale, as shown in figure 3.5).
As for the MDETs activity n. 1, the pupils of control group carried out a similar exercise, training the same concepts. We notice that the average acceleration due to the change in direction of the velocity vector is a difficult concept to understand for pupils at the level of high-school, as can be seen by the low value of P of the related item (item n. 9) of the validation conceptual test (see section 3.5) as well as the results of the same item in the pilot study (see chapter 4).

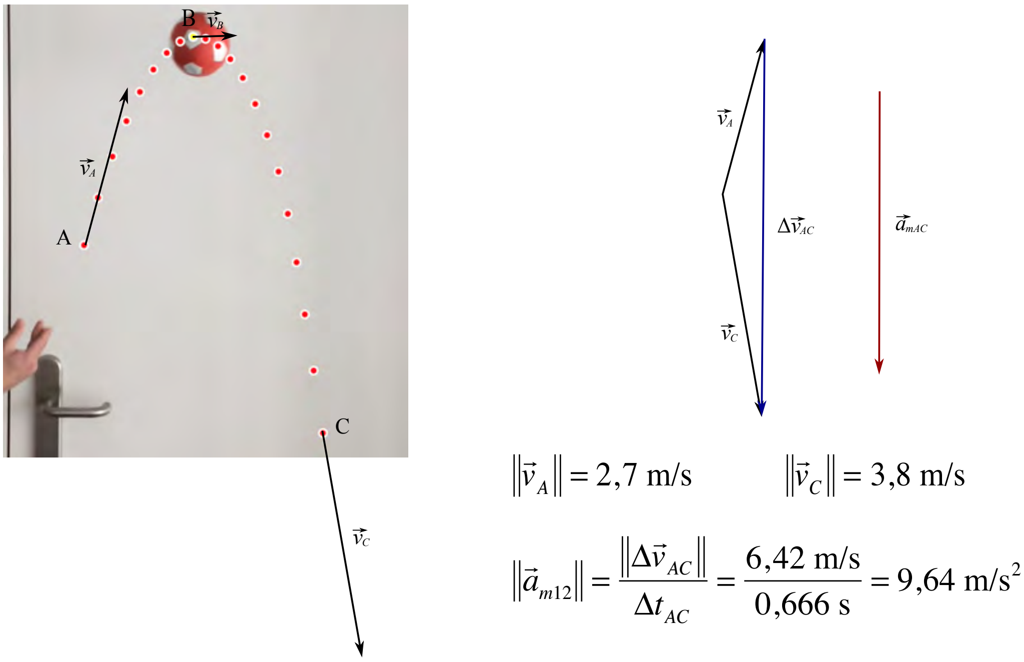


Figure 3.5: The situation of MDETs activity n. 4 is the same as activity n. 1, but here the worked notion is the average acceleration vector.

<u>MDET Activity n. 5: Uniformly Accelerated Linear Motion (UALM)</u>

In order to have an authentic topical context (see section 2.2), for the UALM activity (inclined plane), the pupils of the treatment group were given the opportunity to record a video of a person descending a slide in their out-of-school life and to use this video for the laboratory session in the classroom (figure 3.6, on the left). However, no one preferred this option: all the participants, both in the pilot study and in the main study, preferred to take the measurements in class using a "classic" laboratory situation (a trolley on an inclined rail, see figure 3.6 on the right). We asked them "*Why didn't you want to take a video yourself?*" and the responses were mainly of two types: (1) "*We prefer to take the video in class, because it is simpler.*" or (2) "*We prefer to work on a video already made by someone else, which works well, it does not matter if it is not done by us.*" Indeed the impression was that they consider themselves out-of-age for the playground. The objective of the laboratory sessions was above all for the pupils to take measurements based on their own experience. We have chosen to have the treatment group pupils work with the inclined rail to make them produce their own video.

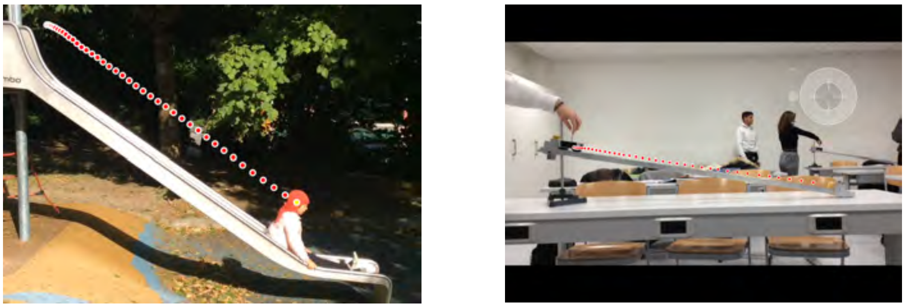


Figure 3.6: The two possible situations of MDETs activity n. 5: the more authentic slide at the playground and the traditional laboratory setup.

Thus, both treatment and control group eventually worked with a standard laboratory situation. The only difference was the use of tablets for the treatment group, and traditional measuring instruments for the control group (stopwatches and rulers). Pupils in both groups performed the graph of velocity (linear, figure 3.7 on the left) and of position (quadratic, figure 3.7 on the right) versus time for this motion. As for the ULM activity, the control group pupils had to produce the graphics reporting the data, while the treatment group pupils used the graphics provided by the apps. Moreover, a regression curve can easily be added, so that the treatment group pupils could better focus on the taught physics contents.

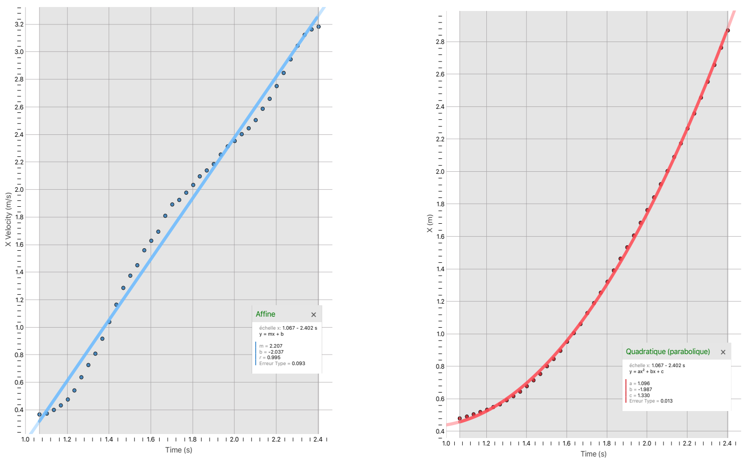


Figure 3.7: The velocity-to-time and position-to-time diagrams output of the app for the MDETs activity n. 5 of UALM.

<u>MDET Activity n. 6: Standing Vertical Jump</u>

This MDETs activity is the last planned for the pilot study and concerns the analysis of a vertical jump. It is the richest experiment in terms of physics contents and is divided into two phases [Darmendrail & Müller, 2020]. The first one consists of pushing upwards (between t_0

and t_1 in the figures 3.8 and 3.9), when the feet are still in contact with the ground. Here the acceleration and the resultant net force are both constant and upward. The pupils could draw the force diagram and had to apply their knowledge of dynamics (gravitation and the Newton's 2nd and 3rd laws) in order to find the pushing force of the person on the ground. The second phase (between t_1 and t_2 in the figures 3.8 and 3.9) is of free fall with a change in the orientation of the velocity. This phase starts as soon as the feet are no longer in contact with the ground: this movement is central in the study of the kinematics of the curriculum, as it allows the pupil to overcome the difficulty of differentiating velocity (which changes orientation during movement) and acceleration (which is constant and opposed to initial velocity), as the latter is the rate of change of the former. Indeed, the link between the acceleration and the resulting force is also established.

Phase 1 (between t_0 and t_1) Phase 2 (between t_1 and t_2)

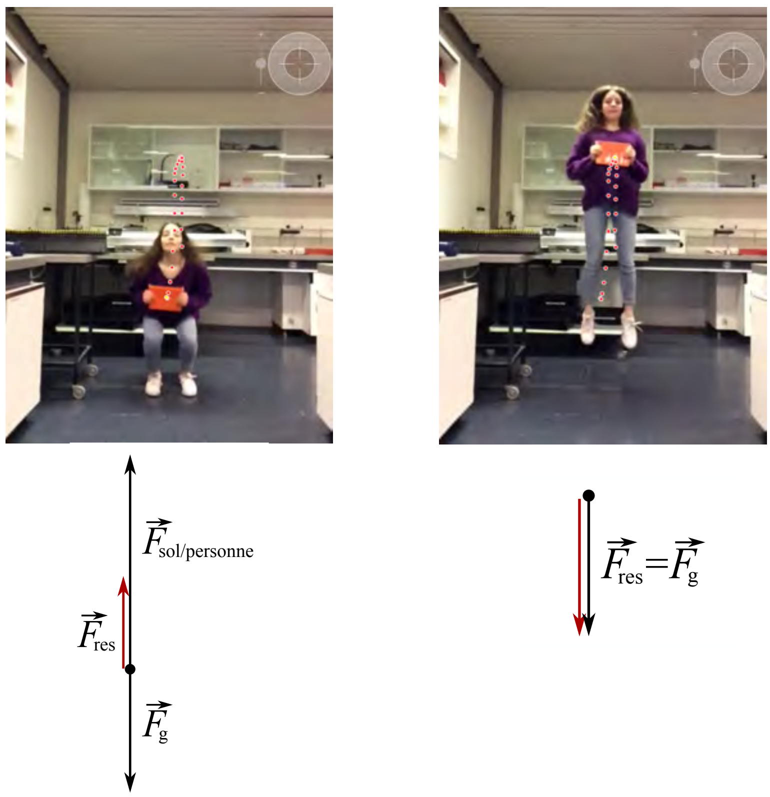
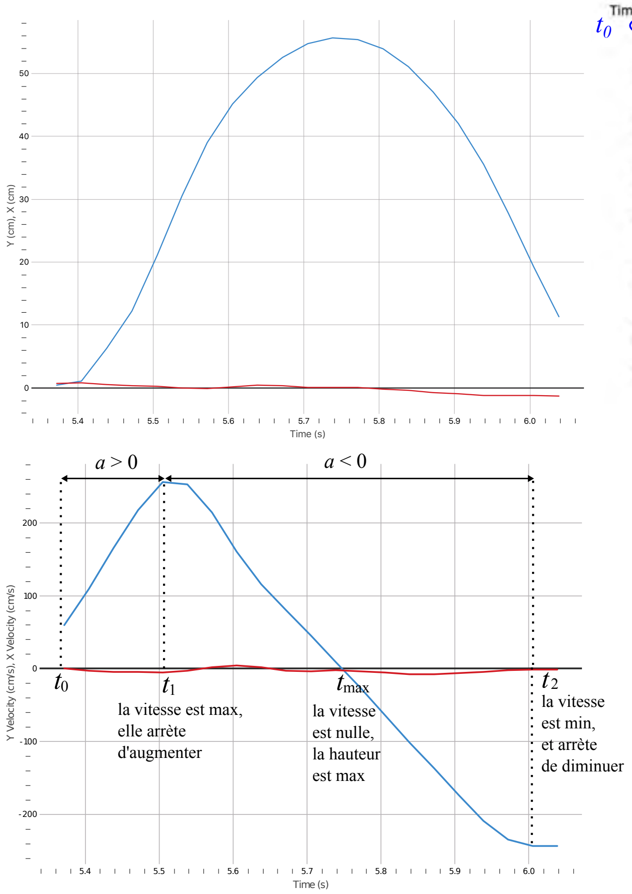


Figure 3.8: Forces diagrams for the two phases of a jump (MDETs activity n. 6).

For this activity, it was not possible to do the equivalent traditional laboratory. This is precisely one of the advantages of using MDETs, as measurements become possible (and therefore the collection of real data) when this is not the case with traditional equipment. In this setting, the pupils of the control group resolved the sheet-exercise with the related-to-reality situation of the standing vertical jump. Furthermore, for the control group the choice was made to replace the MDETs activity n. 6 by another laboratory on Newton's laws, in order to ensure the same teaching time devoted to experiments for all the class-groups of the same teacher. Each teacher was free to choose a different traditional laboratory session on the Newton's laws.



Time (s)	X (cm)	Y (cm)	VX (cm/s)	VY (cm/s)
5.371667	0.673641	0.380284	-0.111874	59.270175
5.405	0.751194	1.064852	-2.729756	109.243505
5.438333	0.517813	6.244227	-4.662729	165.343323
5.471667	0.376024	12.189445	-4.858927	217.179152
5.505	0.21845	21.100331	-5.14489	255.923739
5.538333	-0.037338	30.489041	-3.055137	252.745883
5.571667	-0.097209	39.017769	1.773296	214.344373
5.605	0.142651	45.156357	4.529009	160.943623
5.638333	0.392696	49.381612	2.058642	115.806403
5.671667	0.361342	52.553005	-2.774593	80.223547
5.705	0.04808	54.766203	-3.705682	45.458706
5.738333	0.028948	55.641595	-2.238314	9.43104
5.771667	0.015927	55.368987	-3.562073	-26.452033
5.805	-0.182317	53.94736	-5.673719	-64.09324
5.838333	-0.372923	51.090733	-7.626769	-101.574154
5.871667	-0.748751	47.085087	-7.757241	-136.972529
5.905	-0.927643	42.028126	-6.445498	-173.718543
5.938333	-1.194565	35.535655	-4.501918	-209.345051
5.971667	-1.263532	27.800535	-1.769299	-234.443725
6.005	-1.232759	19.300592	-1.092813	-243.209819
6.038333	-1.300199	11.278472	-1.370992	-243.370749

t_0, v_{y1}, y_{max}, v_{y2}

Figure 3.9: Position-to-time (top-left) and velocity-to-time (bottom-left) diagrams during the jump: the upper position corresponds to the instant where velocity is zero. The constant acceleration, in the first and in the second phase, is found calculating the slope of the velocity-to time graph. On the top-right: output data from the app.

3.4. Control variables

We remind that the dependent variables of our study are

- affective (*interest*, *relation to reality*, *curiosity state* and *self-concept*) and
- of learning (in physics and in mathematics).

The dependent variable is the treatment: yes for the treatment group, or not for the control group.

In order to ensure the study of the effective impact of the use of MDETs on the selected dependent variables, we carried out an inventory of the predictors

1) which are likely to have an influence on these outputs, and

2) which cannot be removed.

We call those kind of predictors "covariates", and aimed at controlling them or keep them as constant as possible during the study.

In view of test economy (i. e. weighted importance versus available time), a selection of control variables was made according to the relevance of each variable considered and the practical possibility of obtaining the information. For example, the social level of the student's family was considered as "sensitive" information, difficult to obtain directly from pupils or from the schools. Another potentially useful information which was not possible to utilize is the mother tongue of the participants: we actually did collect this information in the tests, however, when analyzing the answers, we realized that the interpretation of the word "mother tongue" varied greatly among pupils. For some it was the language commonly spoken at home, for others it was the language used at school, and for others it was the language of origin of the family and not necessarily a language spoken by the student. We noticed that the population of the canton of Geneva is made up of a large proportion of families from all over the world; therefore many citizens from this city speak several foreign languages more often than that of their family of origin. Moreover, the percent of lessons where the homework was not done was not available from the all the participating teachers. Table A.2 in appendix 1 provides the list of the considered variables, including the role of each one, indicated in the third column, i.e. whether it corresponds to a dependent variable, an independent variable or a control variable.

As discussed in chapter 2, the dimensions *interest* (IN), *curiosity as a state* (CS), *relation to reality* (RR) and *self-concept* (SC) were measured as dependent variables in the post-test, and as covariates in the pre-test, as their initial state is an important predictor not only for the affective but also for the learning outputs (see section 2.2.3). Empirical evidences has shown, for example, r = 0.3 corresponding to a Cohen's d = 0.63 for the effect of *interest* on learning [Wild *et al*., 2001], and r = 0.43 and d = 0.95 for the effect of *self-concept* on learning [Hattie, 2008].

As seen in section 2.2.3, while *curiosity as a state* refers to a tendency to be curious specifically about a certain topic (here the physics course), *curiosity as a personality trait* (CT) is defined as the personal tendency to seek new knowledge and understand more about a wide range of subjects [Naylor, 1981; Schmitt & Lahroodi, 2008]. Thus, the former can evolve following the instruction, while the latter is supposed to remain stable over the duration of the study (see section 2.2.3). Although these two types of curiosity are considered as separately constructed, they are correlated with correlation indices ranging from 0.2 [Litman *et al*., 2005] to 0.8 [Reio *et al*., 2006]. The interdependence between *curiosity as a trait* and *interest* is also known [Alexander & Grossnickle, 2016] and, moreover, *curiosity as a trait* is recognized to be a direct predictor of learning [Von Stumm, 2011; Wavo, 2004], which is why we included this covariate in our study.

We expected the initial state of *self-concept* to have an impact on both motivation and learning outputs, as "interest in physics instruction is closely related to the pupils' physics-related self-concept" [Hoffmann, 2002, p. 452]. Furthermore, according to the theoretical framework on curiosity explained in section 2.2.3, the initial "personal factors" evolving in time (*interest*, *relation to reality*, *self-concept*, *curiosity as a state*) and those stable (*curiosity as a personality trait*) may moderate the expectation of success in finding satisfactory resolutions and thus influence the final *curiosity as a state* and *interest* results.

Besides, in the view of the planned intervention, we considered that a better mastery in the use of apps for Smartphones or tablets might be at the origin of a more effective reduction of cognitive load during the MEDT activities and therefore hypothetically lead to a better learning. On the other hand, we assume that pupils having better self-beliefs about their use of the apps are also more familiar with mobile devices and therefore they will be more sensitive to the "material context" created by these devices, leading to stronger effects both on motivation and on learning (see paragraph 2.2.2 and figure 2.4). For this reason we included the *self-concept concerning the use of apps for Smartphones* (SCS) among the control variables, by simply adapting the items of the self-concept in physics.

Another key variable of our investigation, for its known strong impact both on learning and on the motivation outcomes, is *teacher* (see e.g. [Hattie, 2008]). Although several teachers participated in the study, we partially controlled this variable by insuring that each teacher had at least one treatment and one control group, and included the variable *teacher* among the predictors of the analysis. In addition, we took into account the *teacher assessment* (TA) dimension [Dorman, 2003; Fraser *et al*., 1996 (WIHIC), Vogt, 2010], through an anonymous questionnaire in a separate sheet at the same time as the affective post-test. For the analysis, we calculated the average of the ratings of pupils belonging to the same group and assigned this value to each pupil in the appropriate group.

Physics experiments and in particular those with MDETs stimulate pupils *cognitive activation*. Furthermore, we know that cognitive activation, intended as the in-depth elaboration of the information required to perform a task, has an effect on the learning of mathematics while supporting the motivation of pupils [Burge *et al*., 2015]. More generally, it has been shown to produce a more effective education [Baumert *et al*., 2010; Kunter *et al*., 2013], insofar as it is also seen as a mediator between the learning and the interest of a discipline [Lipowsky, 2009]. We therefore included *cognitive activation during the experiments* (CAE) as covariate of our study.

According to cognitive load theory (see section 2.3 and [Sweller, 1994]), the way in which pupils' cognitive abilities are stimulated or overloaded can have an important effect both on learning and motivation, whether positive or negative. The self-perception of a high cognitive load can indicate either excess of *extraneous cognitive load*, which would tend to reduce learning, or as an index of a major contribution of *germane cognitive load*, which results to be beneficial for learning. Thus, the sequences are planned with the aim of keeping the *cognitive load during the experiments* (CLE) as constant as possible in the two groups. Furthermore, the perception of this dimension was measured in the affective post-test. The items selected for

this scale (see table A.2 in appendix 1) cover various aspects of perceived cognitive load created by learning activities as discussed in the literature.
All items are based on validated and published instruments, mostly [Orion *et al*., 1997] and [Yunker, 2010] (SOLEI instrument), and [Paas *et al*.,1994]; some were used in other studies in physics education ([Cors, 2016]; [Hirth, 2019] and [Woithe, 2020]) and have been adapted to the specific context of our study. As for the other selected affective scales, a psychometric validation of instrument as used in this study was carried out and is reported in section 3.6.

As we saw in section 2.3, the multiple functionalities and representations given by the apps of video analysis may require an effort on the part of the learner, to organize and coordinate the information provided. This effort can lead to better learning, but can also be the source of an excessive cognitive load and, as a result, have negative effects on learning. This is the reason why we also measured the perceived *cognitive load due to the apps for Smartphones* (CLS), only in the treatment group.

Non-verbal skills and *visual-spatial abilities* (SA) are other factors having an impact on learning in different branches of science. Indeed, a better mastery of these capacities in the science learning has been shown to have an influence on information processing in working memory, leading pupils with higher visual and spatial skills to a better learning of science [see e.g. Wu & Shah, 2004; Mayer & Moreno, 2003; Khine, 2017]. In particular, Opfermann *et al.* [2017] recently highlighted the importance of visual-spatial abilities in physics learning and we followed their recommendation to include this covariate. Thus, a paper-folding test [Elkstrom *et al*., 1976] was carried out at the beginning of the study (a test where pupils are to imagine the folding and unfolding of pieces of paper).

Previous research has shown that the learner's *prior knowledge* in a domain has an important impact on learning ($d \approx 0.8$) [Hattie, 2009], and this also applies to physics learning [Kohl & Finkelstein, 2005 and 2006] and when the learning of new notions is done with multiple representations [Ainsworth, 2006]. The prior knowledge can enrich the student's ability to refer to old knowledge, reduce the cognitive load, and complete the information when not present in the available representations. Thus, we included the *prior physics grade* as a predictor in our study. Furthermore, we also considered the *prior mathematics grade* as covariate, more than the post grades of the same disciplines as dependent variables.

On the one hand, as we have already pointed out, many mathematical notions of the program, which are studied by pupils at the same time as the mechanics' program, are underlying and essential to the understanding of the physics contents targeted. On the other and, the same mathematics are also at the base of the representations given by the MDETs video analysis apps. In general, the strong interdependence between mathematics and physics learning has been documented since decades [Thorndike, 1946] ($r \approx 0.8$), and has been confirmed by more recent researches [see e.g. Meltzer, 2002; Karam, 2015], reporting size effects ranging between medium and large. Other recent studies exist, confirming the previous results concerning specific topics [Torigoe & Gladding, 2007 and 2011; Pepper *et al*., 2012; Uhden *et al*., 2012; Wilcox *et al*., 2013; Bollen *et al*., 2015].

Since all the activities, the exercises and the explanations of the physics course are based on the understanding of the explanations in French (the spoken language in Geneva), we also added the *prior grade in French* as covariate.

We also considered *gender* among the important predictors, both for affective and cognitive variables. Indeed, the fact that boys obtain better results, concerning affective variables, such as self-concept or learning in physics [see e.g. Lee and D. T. Burkam, 1996; Louis and J. M. Mistele, 2012; Kost et al., 2009; Madsen et al., 2013] or sciences in general [OCED, 2007], has been known for a long time. In addition, studies indicate that female pupils generally have less biographic experiences leading them to the use of new technologies, which could result in a negative effect on learning using new technologies and/or the affective dependent variables [Osborne *et al*., 2003].

3.5. Learning test

3.5.1. Choice of Items

Similarly to the activities of the sequence, the learning test was built from the concepts and notions taught in the curriculum and according to the research questions of the study. The items of the instrument used in the pilot study were thus chosen among a selection of 31 questions, which have been validated during the school year 207-2018. The test of the pilot study was subsequently adapted and refined for the main study (see section 4.6).

Each one of those 31 items was taken as-is or inspired from instruments already existing and validated in the literature. Moreover, when no item concerning some specific concepts was fond, new conceptual questions have been created and validated before the pilot study during this validation phase. The first gathering of 31 adapted questions was mainly made on the basis of the curriculum concepts targeted in the activities of the sequence and the typical relative misconceptions. These 31 items composing the validation tests have been chosen among the questions of two classic references in the evaluation of conceptual knowledge in kinematics and Newtonian dynamics:

- The Force Concept Inventory (FCI) [Hestenes *et al.,* 1992];
- The Test of Understanding Graphs in Kinematics (TUG) [Beichner, 1994].

The first column of table A.3 in appendix 1 consists of the questions as they were asked to the pupils (in French) and the second column indicates its original provenance test and whether any modification or adaptation was made and its reason.

The majority of the items are about one-dimensional kinematics (items 12 to 25 of table A.3), which represents most of the program covered during the duration of the study (i. e. the winter semester). In particular, the presence of questions such as items 12 and 13 (corresponding to the couple of items 19 and 20 of the FCI), or the related items 14 and 15 (corresponding to items 1 and 2 of the MBT) of table A.3, where the interpretation of the chronophotography of a movement is tested. These interpretations are particularly relevant in this our study, because the tracing of a motion by the MDETs' apps provides exactly this kind of real time representations, and therefore a difference in the results between the treatment group and the control group can be expected.

Items 23, 24 and 25 of table A.3 are about “free fall”. While item 24 was taken as-is from the FCI, items 23 and 25 were created specifically for this study. Item 23 is intended to test the understanding of the difference between velocity and acceleration during an uniformly accelerated motion with a change in the direction of the velocity (trained in the MDETs vertical jump activity n. 6). Whereas item 25 was created from the same situation as item 24, and concerns two free falling balls that do not start from the same height: here the aim is to test the understanding of the quadratic dependence between displacement and duration in a uniformly accelerated linear motion.

Items 26 to 31 of table A.3 focus on the three Newton's laws, they mainly come from FCI, except two items (30 and 31), which were created based on questions by teachers, targeting in particular Newton 2nd law in one dimension.

Item 11 is also a newly created question, specifically testing the notion of average speed in a round trip. Hence, this concerns the widespread misconception leading the majority of students to answer by the arithmetic average [Reed, 1985], and it is associated with MDETs activity n. 2, presented in section 3.3.

Items 7 to 10 were created from the context of items 5 and 6 of the FCI, and they are about the basic notions of vector displacement, average velocity and average acceleration in a two-dimensional motion. These are questions associated with MDETs activities n. 1 and 4 presented in section 3.3.

Moreover, both the study of mechanics and the use of video analysis applications require a certain mastery of the mathematical concepts applied to the physics, as using vectors or reading and interpreting graphs. The interpretation of functions applied to physics is present in the kinematics items described above, we therefore selected of few items from the Test of Understanding Vectors (TUV) [Barinol *et al.* 2014], that is items 1 to 5 of table A.3. The only difference with the original items is that, instead of presenting the vectors as abstract mathematical quantities, they have been "dressed" with physical meaning, presenting them as resultant forces, relative velocities or positions, for consistency with the content taught in physics course.

3.5.2. Validation

The following columns of table A.3 of appendix 1 show the result after administering the 31 items to a total sample of 275 pupils. The validation was carried out over 164 1st year pupils as a pre-test (before instruction) and over 111 2nd year pupils as a post-test, after the traditional kinematics and dynamics course by many teachers of the Geneva high school. The tests (pre- and post-) had duration of one the teaching period (45 '), which made it possible to create conceptual tests containing 25 items each. In order to test the 31 selected items, we created 2 validation tests: test A and test B (available in appendix 3). Each one contained 25 items, including 19 items in common, plus 6 items specific to test A and 6 items specific to test B. In this way, each of the 12 items, which is either in test A or in test B, was answered by about half of the validation sample. Thus, 19 items could be validated by the entire sample (N_{pre} = 145; N_{post} = 111), while the 6 items only present in test A ($N_{pre\ A}$ = 96; $N_{post\ A}$ = 61) and those who were only in test B ($N_{pre\ B}$ = 68; $N_{post\ B}$ = 50) have been done by only a part of the sample.

Thus, as shown in the table A.3, the item analysis was performed for the common part of the test having k = 19 items and N_{pre} = 145 or N_{post} = 111 students, and respectively for the tests A and B having each one k = 25 items and the respective $N_{A\ pre/post}$ or $N_{B\ pre/post}$. In order to ensure greater consistency in the analysis, the items focusing on a same specific notion or the items that are related in the literature, are grouped together in the same test, either A or B.
For example,

- The 3 items concerning the kinematics in two dimensions (items 7, 8 and 9 in table A.3) appear only in test A;
- Items 1 and 4 in the table A.3 are both adapted from the same item of TUV [Barinol *et al.,* 2014] and only appear in test B;
- Items 14 and 15 of the same table correspond to a couple of related items from Mechanic Baseline (MBL) test [Hestenes *et al*., 1992] and they are both in test B.

Moreover, the 19 items of the common test relate exclusively to one-dimensional mechanics, and the balance in the proportion of subjects tested in the two tests was ensured. For example, among the 3 different items testing Newton's 3rd law (items 27, 28 and 29 of Table A.3), one is in the common test, one is in the test A and one is in the test B, so that in each test (A or B) we find 2 items on this notion. The same was done for the distribution of items containing the notions of vectors applied to physics, i.e. items 1 (test B), 3 (common test), 4 (test B), 5 (test A), and 6 (test A) in table A.3.

Thus, after administration in each degree (in 1st and in 2nd year), an item analysis was carried out, including Cronbach Alpha α and Fergusons Delta δ for the set of 19 items in common to test A and test B (N_{pre} = 145 or N_{post} = 111). Then, for each test (A or B), the results for the 12 items appearing only in test A or B are given. Before the analysis of each item, the overall results of the 19 common items and of the 6 items specific for each test (A and B) are given for the validation in 1st year level as (1DF, before the instruction), in 2nd year level as post-test (2DF, after the instruction), and for the restricted items chosen in the pilot study.

The 3rd and 4th column of table A.3 indicate the number of responses given among the 5 possible options: A, B, C, D, E or 0 (when there was no response or no single response). The correct answer is indicated with an asterisk (*). The most frequent answer is in bold characters and additionally underlined when it is associated with a known misconception.

In the 5th and 6th column of the same table, the psychometric indices [Ding et al. 2009; Kaplan & Saccuzzo, 2009; Kline, 2005; Field, 2012] of each item are reported. The following column compares these indices with those already existing in the literature, whether for high school or university students. Here, the histograms show the level of difficulty P for the 3 levels: 1DF (1st year of the Geneva high school, before the instruction), 2DF (2nd year of the Geneva high school, after the instruction) and the results from existing literature [SSG 12, Barinol *et al.* 2014, Beichner 1994, Scott & Schumayer 2012, Traxler *et al*. 2018], after instruction (high school or university). An overview of all histograms is shown in Figure A.1. We observe a clear progression of pupils' achievement: the difficulty (or easiness) index P increases from the first year of high school (1DF) to the second year (2DF) and from 2DF to university, when the comparison with university students is possible. The difficulty of pupils in 2DF is comparable with previous studies in high schools. We remind that the pupils in Geneva high school who took this validation test followed non-specialized physics classes.

Following these results, we kept 17 items as part of our instrument: 11 of the 16 common items between A and B, in addition with 2 items only in test A and 4 items only in test B. Moreover, we retained 2 additional items in test A, which we considered outside the analysis for their pedagogical interest, and we added one item replacing one of the tested items. Each time, the reasons of our choices are explained in the relative column of table A.3 of the related item.

The items used in the pilot study instrument were selected taking into account not only the psychometric indices, but also (1) the goals and research questions of the study, therefore the concepts which were more directly concerned by the MDETs activities, and (2) the pedagogical reasons and/or constraints. In particular, the items from the TUV related to vectors were eventually not kept because

- either none of the MDETs activities specifically worked on the concepts evaluated (for example items 1, 3, 4, and this was also the case for item 10 of FCI),
- either all the teachers participating in the study did not plan to work on a specific notion (for example the relative velocity, tested by items 4 and 6),
- or the notion was not specific to the 2nd year program but rather the 1st year one (items 2 and 5).

Furthermore, few items having low psychometrics indices were kept for their pedagogical value, or because they are related to misconceptions on which the MDETs activities are focused. This is for example the case of item 11, on average speed in a round trip. In this case, Reed *et al*. (1985, 1986) estimate that about 85% of students answer that the average speed of a trip composed in two parts of equal distance, each covered with a different speed, corresponds the arithmetic average of the two speeds. This common misconception is explained by Reed *et al*. by the "availability heuristics", and explains the low P that we observed, which in agreement with the previous study. In our study, we want to assess the impact of MDETs in order to overcome this type of misconceptions. This is why we chose to keep the item 11 and the corresponding activity (MDETs Activity n. 2) focused on this topic.

We also chose to keep item 9 about average acceleration in two dimensions. This item is about a misconception commonly observed among students, that acceleration is present only if the intensity of the velocity changes, and no acceleration is present if its direction changes. Apart from the results of our study, no previous literature exists about this specific misconception. Nevertheless, experienced teachers participating to the validation or to the study unanimously find that this misconception is difficult to overcome: the low P observed here seems to confirm this impression and we therefore decided to maintain this item, in order to compare the gain with the use of MDETs during the pilot study.

Finally, we replaced two items (item 16 and 17), whose psychometric parameters were not good (high P and low D) and whose pedagogical interest and consistency with MDETs activities was weak. Instead of these two questions, we added two items from the Motion Content Test, MCT [Svec, 1995], better suited to graphic representations worked in planned activities. The final versions of the conceptual tests of the pilot study are available in the appendix 3.

3.6. Tests for affective variables

The questionnaire on affective variables used in the pilot study consisted of the choice of affective dimensions indicated in the first two column of table A.2 of appendix 1. Here, most of the items selected are based on scales that have already been widely validated and whose reliability has been confirmed by previous studies, mentioned in the section 3.4. However, some items were translated into French and / or adapted to the specificities of the teaching and the hands-on activities planned in the study.

For each scale, the first of the three central columns of table A.2 shows the items existing in the literature in their original language, as well as the relative sources, and the following column of the same table reports our translation and/or adaptation in French. The third central column contains the items newly created for this study, namely by adding sentences expressing the "negative" version of a dimension (e.g. for *relation to reality*: "I do not see any link between the subjects treated in the course of physics and the everyday life ") or typical French expressions, frequently used by pupils to indicate a given dimension (e.g., to express a negative *self-concept in physics*, they often voice: " Je suis nul.le en physique "). Then, for each scale, we chose 5-to-7 items for the affective test of the pilot study, dealing with the number of items foreseen in the pre/post questionnaires and avoiding redundancy. The items chosen for the pilot study questionnaires are indicated in table A.2, with a check mark as well as the acronym and item number in the corresponding dimension. In addition, eventual comments or mentions on the subsequent adapting or replacement of items in the main study are marked (see chapter 5).

This procedure resulted in a pre-test of affective variables common to all students participating in the pilot study, and two affective post-tests: one for the treatment group (including the CLS items) and one for the control group (without the items of CLS). The only difference was the presence of the items of the dimension *cognitive load due to the apps for smartphones* (CLS) in the post-test for the treatment group. Moreover, the dimension *teacher assessment* (TA) was tested in a separate sheet anonymously. For each statement of the affective tests, the students expressed themselves with a rating ranging from 1 ("completely disagree with this statement") to 6 ("completely agree with this statement"). All the affective tests of the pilot study are available in the appendix 3.

In view of the good psychometric parameters of the dimensions of most of the items retained for the affective tests from previous literature (see the respective references in the table A.2), the goal of the analysis of the results of the pilot study was mainly to confirm the correct functioning of the scales. Subsequently, in the main study we reduced to five items for each scale, in order to optimize the time available without overloading the tests. For this purpose, the items with poorer discrimination parameters or showing internal Cronbach scale consistency measure increased by omitting them (see section 3.2) were discarded for the main study (see chapter 5), after the careful examination of the item text and its meaning with respect to the underlying theoretical construct.

In addition to the item elimination procedure described above, we submitted the affective post-test (containing several dimensions that were not in the pre-test, as *cognitive loads* or *involvements*, ...), for a further validation, at N = 41 pupils of the same degree other than those participating in the pilot study. As shown in the table 3.2, despite the relatively small N, the results of the item analysis of this validation are good in general.

Table 3.4: Item analysis for the validation of the post-test measuring the affective variables. N = 41; 6-level items 1= completely disagree, 6 : completely agree; * : created items. For each item (left column) the mean value M, the individual item reliability r_{it} (with standard deviation in brackets), the variation of the Cronbach Alpha α-α^* without the items in question (α^* is the Cronbach Alpha of the dimension without the item) are given [Ding & Beichner, 2009]. The last column gives the α value for each dimension and its confidence interval [Kuder & Richardson,1937].

Item	M (SD)	r_{it}(CI)	α - α*	α
SC1: J'ai pu résoudre les problèmes	4,01 (1,04)	0,71(0,32)	+0,038	0,79
SC2: Mes camarades ont trouvé que j'étais bon(ne)	3,10(1,48)	0,86(0,17)	+0,065	
SC3: J'ai bien compris les sujets traités au cours	3,84(1,06)	0,77(0,27)	+0,050	
SC4: Mes résultats en physique ont été satisfaisants pour moi	3,20(1,40)	0,48(0,48)	-0,023	
SC5: Je m'attends à ce que mes résultats en physique soient bons	4,70(1,09)	0,38(0,53)	-0,021	
7-SC6: J'ai eu des difficultés à comprendre les sujets traités	3,49(1,17)	0,73(0,30)	+0,043	
7-SC7: Je suis nul(le) en physique*	3,28(1,57)	0,79(0,25)	+0,054	
IN1: Suis plus investi pour ce cours que pour les autres matières	3,22(1,26)	0,62(0,40)	+0,053	0,66
IN2: J'ai bien aimé résoudre des problèmes de physique	3,34(1,17)	0,59(0,41)	+0,047	
IN3: J'ai bien aimé le cours de physique	3,62(1,28)	0,63(0,38)	+0,059	
IN4: J'ai fait des recherches dans des livres, les journaux, etc.	2,89(1,75)	0,57(0,43)	-0,011	
IN5: En plus des devoirs, j'ai consacré du temps libre …	2,49(1,21)	0,56(0,44)	+0,034	
7-IN6: J'ai trouvé ennuyeux de résoudre des problèmes*	3,51(1,19)	0,45(0,50)	+0,002	
7-IN7: Je me suis ennuyé dans les heures de physique*	3,23(1,07)	0,64(0,38)	+0,065	

Table 3.4 - continued

CT1: Je trouve fascinant d'apprendre des nouvelles choses	4,60(0,99)	0,82(0,22)	+0,082	0,82
CT2: J'aime apprendre des choses que je ne connais pas	4,83(0,89)	0,76(0,27)	+0,038	
CT3: Ls. j'apprends qqe ch. de nouveau, je veux en savoir plus	3,85(1,10)	0,78(0,25)	+0,044	
CT4: J'aime faire des rech. sur les ch. que je ne comprends pas	4,00(1,30)	0,61(0,40)	-0,023	
CT5: J'aime essayer de résoudre des problèmes qui m'intriguent	3,91(1,17)	0,53(0,46)	-0,030	
CT6: Je veux toujours examiner les choses en profondeur	3,43(1,09)	0,79(0,24)	+0,048	
CS1: Je voudrais en savoir davantage sur les sujets traités	3,28(1,18)	0,76(0,28)	+0,084	0,72
CS2: Je voudrais mieux comprendre les sujets traités	4,63(1,18)	0,52(0,46)	-0,038	
CS3: Je trouve fascinants les sujets traités au cours	3,17(1,07)	0,70(0,33)	+0,057	
CS4: Le cours a éveillé ma curiosité à propos des sujets traités	3,49(1,25)	0,86(0,18)	+0,156	
CS5: J'aime passer du temps à réfléchir sur les sujets traités	2,87(1,10)	0,61(0,40)	+0,010	
RR1: Les probl. sont utiles pour les situat. en dehors de l'école	3,42(1,36)	0,79(0,15)	+0,019	0,88
RR2: Les sujets sont utiles pour des sit. de la vie quotidienne	3,13(1,26)	0,82(0,13)	+0,028	
RR3: Le cours a traité des situations de la vie quotidienne	3,76(1,39)	0,72(0,19)	+0,003	
RR4: Les sujets sont utiles pour des sit. en dehors de l'école	3,28(1,26)	0,77(0,16)	+0,018	
RR5: Il m'arrive de relier les contenus à des sit. de la vie quot.*	3,26(1,44)	0,71(0,19)	+0,003	
7-RR6: Je ne vois pas de liens entre les sujets et la vie quot.*	4,03(1,39)	0,85(0,11)	+0,047	
CLE1: Me concentrer sur les act., sans me battre avec le matériel	5,05(0,94)	0,70(0,33)	+0,072	0,70
CLE2: J'ai pu démarrer les activités rapidement.	4,02(0,91)	0,74(0,30)	+0,087	
CLE3: J'ai eu des informations suff. pour les expériences	4,74(0,77)	0,40(0,53)	-0,019	
CLE4: Les activités expérimentales étaient simples à effectuer	4,33(1,17)	0,63(0,38)	+0,015	
7-CLE5: Peine à comprendre les notions des expériences	3,60(1,02)	0,74(0,30)	+0,090	
7-CLE6: Problèmes à utiliser les instruments de mesure	4,94(0,98)	0,53(0,46)	-0,003	
CAE1: J'étais concentré lors des expériences	4,99(0,75)	0,71(0,32)	+0,078	0,70
CAE2: Je me suis engagé(e) activement lors des expériences	4,72(0,77)	0,46(0,49)	-0,020	
CAE3: J'ai eu un regard critique sur les idées testées	3,60(1,12)	0,84(0,19)	+0,127	
CAE4: Différencier les choses importantes de celles moins imp.	3,93(1,12)	0,68(0,35)	+0,032	
CAE5: Relier aux connaissances antérieures	4,05(1,08)	0,66(0,36)	+0,027	
INV1: J'ai participé activement	3,60(1,14)	0,72(0,31)	+0,098	0,67
INV2: J'ai posé souvent des questions	3,21(1,11)	0,36(0,54)	-0,061	
INV3: J'ai expliqué mes idées sur les sujets à mes camarades	2,85(1,35)	0,69(0,34)	+0,070	
INV4: Discuté avec les camarades sur la résolution des prob.	4,06(1,33)	0,64(0,38)	+0,098	
INV5: On m'a demandé d'expliquer comm. j'ai résolu des prob.	3,51(1,62)	0,74(0,29)	+0,038	
AT1: L'e. pris du temps pour nous aider si nous avions des prob.	4,39(0,90)	0,55(0,44)	+0,002	0,62
AT2: Les explications de l'e. nous ont aidés à mieux comprendre	4,40(0,91)	0,63(0,39)	+0,051	
AT3: L'e. donnait l'impression d'être passionné par la physique	5,38(0,79)	0,50(0,47)	+0,090	
AT4: L'enseignant nous encourageait	4,05(0,92)	0,64(0,38)	+0,060	
AT5: L'e. s'est déplacé dans la classe pour rép. aux questions	4,88(1,05)	0,57(0,43)	-0,020	

4. RESULTS OF THE PILOT STUDY

This chapter is mainly devoted to the presentation of the results of the pilot study (sections 4.2 to 4.5) about:

1. the development of the tests (psychometric values, item and instrument analysis) and
2. the results of the participating pupils.

Furthermore, for a consistent reading, some explanations of specific results will be given directly following the presentation in sections 4.2 to 4.5. The consequent adaptations made to the sequence, activities and instruments in view of the main study are explained in section 4.6.

4.1. Implementation and progress

Before discussing the results, we will nonetheless recall in this section some specific facts about the conduct of the pilot study; we refer the reader to chapter 3 for the details on the sample, setting, design and methods of the pilot study.

The conceptual post-test brought together the 20 items selected in the validation phase (see section 3.5 and table A.3 of appendix 1), while the conceptual pre-test was made up of a subset of 14 items that do not require any prior knowledge to have an idea, even false, of answer (appendix 5). The affective tests and the non-verbal abilities test are the result of the analysis and the validation described in section 3.5. All the tests administered during the pilot study are available in the appendix 3. Summarizing, at the beginning of the pilot study each student completed:

- The conceptual pre-test,
- The affective pre-test and,
- The spatial abilities test.

After the instructions, about six months later, the same students completed

- The conceptual post-test (QCM in physics), which counted in the final mark,
- The affective post-test (nominal, different between the treatment group and the control group) and
- The anonymous questionnaire *teacher assessmen*t.

The participating teachers were able to complete the sequences and the tests as planned in their class-groups. During the semester, three pupils left the high school and could not complete the pilot study, and one pupil joined the group of participants, so that in the end we could make the post-test item analysis with N = 103 students a pre/post comparison with N = 102 pupils. The teachers also claimed that on the one hand they had the impression of an initial enthusiasm on the part of certain pupils of the treatment group about the use of tablets for the physics laboratories. However, this feeling of enthusiasm faded away throughout the semester. On the other hand, in the three treatment groups, the teachers stated that pupils needed a first acquaintance with the applications and handling of tablets (image stabilization, tips for tracing, etc.). Nevertheless, this appropriation phase is also present in traditional laboratories.

4.2. Affective outcomes

4.2.1. Pre-test

For each affective dependant variable, the item analysis of the pre-test according to the analysis methods explained in section 3.2, are given in table 4.1. The French version of each item is on the first left side column of the table and the relative mean value M (standard deviation), the individual item-test reliability r_{it} (confidence interval), and the variation of the KR20 Cronbach Alpha α-α^* are given [Ding & Beichner, 2009][1].

Table 4.1: Item analysis of the affective dependent variables in the pre-test of the pilot study. N = 105; N_{TG} = 61; N_{CG} = 44; 6-level items 1 = completely disagree, 6 = completely agree; * = created items. $^{-}$ = scales of "negative" items are inverted (value = 7 - rating).

Item	M(SD)	r_{it}(CI)	α - α*	α
SC1: J'ai pu résoudre les problèmes	4,15 (0,98)	0,68(0,21)	+0,012	
SC2: Mes camarades ont trouvé que j'étais bon(ne)	3,47(1,34)	0,85(0,11)	+0,042	
SC3: J'ai bien compris les sujets traités au cours	3,85(1,04)	0,85(0,11)	+0,039	
SC4: Mes résultats en physique ont été satisfaisants pour moi	3,82(1,38)	0,66(0,22)	-0,002	0,86 (0,08)
SC5: Je m'attends à ce que mes résultats en physique soient bons	4,49(0,96)	0,49(0,29)	-0,011	
SC6^{-}: J'ai eu des difficultés à comprendre les sujets traités	3,32(1,24)	0,78(0,15)	+0,027	
SC7^{-}: Je suis nul(le) en physique*	3,77(1,38)	0,85(0,11)	+0,040	
SC: Average values	3,84(1,19)	0,74(0,17)	-	
IN1: Suis plus investi pour ce cours que pour les autres matières	3,42(1,31)	0,59(0,25)	+0,008	
IN2: J'ai bien aimé résoudre des problèmes de physique	3,60(1,12)	0,74(0,17)	+0,051	
IN3: J'ai bien aimé le cours de physique	3,68(1,19)	0,72(0,19)	+0,044	
IN4: J'ai fait des recherches dans des livres, les journaux, etc.	3,10(1,52)	0,53(0,28)	-0,023	0,78 (0,13)
IN5: En plus des devoirs, j'ai consacré du temps libre …	2,61(1,30)	0,65(0,22)	+0,025	
IN6^{-}: J'ai trouvé ennuyeux de résoudre des problèmes*	3,69(1,09)	0,76(0,17)	+0,054	
IN7^{-}: Je me suis ennuyé dans les heures de physique*	3,50(1,13)	0,69(0,20)	+0,038	
IN: Average values	3,37(1,24)	0,67(0,21)	-	
CS1: Je voudrais en savoir davantage sur les sujets traités	3,96(1,02)	0,77(0,16)	+0,059	
CS2: Je voudrais mieux comprendre les sujets traités	4,34(1,09)	0,56(0,27)	**-0,031**	
CS3: Je trouve fascinants les sujets traités au cours	3,38(1,02)	0,83(0,12)	+0,085	0,79 (0,13)
CS4: Le cours a éveillé ma curiosité à propos des sujets traités	3,78(1,14)	0,77(0,16)	+0,057	
CS5: J'aime passer du temps à réfléchir sur les sujets traités	2,92(1,26)	0,76(0,16)	+0,041	
CS: Average values	3,68(1,11)	0,74(0,17)	-	
RR1: Les probl. sont utiles pour les situat. en dehors de l'école	3,14(1,19)	0,83(0,12)	+0,030	
RR2: Les sujets sont utiles pour des sit. de la vie quotidienne	3,32(1,07)	0,72(0,19)	+0,008	
RR3: Le cours a traité des situations de la vie quotidienne	3,55(1,19)	0,79(0,15)	+0,020	
RR4: Les sujets sont utiles pour des sit. en dehors de l'école	3,42(1,18)	0,83(0,13)	+0,028	0,88 (0,07)
RR5: Il m'arrive de relier les contenus à des sit. de la vie quot.*	3,41(1,36)	0,79(0,15)	+0,016	
RR6^{-}: Je ne vois pas de liens entre les sujets et la vie quot.*	3,92(1,36)	0,81(0,14)	+0,020	
RR: Average values	3,46(1,22)	0,79(0,14)	-	

[1] α^* is the Cronbach Alpha of the dimension without the item in question.

According to the criteria on the value ranges explained in section 3.2, these results can be considered as globally good. As for the validation of the affective post-test (see section 3.6 and, in particular, table 3.4) the item of the *curiosity state* scale CS2 has lower r_{it}, with respect to the other items of the same scale, and it decreases the α. We observed that our literal translation from German [Pawek, 2009] has not exactly the same meaning in English ("I want to understand better") and in French ("Je voudrais mieux comprendre"). The French version of this sentence is rather interpreted as a personal assessment of the possibility that the pupil had to learn: it concerns external factors (time, teaching, ...) that would had limited the comprehension of the pupil. Therefore it does not concern the pupil's own motivation to learn more about the studied subjects. This item is rather closer to statements of the type « I would have appreciated to have a better teaching about those subjects » or « I would have appreciated to dispose of more time to work those subjects ».

<u>Factor analysis for the scale curiosity state</u>

A factor analysis was thus carried out in order to verify whether the dimension *curiosity state* was homogenous or a substructure was present. Following the theoretical framework described in section 3.2.2, we chose a factorization according to the principal components, since we did not suppose the presence of a priori correlations between variables. The number of components could be estimated by inspecting the scree-plot of this scale (figure 4.1) and the relative table 4.2. We observe two changes in the slope indicating the possibility of the presence of two components. Moreover the two greatest eigenvalues explain 75% of the variance.

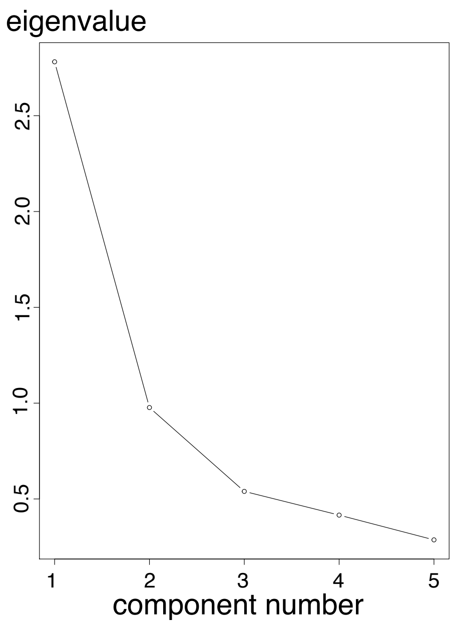


Figure 4.1: Scree-plot for the scale curiosity state in the pre-test.

Table 4.2: Results of the principal component analysis for *curiosity state* in the pre-test, including eigenvalues of each component and the proportion of modeled and cumulative variance.

Component	Eigenvalue	Modeled variance	Cumulative variance
1	2.78	0.56	0.56
2	0.98	0.20	0.75
3	0.54	0.11	0.86
4	0.42	0.08	0.94
5	0.29	0.06	1.00

For this analysis, the KMO test (see section 3.2.2) indicated an average MSA index of 0.74, and values going from 0.63 (for CS2, the only one below 0.7) to 0.81, i.e. a globally good fit. Comparing the solutions with one or two components before and after oblique rotation [Osborne *et al*., 2008], the best model turned out to be the two components analysis, whose loadings greater than 0.3 are indicated in table 4.3. We therefore discarded the item CS2 for the *curiosity state* scale in the following of the analysis.

Table 4.3: Loadings greater than 0.3 for the analysis with three factors after oblique rotation.

Item	Component 1	Component 2
CS1	0.47	0.56
CS2	-	0.96
CS3	0.87	-
CS4	0.87	-
CS5	0.83	-

4.2.2. Post-test

Table 4.4 summarizes the post-test item analysis for the affective dependent variables. As for the affective pre-test, all the dimensions of the post-test worked very well overall, especially for the *relation to reality* scale. Similarly to what observed in the validation of the affective post-test and in the pre-test results, the item CS2 had lower item-test reliability r_{it} with respect to the other items of *curiosity state* dimension and it decreases the α, which consistent with our previous analysis. We therefore continued the analysis by dropping the item CS2, and we recalculated the α for the relative dimension. By discarding CS2, the α of the curiosity as a state dimension increased from 0.76 to 0.86. Thus in the main study we replaced the word "comprendre" (understand) of CS2 by the word "approfondir" ("deepen"), as this word better conveys the idea of curiosity in French.

Table 4.4: Item analysis of the affective dependent variables in the post-test of the pilot study. N = 103; N_{TG} = 59; N_{CG} = 44; 6-level items 1 = completely disagree, 6 = completely agree; * = created items. $^{-}$ = scales of “negative” items are inverted (value = 7 - rating).

Item	M (SD)	r_{it}(CI)	α - α*	α
SC1: J’ai pu résoudre les problèmes	3,89 (1,19)	0,74(0,18)	+0,022	0,86 (0,09)
SC2: Mes camarades ont trouvé que j’étais bon(ne)	3,16(1,25)	0,79(0,14)	+0,032	
SC3: J’ai bien compris les sujets traités au cours	3,75(1,19)	0,81(0,13)	+0,035	
SC4: Mes résultats en physique ont été satisfaisants pour moi	3,47(1,56)	0,77(0,16)	+0,021	
SC5: Je m’attends à ce que mes résultats en physique soient bons	4,45(1,07)	0,56(0,27)	-0,004	
SC6^{-}: J’ai eu des difficultés à comprendre les sujets traités	3,16(1,21)	0,78(0,15)	+0,029	
SC7^{-}: Je suis nul(le) en physique*	3,44(1,43)	0,70(0,20)	+0,009	
SC: Average values	3,61(1,27)	0,73(0,18)	-	
IN1: Suis plus investi pour ce cours que pour les autres matières	3,55(1,43)	0,61(0,25)	+0,017	0,75 (0,15)
IN2: J’ai bien aimé résoudre des problèmes de physique	3,50(1,09)	0,67(0,22)	+0,043	
IN3: J’ai bien aimé le cours de physique	3,51(1,17)	0,67(0,22)	+0,043	
IN4: J’ai fait des recherches dans des livres, les journaux, etc.	2,87(1,63)	0,59(0,26)	-0,007	
IN5: En plus des devoirs, j’ai consacré du temps libre …	2,61(1,46)	0,76(0,17)	+0,068	
IN6^{-}: J’ai trouvé ennuyeux de résoudre des problèmes*	3,72(1,07)	0,59(0,25)	+0,025	
IN7^{-}: Je me suis ennuyé dans les heures de physique*	3,65(1,06)	0,59(0,26)	+0,024	
IN: Average values	3,34(1,27)	0,64(0,23)	-	
CS1: Je voudrais en savoir davantage sur les sujets traités	3,71(1,21)	0,79(0,15)	+0,082	0,76 (0,15) 0,86* (0,92)*
CS2: Je voudrais mieux **comprendre** les sujets traités	4,69(1,27)	0,43(0,32)	-0,092	
CS3: Je trouve fascinants les sujets traités au cours	3,21(1,09)	0,75(0,17)	+0,063	
CS4: Le cours a éveillé ma curiosité à propos des sujets traités	3,66(1,18)	0,80(0,14)	+0,088	
CS5: J’aime passer du temps à réfléchir sur les sujets traités	3,04(1,06)	0,85(0,11)	+0,114	
CS: Average values	3,62(1,16)	0,73(0,18)	-	
RR1: Les probl. sont utiles pour les situat. en dehors de l’école	3,61(1,31)	0,84(0,12)	+0,015	0,92 (0,051)
RR2: Les sujets sont utiles pour des sit. de la vie quotidienne	3,43(1,22)	0,88(0,09)	+0,024	
RR3: Le cours a traité des situations de la vie quotidienne	3,97(1,18)	0,77(0,16)	+0,004	
RR4: Les sujets sont utiles pour des sit. en dehors de l’école	3,57(1,35)	0,91(0,07)	+0,029	
RR5: Il m’arrive de relier les contenus à des sit. de la vie quot.*	3,71(1,37)	0,80(0,15)	+0,005	
RR6^{-}: Je ne vois pas de liens entre les sujets et la vie quot.*	4,33(1,31)	0,84(0,12)	+0,016	
RR: Average values	3,76(1,29)	0,84(0,12)	-	

4.2.3. Comparison of pre- and post- results

Table 4.5 gives an overview of the outcomes’ mean values, before and after the instruction, for the treatment group, for the control group as well as for all the participants in the pilot study. We observed that, in general, the control group had mean values higher than the treatment group, and this since the beginning of the study: these differences were maintained during the study. Overall the variations of the dependent variables' means between the pre- and post-test were always (1) quite small and (2) slightly negative for all affective outcomes but *relation to reality* (RR). We therefore did not expect to see an effect of the use of MDETs on the affective dependent variables (i.e. no significant difference between the change in treatment group versus control group). This feeling must be confirmed by the ANCOVA analysis, in the section 4.5.

Table 4.5: Averages values (6-level items 1 = completely disagree, 6 = completely agree) of the affective outcomes for the pre- and post-tests. Compare results for N = 102 pupils participating to the pilot study (N_{TG} = 59; N_{CG} = 43). The * indicates that the average was calculated dropping the item CS2.

Example of item (Translated from French)	α pre/post		Mean (standard deviation)			Difference
			Group	PRE	POST	
SC: My classmates thought I was good at physics.	0,86	0,86	TG	3,79(0,91)	3,48(0,91)	-0,31
			CG	3,92(0,81)	3,79(0,97)	-0,13
			tot	3,85(0,86)	3,61(0,94)	-0,24
IN: I liked the physics class.	0,78	0,75	TG	3,26(0,81)	3,23(0,81)	-0,04
			CG	3,50(0,77)	3,49(0,81)	-0,01
			tot	3,36(0,79)	3,34(0,81)	-0,03
CS: The course aroused my curiosity about the topics covered.	0,82*	0,86*	TG	3,36(0,95)*	3,19(0,96)*	-0,17
			CG	3,68(0,78)*	3,69(0,88)*	+0,01
			tot	3,50(0,89)*	3,40(0,96)*	-0,10
RR: The subjects of the physics course are useful for everyday situations.	0,88	0,92	TG	3,23(1,01)	3,61(1,07)	+0,39
			CG	3,73(0,81)	3,97(1,09)	+0,24
			tot	3,44(0,96)	3,76(1,09)	+0,32

4.3. Conceptual test

4.3.1. Pre-test

The characteristics averages and the range of values of the conceptual pre-test are shown in table 4.6, including the Cronbach's alpha and the Fergusons' Delta δ. The details of the item analysis, including a brief description of each item and its psychometric characteristics, are available in table A.4 of appendix 1.

For each item of the pre-test, the number of the given answers (A, B, C, D, E or null answer) is shown in table 4.7. Here we could observe a large amount of misconceptions (underlined numbers), which correspond to those also observed in the validation. All the characteristics are acceptable to good for a concept pre-test: pupils answered the pre-test questions rather incorrectly and, for many items, the most frequent answers correspond to the misconceptions that we analyzed in the validation phase (see section 3.5 and table A.3 of appendix 1), and that we found here again.

Table 4.6: Instrument analysis of the conceptual pre-test. MCQ with 1 correct answer out of 5, k =14 items and dichotomous scale level; N = 105; N_{TG} = 61; N_{CG} = 44.

Characteristics	**Average value (confidence interval)**	**range of values**
Item difficulty P	0,28(0,42)	[0,09 ; 0,57]
Item discrimination D	0,39	[0,17 ; 0,63]
Item-test correlation r_{it}	0,40(0,32)	[0,18 ; 0,59]
Reliability (internal consistency) α	0,58(0,23)	-
$\Delta\alpha_C = \alpha - \alpha^*$(after elimination)	-	[-0,024; +0,061] (1 item < 0)
Fergusons Delta δ	0,88	-

Table 4.7: Occurrences of each answer. The first line is the number of the item in the pre-test (LPR). The right answer is indicated with *, the most frequents in bold characters, underlined when a misconception is present (see the table A.3 on items' validation).

LPR	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
A	17	17	**<u>70</u>**	28	14	32	18*	17	13	3	35	11	48	25*
B	5	2	18*	**53***	23	1	15	29	4	11	24*	2	5	3
C	**<u>58</u>**	4	4	5	**<u>45</u>**	26*	0	**<u>49</u>**	31*	28	2	14*	0	**<u>66</u>**
D	17*	29	0	5	12*	2	1	1	**<u>40</u>**	**60***	**<u>36</u>**	18	3	8
E	7	**50***	11	5	11	**<u>38</u>**	**<u>69</u>**	9*	17	2	8	**<u>57</u>**	**49***	2
0	1	3	2	9	0	6	2	0	0	1	0	3	0	1

As expected for a conceptual pre-test on mechanics, the difficulty scores are generally low and therefore the discrimination index decreased. We notice however that four items presented a quite high P already in the pre-test (i.e. *before* the instruction). These are the questions for which the asterisk (correct answer) coincides with the bold character (most frequent) in the table 4.7, namely (see table A.4 in appendix 1)

- Item 2 (LPR2) on the visualization of the velocity from the trajectory of a linear motion (FCI 19);
- Item 4 (LPR4) concerning the velocity diagram from the trajectory (MBT 1);

- Item 10 (LPR10) on the 1st Newton's law and gravitation: lift at constant velocity (from FCI 17);

- Item 13 (LPR13) on the 3rd Newton's law: frontal collision (FCI 14).

This indicates that, although they did not benefited yet from an instruction in kinematics, pupils comes with pre-existing constructs on these notions. This confirms a known result in physics education research (see section 2.3.1).

Factor analysis

An exploratory factor analysis (see section 3.2.2) was conducted for the conceptual pre-test, with the aim of seeing if some of the items presented correlations, or if any unifying theme was already visible in the results. We considered that this test was constructed based on six a priori hypotized conceptual dimensions:

1) One-dimensional kinematics: LPR1, LPR2, LPR4, LPR5, LPR6 and LPR7,
2) Free fall (also one-dimensional kinematics): LPR8, LPR9 and LPR10,
3) Newton 1st law: LPR11,
4) Newton 2nd law: LPR12,
5) Newton 3rd law: LPR13, LPR14,
6) Average speed in a return trip: LPR3.

Dimensions 1), 2) and 6) can be merged in "one-dimensional kinematics" and the items on kinematics and those on the Newton's law can in their turn be merged in the same dimension. However, as explained in section 3.2.2, we did not expect a clear subdivision of dimensions for this type of test, where several items can be considered as belonging to more than one conceptual dimension and indeed only the dichotomous nature of the responses is considered.

In order to produce a stable factor solution, factor analyses require at least three items per factor (section 3.2) and here some themes concern only one (as Newton 2nd law) or two items (as Newton 3nd law). Furthermore, for this test, we have subject-to-item ratio greater than 7:1, and no noticeable differences in the results of the item analysis. The average of KMO indices is 0.58, which is acceptable for the analysis (see section 3.2.2). Therefore we proceeded with an exploratory principal axis factor analysis, based on the dichotomous data of all the items from the pre-test. The number of factors estimated by inspecting the scree-plot of the resulting eigenvalues is shown in figure 4.2. Here six loadings are greater than unity (see table 4.8) and a no sharp changes in the slope are present. As explained in section 3.2.2, in order to identify the most suitable factor structure, we compared several solutions with a number of factors from three to six and rotated through oblique rotation for clarify and simplify the data structure [Osborne *et al.*, 2008].

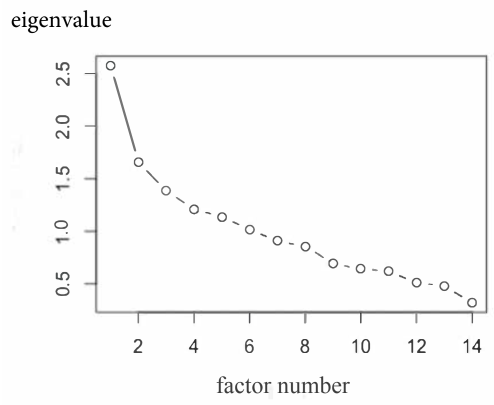


Figure 4.2: Scree-plot showing loadings with 14 factors (number of the items of the pre-test).

Table 4.8: Results of exploratory factoring showing the first six dominant factors, including their eigenvalues and the proportion of the modeled and cumulative variance.

Factor	Eigenvalue	Modelled variance	Cumulative variance
1	2.58	0.18	0.18
2	1.66	0.12	0.30
3	1.39	0.10	0.40
4	1.21	0.09	0.49
5	1.13	0.08	0.57
6	1.01	0.07	0.64

The model with six factors better fitted the data, according to the hypotized conceptual dimensions recognizable in the table 4.9. Here we can distinguish the 3rd Newton Law (F4); the 1st Newton law (F5) and the 2nd Newton law (F3). Moreover F1, F2 and F6 combine the items from one-dimensional kinematics including free fall.

Table 4.9: Loadings greater than 0.3 for the six factors analysis, after applying an oblique rotation.

Item	F1	F2	F3	F4	F5	F6
LPR1	0.60					
LPR2	0.52					0.40
LPR3			0.58			0.47
LPR4		0.56				
LPR5						0.46
LPR6						0.82
LPR7	0.81					
LPR8		0.56	0.51			
LPR9		0.79				
LPR10						0.46
LPR11					0.79	
LPR12			0.80			
LPR13				0.72		
LPR14				0.84		

4.3.2. Post-test

The characteristics average values of the conceptual post-test are given in table 4.10, while the table A.5 in appendix 1 summarizes the item analysis of the same post-test, including a short description of each item (LPO1, LPO2, … , LPO20) and its psychometric characteristics. In addition, for each item of the post-test, the occurrences of the answers (A, B, C, D, E or null answer) are shown in table 4.11. We observed in table 4.11 that, although most misconceptions were successfully removed, five persisted in the post-test (underlined numbers):

- LPO3: the average speed on a return trip (same distance) is the arithmetic average between of two forward/backward speeds.

- LPO6: if the velocity has a constant intensity, there is no acceleration.

- LPO14: in a free falling motion with a change in the velocity's orientation, the acceleration is not constant (it is maximal at the beginning and at the end of the flight).

- LPO17: if a body moves with constant velocity, the resultant force on it is not zero and has the same orientation as its velocity.

- LPO20: during an interaction, the more massive object exerts a more intense force than the less massive object.

Table 4.10: Instrument analysis of the conceptual post-test of the pilot study. MCQ with 1 correct answer out of 5, k = 20 items and dichotomous scale level; N = 103; N_{TG} = 59; N_{CG} = 44.

Characteristics	**Average value (confidence interval)**	**range of values**
Item difficulty P	0,48(0,45)	[0,06 ; 0,79]
Item discrimination D	0,44(0,20)	[-0,01 ; 0,78]
Item-test correlation r_{it}	0,38(0,13)	[0,01 ; 0,59]
Reliability (internal consistency) α	0,69(0,18)	
$\Delta\alpha_C = \alpha - \alpha^*$(after elimination)		[-0,028; +0,061]
Fergusons Delta δ	0,92	

As for LPO 18, the majority of the pupils answered that, "if you push with the same force two balls, one of which is 3 times less massive than the other, the lighter one reaches a speed approximately greater, but not *exactly* 3 times", which is not correct. Those pupils could have understood the 2nd Newton's law and still answered incorrectly because of the word "exactly". Therefore we could not associate a misconception with the most frequent answer, and concluded that item LPO18 had to be changed in the main study, in order to avoid this bias.

The lower limit in the ranges of the psychometric indices of table 4.10 is explained by item LPO15, which had especially unsatisfactory parameters (see also table A.5). LPO15 correspond to item 1 from the *Force Concept Inventory* (FCI) [Hestenes *et al.,* 1992], and asks about the free falling time from the same height of two objects of different masses. The pupils answered well overall (P = 0.65), however the discrimination index for this item was negative (D = -0.01), the item-test reliability was low (r_{it} = 0.01) and it decreased the alpha of 0.028, indicating that the answers were not consistent with those of the rest of the test. Moreover, we could not obtain a satisfactory explanation from the teachers regarding this result, and thus we removed LPO15 from the following of the pilot study analysis.

Table 4.11: Occurrences of each answer of the post-test in percent. The right answer is indicated with *, the most given is in bold characters, underlined when a misconception is present (see the table A.3 in appendix 1 on the validation of the instrument). The item number of the post-test (LPO) and of the pre-test (LPR) are indicated in the first two lines.

LPO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	(15)	16	17	18	19	20
LPR	**1**	**2**	**3**				**4**		**5**	**6**	**7**			**8**	**9**	**10**	**11**	**12**	**13**	**14**
A	1	10	**52**	2	3	8	27	5	14	23	**64***	10	8	18	7	3	**47**	20	27	39*
B	2	2	22*	2	10	3	**70***	4	22	0	15	16	**62***	19	1	6	35*	5	2	3
C	34	0	7	**81***	20	16	1	13	14	**50***	1	26	19	**55**	**67***	31	0	21*	0	**61**
D	**62***	21	1	11	**64***	6*	3	**57***	**47***	1	0	**31***	11	3	20	**60***	15	13	0	0
E	4	**70***	21	7	5	**70**	2	24	6	25	23	20	3	**8***	8	2	6	**43**	**74***	0
0	0	0	0	0	1	0	0	0	0	4	0	0	0	0	0	1	0	1	0	0

Factor analysis

The interdependence and, at the same time, the diversity of the items is the consequence of the educational objectives discussed in chapter 3, which prevailed in the construction of the conceptual post-test. Thus, as it was the case for the results of the pre-test and as discussed in section 3.2.2, when performing a factor analysis we do not expect to find a clear separation between subscales. Nevertheless, similarly to what have been done for the conceptual pre-test (see section 4.3.1) and with the same considerations of caution, we performed an exploratory factor analysis (see section 3.2.2) based on the dichotomous data of the conceptual post-test, following [Osborne *et al.*, 2008], and yet excluding the item LPO15 for the reasons explained above.

For this test, N = 103 and k = 20 items, leading to a subject-to-item ratio is greater than 5:1. Although this value is not critically low, the analysis would benefit from a larger sample size. The average of KMO indices is 0.66, which is acceptable for the analysis (see section 3.2.2).

Similarly to the conceptual pre-test six main a priori conceptual dimensions are present in this test:

1) One dimensional kinematics: LPO1, LPO2, LPO7, LPO8, LPO9, LPO10, LPO11, LPO12 and LPO13;
2) Free fall (also one-dimensional kinematics): LPO14 and LPO16;

3) Dynamics: LPO17 (1^{st} law), LPO18 (2^{nd} law), LPO19 and LPO20 (3^{rd} law);
4) Average speed: LPO3;
5) 2D kinematics: LPO4, LPO5 and LPO6.

Conceptual dimensions 1), 2) and 4) can be regrouped in “one-dimensional kinematics”, and 1), 2), 4) and 5) can be regrouped in “kinematics”.

The number of factors estimated by inspecting the scree plot of the resulting eigenvalues is shown in figure 4.3 (for the interpretation of the scree plot we refer to what explained in the section 3.2.2). Here we observe that eight loadings greater than 1. However a sharp change in the slope is present after the second eigenvalue and we could see in the table 4.12 that the contributions to the variance count only for less than 8% starting from the third factor.

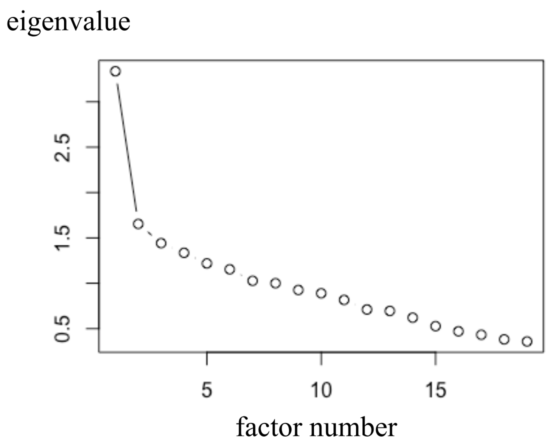


Figure 4.3: Scree-plot showing loadings with 19 factors (number of the items of the post-test excluding LPO15).

Table 4.12: Result of the factor analysis for the first eight dominant factors, including their eigenvalues, the proportion of the modeled and cumulative variance.

Factor	Eigenvalue	Modeled variance	Cumulative variance
1	3.34	0.18	0.18
2	1.65	0.09	0.26
3	1.44	0.08	0.34
4	1.34	0.07	0.41
5	1.22	0.06	0.47
6	1.15	0.06	0.53
7	1.03	0.05	0.59
8	1.00	0.05	0.64

Similarly to the factorial analysis of the pre-test (see also section 3.2.2), here we identified the most suitable factorial structure by comparing several oblique rotated solutions between two and eight factors. Finally, the model with two factors turned out to be the “cleanest” fitting the data. Models with more than two factors are not consistent with the conceptual dimensions given above. In the model presented in table 4.13, the majority of the items classified a priori as “one-dimensional kinematics” were in the first factor, and three items out of the four in the conceptual dimension "dynamics" belonged to the second factor. However the saturations of items LPO19 (Newton's 3^{rd} law) and LPO14 (free fall with change in the direction of velocity) did not exceed 0.30 in either of the two factors.

Table 4.13: Loadings greater than 0.30 for the two factors analysis, after applying an oblique rotation.

Item	F1	F2
LPO1	0.66	
LPO2	0.52	
LPO3		0.66
LPO4		0.52
LPO5		0.53
LPO6		0.59
LPO7	0.59	
LPO8	0.56	
LPO9	0.58	
LPO10	0.41	
LPO11	0.34	
LPO12	0.40	
LPO13	0.70	
LPO14		
LPO16	0.40	
LPO17		0.39
LPO18		0.45
LPO19		
LPO20		0.44

4.3.3. Comparison of pre- and post- results

Tables 4.14 and 4.15 compare the item analysis of the pre- and of the post-test, excluding LPO15. The characteristics average values of the conceptual tests, including separate values for the treatment and the control group, are given in table 4.14.

Table 4.14: Comparing the characteristics average values of the conceptual pre- and post-test. The values of some parameters change slightly from those in tables 4.6 and 4.10 because the item LPO15 (corresponding to LPR9) is omitted.

Pre test		**N**		**α**		**δ**
k = 14		105		0,58(0,23)		0,88
Characteristic	**Average value (std. deviation) TG/CG/tot**			**Range of values TG/CG/tot**		
Difficulty P	0,25(0,14)	0,30(0,17)	0,27(0,16)	$0,07 \leq P_{TG} \leq 0,54$	$0,09 \leq P_{CG} \leq 0,60$	$0,08 \leq P \leq 0,57$

Post test		**N**		**α**		**δ**
k = 19		103		0,72(0,16)		0,93
Characteristic	**Average value (std. deviation) TG/CG/tot**			**Range of values TG/CG/tot**		
Difficulty P	0,43(0,44)	0,52(0.45)	0,47(0,45)	$0,02 \leq P_{TG} \leq 0,76$	$0,09 \leq P_{CG} \leq 0,93$	$0,06 \leq P \leq 0,79$
Discrimination D	0,47(0,23)	0,44(0,21)	0,47(0,18)	$0,07 \leq D_{TG} \leq 0,84$	$0,18 \leq D_{CG} \leq 0,85$	$0,16 \leq D \leq 0,78$
Item-test correlation rit	0,39(0,13)	0,38(0,13)	0,40(0,10)	$0,16 \leq r_{itTG} \leq 0,57$	$0,21 \leq r_{itCG} \leq 0,65$	$0,25 \leq r_{it} \leq 0,59$

Overall, the values of Cronbach's alpha, Fergusons' delta δ and mean difficulties increased in the post-test compared to the pre-test, because the effect of instruction improved the consistency of pupils' correct answers on average. Nevertheless, the range of values indicate that the minimum values of the indices of difficulty remained low in the post-test: although most of the "difficult" items ($P < 0.20$) in the pre-test increased their P in the post-test, some persistent misconceptions remained after the instruction. In order to better explain these values, it is interesting to make a comparison at the level of individual items.

Thus, table 4.15 compares the psychometric indices of each item, for item presents both in the pre- and the post-test (we remind that some items were only present in the post-test). The parameters as well as the specific gain (see section 3.2) of each item are also indicated for the treatment group (TG), for the control group (CG) and in total.

Table 4.15: Comparing the item parameters of the conceptual pre- and post-test without LPO15. Difficulties and gains are calculated for N = 102 (N_{TG} = 59 and N_{CG} = 43): only pupils that were present from the beginning to the end of the pilot study. D, r_{it} and α are calculated for N_{pre} = 105 and N_{post} = 103. In the 2[nd] and 3[rd] columns, the right answer is indicated with *, the most frequent is in bold characters, underlined when a misconception is present.

Item keywords (source)	Ans. PRE A/B/C /D/E/0	Ans. POST A/B/C/ D/E/0	Analysis PRE (confidence interval)		Analysis POST (confidence interval)		Learning gain g
LPO1: Visualize acceleration from trajectory in LM (FCI 20)	17 5 **58** 17* 7 1	1 2 34 **62*** 4 0	P = 0,16 (0,37) D = 0,44 r_{it} = 0,54(0,28) α - α* = +0,049	P_{TG} = 0,15 P_{CG} = 0,16	P = 0,61(0,49) D = 0,64 r_{it} = 0,50(0,29) α - α* = +0,022	P_{TG} = 0,58 (0,50) D_{TG} = 0,73 r_{itTG} = 0,51(0,38) α - $α^*_{TG}$ = +0,026 P_{CG} = 0,65 (0,48) D_{CG} = 0,68 r_{itCG} = 0,49(0,46) α - $α^*_{CG}$ = +0,024	Gain for TG : 0,50 CG : 0,58 Tot: 0,53
LPO2: Visualize velocity from trajectory in LM (FCI 19)	17 2 4 29 **50*** 3	10 2 0 21 **70*** 0	P = 0,48(0,50) D = 0,61 r_{it} = 0,48(0,30) α - α* = +0,032	P_{TG} = 0,44 P_{CG} = 0,53	P = 0,68(0,47) D = 0,54 r_{it} = 0,45(0,31) α - α* = +0,017	P_{TG} = 0,76 (0,43) D_{TG} = 0,46 r_{itTG} = 0,41(0,43) α - $α^*_{TG}$ = +0,016 P_{CG} = 0,56 (0,50) D_{CG} = 0,85 r_{itCG} = 0,65(0,36) α - $α^*_{CG}$ = +0,047	Gain for TG : 0,58 CG : 0,07 Tot: 0,38
LPO3: Average speed and the average of two speeds (created)	**70** 18* 4 0 11 2	**52** 22* 7 1 21 0	P = 0,17(0,37) D = 0,31 r_{it} = 0,42(0,32) α - α* = +0,025	P_{TG} = 0,17 P_{CG} = 0,16	P = 0,22(0,41) D = 0,51 r_{it} = 0,45(0,31) α - α* = +0,017	P_{TG} = 0,15 (0,36) D_{TG} = 0,43 r_{itTG} = 0,41(0,43) α - $α^*_{TG}$ = +0,016 P_{CG} = 0,30 (0,46) D_{CG} = 0,52 r_{itCG} = 0,46(0,48) α - $α^*_{CG}$ = +0,020	Gain for TG : -0,02 CG : 0,16 Tot: 0,06
LPO4: Instant velocity (created from situation of 5 and 6 of FCI)	-	2 2 **81*** 11 7 0	-		P = 0,79(0,41) D = 0,42 r_{it} = 0,39(0,33) α - α* = +0,011	P_{TG} = 0,68 (0,47) D_{TG} = 0,41 r_{itTG} = 0,36(0,45) α - $α^*_{TG}$ = +0,008 P_{CG} = 0,95 (0,21) D_{CG} = 0,24 r_{itCG} = 0,34(0,53) α - $α^*_{CG}$ = +0,009	No gain, but great difference of P between TG and CG
LPO5: Average velocity (created from situation of 5 and 6 of FCI)	-	3 10 20 **64*** 5 1	-		P = 0,62(0,49) D = 0,50 r_{it} = 0,33(0,35) α - α* = +0,002	P_{TG} = 0,54 (0,50) D_{TG} = 0,44 r_{itTG} = 0,35(0,45) α - $α^*_{TG}$ = +0,007 P_{CG} = 0,72 (0,45) D_{CG} = 0,18 r_{itCG} = 0,22(0,57) α - $α^*_{CG}$ = -0,007	No gain, but great difference of P between TG and CG
LPO6: Average acceleration (created from situation of 5 and 6 of FCI)	-	8 3 16 6* **70** 0	-		P = 0,06(0,24) D = 0,16 r_{it} = 0,26(0,36) α - α* = +0,004	P_{TG} = 0,02 (0,13) D_{TG} = 0,07 r_{itTG} = 0,18(0,50) α - $α^*_{TG}$ = +0,003 P_{CG} = **0,12** (0,32) D_{CG} = 0,27 r_{itCG} = 0,28(0,55) α - $α^*_{CG}$ = +0,005	No gain, but great difference of P between TG and CG

Table 4.15 continued

LPO7: Velocity diagram from trajectory in LM (MBT 1)	28 **53*** 5 5 5 9	27 **70*** 1 3 2 0	P = 0,49(0,50) D = 0,51 r_{it} = 0,38(0,33) α - α* = +0,007	P_{TG} = 0,39 P_{CG} = 0,63	P = 0,68(0,47) D = 0,59 r_{it} = 0,48(0,30) α - α* = +0,019	P_{TG} = 0,66 (0,48) D_{TG} = 0,70 r_{itTG} = 0,52(0,38) α - $α^*_{TG}$ = +0,027 P_{CG} = 0,70 (0,46) D_{CG} = 0,53 r_{itCG} = 0,42(0,50) α - $α^*_{CG}$ = +0,015	Gain for TG : 0,44 CG : 0,21 Tot: 0,37
LPO8: Acceleration diagram from trajectory in LM (MBT 1)	-	5 4 13 **57*** 24 0	-		P = 0,56(0,50) D = 0,67 r_{it} = 0,50(0,29) α - α* = +0,021	P_{TG} = 0,51 (0,50) D_{TG} = 0,84 r_{itTG} = 0,54(0,37) α - $α^*_{TG}$ = +0,030 P_{CG} = 0,63 (0,49) D_{CG} = 0,57 r_{itCG} = 0,41(0,50) α - $α^*_{CG}$ = +0,014	-
LPO9: Position-to-time diagram (TUG 8)	14 23 **45** 12* 11 0	14 22 14 **47*** 6 0	P = 0,11(0,31) D = 0,31 r_{it} = 0,41(0,32) α - α* = +0,025	P_{TG} = 0,10 P_{CG} = 0,12	P = 0,45(0,50) D = 0,65 r_{it} = 0,51(0,29) α - α* = +0,023	P_{TG} = 0,39 (0,49) D_{TG} = 0,65 r_{itTG} = 0,53(0,37) α - $α^*_{TG}$ = +0,029 P_{CG} = 0,53 (0,50) D_{CG} = 0,66 r_{itCG} = 0,44(0,39) α - $α^*_{CG}$ = +0,017	Gain for TG : 0,32 CG : 0,49 Tot: 0,38
LPO10: Instant velocity as slope in the position to time diagram (MCT 30)	32 1 26* 2 **38** 6	23 0 **50*** 1 25 4	P = 0,25(0,43) D = 0,39 r_{it} = 0,47(0,30) α - α* = +0,034	P_{TG} = 0,20 P_{CG} = 0,30	P = 0,49(0,50) D = 0,68 r_{it} = 0,51(0,29) α - α* = +0,023	P_{TG} = 0,44 (0,50) D_{TG} = 0,61 r_{itTG} = 0,46(0,41) α - $α^*_{TG}$ = +0,019 P_{CG} = 0,56 (0,50) D_{CG} = 0,73 r_{itCG} = 0,56(0,42) α - $α^*_{CG}$ = +0,034	Gain for TG : 0,30 CG : 0,35 Tot: 0,32
LPO11: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified)	18* 15 0 1 **69** 2	64* 15 1 0 23 0	P = 0,17(0,37) D = 0,49 r_{it} = 0,59(0,25) α - α* = +0,061	P_{TG} = 0,15 P_{CG} = 0,19	P = 0,63(0,49) D = 0,40 r_{it} = 0,31(0,35) α - α* = +0,001	P_{TG} = 0,58 (0,50) D_{TG} = 0,44 r_{itTG} = 0,29(0,47) α - $α^*_{TG}$ = 0,000 P_{CG} = 0,70 (0,46) D_{CG} = 0,28 r_{itCG} = 0,31(0,54) α - $α^*_{CG}$ = +0,002	Gain for TG : 0,50 CG : 0,61 Tot: 0,55
LPO12: Time diagram from velocity diagram (created)	-	10 16 26 **31*** 20 0	-		P = 0,30(0,46) D = 0,38 r_{it} = 0,35(0,34) α - α* = +0,005	P_{TG} = 0,27 (0,45) D_{TG} = 0,33 r_{itTG} = 0,28(0,47) α - $α^*_{TG}$ = +0,002 P_{CG} = 0,35 (0,48) D_{CG} = 0,38 r_{itCG} = 0,41(0,50) α - $α^*_{CG}$ = +0,014	-
LPO13: Acceleration diagram from velocity diagram (TUG 14)		8 **62*** 19 11 3 0	-		P = 0,60(0,49) D = 0,78 r_{it} = 0,59(0,25) α - α* = +0,033	P_{TG} = 0,56 (0,50) D_{TG} = 0,81 r_{itTG} = 0,57(0,35) α - $α^*_{TG}$ = +0,034 P_{CG} = 0,65 (0,48) D_{CG} = 0,75 r_{itCG} = 0,61(0,38) α - $α^*_{CG}$ = +0,040	-

Table 4.15 continued

LPO14: *g* during a free fall with change in velocity's orientation (created)	17 29 **49** 1 9* 0	18 19 **55** (conf *v* and *a*) 3 8* 0	P = 0,08(0,27) D = 0,17 r_{it} = 0,37(0,33) α - α* = +0,020	P_{TG} = 0,07 P_{CG} = 0,09	P = 0,08(0,27) D = 0,16 r_{it} = 0,25(0,36) α - α* = +0,003	P_{TG} = 0,07 (0,25) D_{TG} = 0,11 r_{itTG} = 0,16(0,50) $α - α^*_{TG}$ = +0,001 P_{CG} = 0,09 (0,29) D_{CG} = 0,27 r_{itCG} = 0,36(0,52) $α - α^*_{CG}$ = +0,011	Gain for TG : 0,000 CG : 0,000 Tot: 0,000
LPO16: Quadratic relationship between distance and time in free fall : UALM (created from FCI 1)	3 11 28 **60*** 2 1	3 6 31 **60*** 2 1	P = 0,57(0,50) D = 0,46 r_{it} = 0,36(0,33) α - α* = +0,003	P_{TG} = 0,54 P_{CG} = 0,60	P = 0,59(0,49) D = 0,58 r_{it} = 0,43(32) α - α* = +0,013	P_{TG} = 0,56 (0,50) D_{TG} = 0,72 r_{itTG} = 0,56(0,36) $α - α^*_{TG}$ = +0,032 P_{CG} = 0,63 (0,49) D_{CG} = 0,28 r_{itCG} = 0,23(0,56) $α - α^*_{CG}$ = -0,008	Gain for TG : 0,04 CG : 0,02 Tot: 0,05
LPO17: 1st Newton's law and gravitation – lift at constant velocity (FCI 17, answer E modified)	**35** 24* 2 **36** 8 0	**47** 35* 0 15 6 0	P = 0,22(0,41) D = 0,24 r_{it} = 0,18(0,37) α - α* = -0,024	P_{TG} = 0,25 P_{CG} = 0,16	P = 0,34(0,48) D = 0,49 r_{it} = 0,40(0,33) α - α* = +0,011	P_{TG} = 0,31 (0,46) D_{TG} = 0,54 r_{itTG} = 0,44(0,42) $α - α^*_{TG}$ = +0,018 P_{CG} = 0,40 (0,49) D_{CG} = 0,38 r_{itCG} = 0,34(0,53) $α - α^*_{CG}$ = +0,004	Gain for TG : 0,07 CG : 0,27 Tot: 0,16
LPO18: 2nd Newton's law – acceleration is inversely proportional to the mass (created – acceleration of two different masses with the same net force)	11 2 14* 18 **57** 3	20 5 21* 13 **43 (!)** 1	P = 0,13(0,34) D = 0,12 r_{it} = 0,25(0,36) α - α* = -0,001	P_{TG} = 0,08 P_{CG} = 0,19	P = 0,21(0,41) D = 0,28 r_{it} = 0,30(0,35) α - α* = +0,003	P_{TG} = 0,15 (0,36) D_{TG} = 0,14 r_{itTG} = 0,21(0,49) $α - α^*_{TG}$ = -0,001 P_{CG} = 0,28 (0,45) D_{CG} = 0,45 r_{itCG} = 0,35(0,53) $α - α^*_{CG}$ = +0,007	Gain for TG : 0,07 CG : 0,11 Tot: 0,09
LPO19: 3rd Newton's law – frontal collision (FCI 14)	**48** 5 0 3 49* 0	27 2 0 0 **74*** 0	P = 0,45(0,50) D = 0,63 r_{it} = 0,47(0,30) α - α* = +0,030	P_{TG} = 0,39 P_{CG} = 0,53	P = 0,72(0,45) D = 0,24 r_{it} = 0,27(0,36) α - α* = -0,002	P_{TG} = 0,68 (0,47) D_{TG} = 0,31 r_{itTG} = 0,27(0,48) $α - α^*_{TG}$ = -0,001 P_{CG} = 0,77 (0,43) D_{CG} = 0,26 r_{itCG} = 0,21(0,57) $α - α^*_{CG}$ = -0,005	Gain for TG : 0,47 CG : 0,51 Tot: 0,48
LPO20: 3rd Newton's law – accelerated system in contact (FCI 15, answer D modified)	25* 3 **66** 8 2 1	39* 3 **61** 0 0 0	P = 0,25(0,43) D = 0,40 r_{it} = 0,32(0,35) α - α* = +0,002	P_{TG} = 0,22 P_{CG} = 0,28	P = 0,37(0,49) D = 0,32 r_{it} = 0,27(0,36) α - α* = -0,004	P_{TG} = 0,34 (0,48) D_{TG} = 0,26 r_{itTG} = 0,29(0,47) $α - α^*_{TG}$ = +0,001 P_{CG} = 0,42 (0,50) D_{CG} = 0,19 r_{itCG} = 0,21(0,57) $α - α^*_{CG}$ = -0,011	Gain for TG : 0,15 CG : 0,21 Tot: 0,17

As expected form the discussion above (section 4.3.2) and as shown in tables 4.10 and 4.11, excluding LPO15 leaded to better psychometric parameters, especially for the treatment group. Moreover, as it is the case for the affective variables, the mean values of P are generally higher for the control group than for the treatment group, and this since the beginning of the study. This difference between the two groups was therefore maintained during the investigation. The overall better results of the control group are also reflected in the overall gain (see section 3.2) presented in table 4.16. Not only the pupils of the control group obtained better results than those of the treatment group, but they also had, on average, a better progression during the semester. This holds for all items except:

- LPO3, LPO9 and LPO17, for which the gain of control group exceeded that of treatment group by more than 10%;
- LPO2 and LPO7, for which the gain of treatment group exceeded that of control group by about 20%.

We will see in section 4.5 on the ANCOVA analysis whether these differences are significant. Here we point out some qualitative observations, which are relevant in view of possible changes of the sequence and of the conceptual test of the main study (see section 4.6).
In particular, the results of a few items deserve attention:

- As expected, item LPO3 turned out to be particularly difficult. Although it is not the only difficult item, here the gain was also small: the only positive change is that the part of the pupils who answered according to the misconception of answer A [Reed *et al*., 1985 and 1986] decreased, especially in favor of the last answer ("There is not sufficient information to answer the question"). However this change was not considered when performing the analysis and calculating the gain, as we only took into account the "right or wrong" results. We notice in particular that the pupils of the treatment group had a slightly negative gain for this item. By consulting the participating teachers, one possible explanation was that the activity linked to this item (MDET activity n. 4) was carried out at the beginning of the year. It was therefore the first MDETs activity where pupils had to trace the motion and obtain the data using the apps. Tablets give much information about motion, which is not understood by pupils yet, at the beginning of the year (especially the graphics representation, seen the first time only when studying uniform linear motion, then few weeks later). As a consequence, there may have been an additional cognitive load trying to understand the tablets output. A change is to be considered in the main study (see section 4.6), in order to avoid this possible cognitive overload. For example by carrying out the MDETs activity n. 4 with a video recorded in advance and common to all pupils, where the teacher would shows how to make the tracing of the video and the data extraction with the apps. Pupils then would receive the same data common to everyone and would not access directly the time diagrams. This would therefore be an exercise with real data not taken directly from pupils, as MDETs activity n. 1.

- LPO6 was also a particularly difficult item and we decided to include it in the post-test for educational reasons, namely because this item tests the misconception very widespread among the pupils that in a uniform movement in two dimensions the acceleration is zero. This misconception is linked to a real difficulty in understanding the vector nature of velocity and the possibility of varying in its direction and not only its intensity. There does not seem to be a beneficial effect of activities with the tablets on item LPO6, as well as on the other two two-dimensions kinematics items, linked to

LPO6, that is LPO4 and LPO5. Nevertheless, for LPO6 all other parameters were good and it contributed to the increase of the α of the test, which is why we included it in the analysis.

- Another item that turned out to be especially difficult was LPO14. We remind that in the validation tests, the difficulty P of this item went from 0.05 in the pre-test to 0.23 in the post-test. Despite the modifications done (with respect to the validation tests) to make the answers more precise, the difficulty stagnated in the post-test, remaining below 0.1. As a consequence, also the discrimination D was low and the gain is almost zero, both for the treatment and for the control group.

- The majority of the pupils answered item LPO 18 that, "if you push with the same force two balls, one of which is 3 times less massive than the other, the lightest reaches a speed approximately greater, but not *exactly* 3 times" (answer E), which is wrong. Those pupils could have well understood the 2nd Newton's law and still answered incorrect because of the word "exactly". Because of this possibility of interpretation of the responses, the parameters could have been weakened and LPO18 should be changed in the main study.

- The two items on Newton's 3rd law had a worse discrimination D than during the validation test and their contribution to the α was zero for LPO19 and slightly negative for LPO20.

Table 4.16: Learning gains (see section 3.2) of treatment group, control group and in total. The top table shows the gains taking into account only the items present both in the pre- and in the post-test, excluding LPO15 (=LPR12). The bottom table shows the gains taking into account the items of the pre-test and all the items of the post-test, excluding LPO15 (=LPR12)..

14 items pre → same 14 items post	**TG**	**CG**	**Tot**
Gain of average P	25%	29%	27%
Average of gains	25%	29%	27%
14 items pre → 19 items post	**TG**	**CG**	**Tot**
Gain of average P	**25%**	**32%**	**28%**
Average of gains	24%	31%	27%

4.4. Characteristics of covariates

4.4.1. Affective tests

For each covariate tables 4.17 and 4.18 respectively report the item analysis and the mean values of each dimension for the treatment group, the control group and total.

Table 4.17: Item analysis of control variables scales in the affective tests. N = 105 (pre) or 103 (post) except for the CLS scale (N_{TG} = 59); 6-level items 1 = completely disagree, 6 = completely agree; * = created items. $^{-}$ = scales of "negative" items are inverted (value = 7 - rating).

Item	M (SD)	r_{it}(CI)	α - α*	α
CT1: Je trouve fascinant d'apprendre des nouvelles choses	4,97(0,95)	0,85(0,11)	+0,045	
CT2: J'aime apprendre des choses que je ne connais pas	5,13(0,84)	0,78(0,15)	+0,027	
CT3: Ls. j'apprends qqe ch. de nouveau, je veux en savoir plus	4,30(0,99)	0,80(0,14)	+0,031	0,86 (0,08)
CT4: J'aime faire des rech. sur les ch. que je ne comprends pas	4,26(1,15)	0,76(0,17)	+0,016	
CT5: J'aime essayer de résoudre des problèmes qui m'intriguent	4,30(1,11)	0,73(0,18)	+0,011	
CT6: Je veux toujours examiner les choses en profondeur	3,73(1,18)	0,74(0,18)	+0,010	
CT: Average values	4,44(1,04)	0,78(0.16)	-	
CLE1: Me concentrer sur les act., sans me battre avec le matériel	4,41(1,18)	0,73(0,19)	+0,093	
CLE2: J'ai pu démarrer les activités rapidement.	3,73(1,14)	0,66(0,22)	+0,061	
CLE3: J'ai eu des informations suff. pour les expériences	4,33(1,04)	0,47(0,30)	-0,005	0,68 (0,19)
CLE4: Les activités expérimentales étaient simples à effectuer	3,79(1,17)	0,72(0,19)	+0,087	
CLE5^{-}: Peine à comprendre les notions des expériences	3,20(1,28)	0,66(0,22)	+0,050	
CLE6^{-}: Problèmes à utiliser les instruments de mesure	4,48(1,10)	0,45(0,31)	-0,018	
CLE: Average values	3,99(1,15)	0,62(0,24)	-	
CAE1: J'étais concentré lors des expériences	4,52(0,97)	0,61(0,25)	+0,067	
CAE2: Je me suis engagé(e) activement lors des expériences	4,22(1,15)	0,63(0,24)	+0,059	
CAE3: J'ai eu un regard critique sur les idées testées	3,79(1,11)	0,62(0,24)	+0,056	0,58 (0,26)
CAE4: Différencier les choses importantes de celles moins imp.	4,07(1,03)	0,60(0,25)	+0,053	
CAE5: Relier aux connaissances antérieures	4,32(1,16)	0,61(0,25)	+0,039	
CAE: Average values	4,19(1,09)	0,61(0,25)	-	
INV1: J'ai participé activement	3,45(1,28)	0,79(0,15)	+0,101	
INV2: J'ai posé souvent des questions	3,31(1,27)	0,71(0,19)	+0,058	
INV3: J'ai expliqué mes idées sur les sujets à mes camarades	3,33(1,34)	0,74(0,18)	+0,070	0,73 (0,17)
INV4: Discuté avec les camarades sur la résolution des prob.	3,80(1,35)	0,69(0,21)	+0,040	
INV5: On m'a demandé d'expliquer comm. j'ai résolu des pr.	3,90(1,32)	0,55(0,27)	-0,026	
INV: Average values	3,56(1,31)	0,70(0,20)	-	
SCS1: Je suis à l'aise avec l'utilisation des apps	4,50(1,25)	0,70(0,20)	+0,084	
SCS2: Les apps m'aident à comprendre des choses	3,74(1,30)	0,76(0,16)	+0,117	
SCS3^{-}: Les apps ne me semblent pas utiles pour apprendre	4,07(1,25)	0,68(0,21)	+0,075	
SCS4^{-}: Parf. les apps font des choses que je ne comprends pas	3,48(1,36)	0,48(0,30)	-0,024	0,67 (0,20)
SCS5^{-}: Si j'ai des problèmes avec les apps je me sens démuni	4,48(1,05)	0,43(0,31)	-0,009	
SCS6: J'utilise des apps pour effectuer des mesures (nb. de pas)*	4,64(1,35)	0,61(0,24)	+0,033	
SCS: Average values	4,14(1,27)	0,61(0,24)	-	
AT1: L'e. pris du temps pour nous aider si nous avions des prob.	4,90(1,02)	0,80(0,14)	+0,105	
AT2: Les explications de l'e. nous ont aidés à mieux comprendre	4,08(1,06)	0,73(0,19)	+0,057	
AT3: L'e. donnait l'impression d'être passionné par la physique	5,06(0,99)	0,59(0,26)	-0,004	0,74 (0,16)
AT4: L'enseignant nous encourageait	4,23(1,18)	0,74(0,18)	+0,054	
AT5: L'e. s'est déplacé dans la classe pour rép. aux questions	5,23(0,89)	0,64(0,23)	+0,027	
AT: Average values	4,70(1,03)	0,78(0,20)	-	

Table 4.17 continued

CLS1: Me concentrer sur les act. sans me battre avec les apps.	3,36(1,65)	0,79(0,20)	+0,021	
CLS2: Reçu des informations suff. pour utiliser les appls.	4,47(1,13)	0,64(0,31)	+0,004	
CLS3^{-}: Les applications étaient difficiles à utiliser	3,90(1,51)	0,78(0,21)	+0,023	
CLS4^{-}: Difficile de comprendre les instructions pour les apps.	4,12(1,34)	0,85(0,15)	+0,035	0,87 (0,10)
CLS5^{-}: Eu des probs en effectuant les mesures avec les tabs.	3,46(1,56)	0,77(0,22)	+0,019	
CLS6: Pratique d'utiliser des tablettes pour les activités de phy.	3,96(1,47)	0,75(0,23)	+0,017	
CLS7: L'util. des tabs. m'a aidé à mieux comprendre les sujets	3,50(1,19)	0,69(0,27)	+0,010	
CLS: Average values	3,82(1,41)	0,75(0,23)	-	

Table 4.18: Averages values of affective control variables. Pre-test: N = 105, N_{TG} = 61 N_{CG} = 44. Post-test: N =103, N_{TG} = 59 and N_{CG} = 44. For CLS: N = N_{TG} = 59.

Example of item	Test	α	Group	Mean
CT: I feel curious about new things.	pre	0,86	TG	4,31(0,82)
			CG	4,62(0,77)
			tot	4,44(0,81)
CLE: I could rapidly begin with the experiments.	post	0,68	TG	3,80(0,68)
			CG	4,24(0,70)
			tot	3,99(0,72)
CAE: I was focused when doing the experiments.	post	0,58	TG	4,12(0,67)
			CG	4,29(0,66)
			tot	4,19(0,67)
INV: I give my opinions during class discussions.	post	0,73	TG	3,51(0,90)
			CG	3,62(0,95)
			tot	3,56(0,92)
SCS: Smartphones' apps help me understanding things.	pre	0,67	TG	4,09(0,76)
			CG	4,22(0,82)
			tot	4,14(0,78)
CLS: I could well concentrate on experiments, without "struggling" with the app.	post	0,87	TG	3,82(1.07)
TA: The teacher responded to my questions and comments.	post	0,74	TG	4,38(0,29)
			CG	4,76(0,26)
			tot	4,54(0,33)

In view of the recommended ranges seen in section 3.2, satisfactory or even good results were obtained, although the following remarks are in order.

- The last item of *involvement* (INV5: "I was asked to explain how I solved problems") differs slightly from the others of the same scale, insofar as it concerns rather an external factor asking for the pupil's participation, and not spontaneous participation. For example, the teacher could have asked the pupil how he solved a problem, and he might have given his explanation without the will to do that. Thus, we replaced this item in the main study affective post-test, by “J’ai débattu sur les sujets traités en classe ” (“I debated on the subjects covered in class”), which will be the new INV5 item.

- The dimensions *cognitive load during the experiment* (CLE) and *cognitive activation during the experiment* (CAE) had lower values of α with respect to the other variables. However, although the α is considered as an important indicator for the consistency of a test, it should always be considered with all the other parameters. In our case table 4.18 shows that item-test correlations r_{it} were good for all items of both CLE and CAE scales. Indeed, Sijtsma (2009) emphasizes that, taken individually, the α is not a measure of internal consistency or of the degree of unidimensionality of a test and it has rather to be considered as a lower bound to estimate the reliability of a test [Lord & Novick, 1968; Zimmermann 1972].

Note in table 4.18, that the mean values are comparable for the treatment group and for the control group for all these variables. In particular for the cognitive load during the experiment, the difference between the values of the two groups is within the standard deviation.

4.4.2. Spatial abilities

The psychometrics averages and ranges of values of the multiple choice *spatial abilities* test (“Paper Folding” test from [Elkstrom *et al*., 1976], pp. 176) are indicated in table 4.19, while the results for individual items are available in table A.6 of appendix 1. For each item of the same test, the number of the given answers (A, B, C, D, E or null answer) is shown in table 4.20.

Table 4.19: Instrument analysis of the spatial abilities test in pilot study, k = 20 items, one right answer on five. N = 103.

Characteristics	Average value (confidence interval)	Range of values
Item difficulty P	0,67(0,27)	[0,15 ; 0,97]
Item discrimination D	0,46(0,20)	[0,08 ; 0,84]
Item-test correlation r_{it}	0,45(0,11)	[0,21 ; 0,66]
Reliability (internal consistency) α	0,80(0,11)	
$\Delta\alpha_C = \alpha - \alpha^*$ (after elimination of the item in question)		[+0,001; +0,021]
Fergusons Delta δ	0,91	

This instrument was already validated from previous research and, according to the criteria on the value ranges of section 3.2, these results were fully satisfactory and confirmed the reliability of this test. The lower values in the range of results for the discrimination D and item-test reliability r_{it} correspond to items whose difficulty exceeded 95%. Those are the first items at the start of each series of 10 questions. Although they turned out to be easy for pupils of the high school, they were a good entry point into the test in order to familiarize pupils with the typology of questions.

Table 4.20: Occurrences of each answer. The right answer is indicated with *, the most given is in bold characters. The item number of the test (SA) is indicated in the first line.

SA	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	**98***	9	2	13	12	4	**41***	4	2	0	1	0	**100***	0	2	**88***	2	2	8	27
B	0	7	**78***	3	**79***	0	9	4	17	1	0	**98***	0	2	**54***	3	12	13	5	10
C	2	3	7	5	1	1	5	**66***	3	5	**102***	2	2	4	8	0	1	**34**	2	21*
D	0	**82***	2	**77***	4	0	13	4	12	15	0	2	2	0	1	3	10	16*	**75***	13
E	0	1	9	2	4	**92**	13	1	19*	**46***	1	2	1	**95***	34	6	**78***	12	0	2
0	5	3	7	5	5	8	24	26	**52**	38	1	1	0	4	6	5	2	28	15	**32**

It is interesting to compare table 4.20 with the equivalent tables for the conceptual tests (tables 4.5 and 4.8). For the items whose difficulty is lower than about 0.5, in the spatial abilities test the correct answer was always also the most frequent, while in the conceptual tests many incorrect answers were particularly popular, corresponding to misconceptions. In other words, in table 4.20 there are no answers in bold form (most frequent) without asterisk (correct answer), as it was the case for conceptual tests.

4.5. ANCOVA analysis

4.5.1. Implementation

The ANCOVA analysis (see section 3.2) was carried out by collecting in the same electronic annexed file (Data_ANCOVA_PS.txt) all the data corresponding to the variables in the table A.2 of appendix 1, for the 102 pupils who participated in the pilot study, from the beginning to the end of the semester[2]. In particular, we compared the grades of mathematics, physics and French at the beginning and at the end of the semester, more than the specific option chosen by each pupil. The ANCOVA analysis was conceived in several steps using R studio [R Core Team, 2014].

1) First, we checked that the data for all variables followed a Gaussian distribution and we performed the Levene's test with p-value > 0.05 to make sure to have equal variances.

2) For each dependent variable, we performed a simple one-way ANOVA with one categorical predictor (considered as independent variable) and one numerical outcome, in order to test if the independent variable of our study (i.e. the variable *treatment*: with or without MDETs) and possibly covariates had a statistically significant effect using the r-squared size effect (see section 3.2).

3) If an effect of the independent variable and of one or more covariates was found in step (2), we checked the independence of the covariate from the independent variable before adding it to the model (first ANCOVA condition explained in section 3.2).

4) Once all the covariates were determined, we took them into account in the model and proceeded with the main analysis with the independent variable, the outcome and one or more covariates. If the effect of the independent variable was present, we calculated its size by the total eta squared η_t^2 (see section 3.2).

In the following sections, we present the main results of the procedure of the analysis, referring the interested reader to appendix 4 for details.

4.5.2. Effect on affective outcomes

There was no effect of the intervention on any affective dependent variable. However, we report here, as an example, the analysis procedure for the variable *post curiosity state*, the only one for which the first step of the procedure described in the section 4.5.1 (one way ANOVA) indicated an effect of the independent variable (*treatment*) on the dependent

[2] We excluded items CS2 of the affective tests and LPO15 of the conceptual post-test, for the reasons mentioned in the previous sections.

variable (here *curiosity state* in the post-test). Hence, we probed the effect of all the covariates on the variable *post curiosity state* with the one-way ANOVA of step (2), as shown in table 4.21.

Table 4.21: Results of the one-way ANOVA for the effect of several predictors on the outcome *post curiosity state*. *1 to 57 degrees of freedom (only for the treatment group). ** Average on all group used as individual value; + : the correlation refer to a positive slope (Pearson r >0).

Outcome	DV/predictor	Type of correlation	adj. r^2	p-value	Effect
POST_CS	TREATMENT	CG > TG	0.058	0.0082	S
POST_CS	GENDER	-	-	0.55	-
POST_CS	USE_APP	-	-	0.22	-
POST_CS	LEVEL_MA	-	-	0.53	-
POST_CS	OS	-	-	0.81	-
POST_CS	MA_GRADE_POST	-	-	0.96	-
POST_CS	PY_GRADE_POST	-	-	0.18	-
POST_CS	FR_GRADE_POST	-	-	0.61	-
POST_CS	MA_GRADE_PRE	-	-	0.13	-
POST_CS	PY_GRADE_PRE	-	-	0.31	-
POST_CS	FR_GRADE_PRE	-	-	0.65	-
POST_CS	SPATIAL_ABILITIES	-	-	0.063	-
POST_CS	PRE_RR	+	0.059	0.0078	S
POST_CS	PRE_IN	+	0.15	2.7e-05	M
POST_CS	PRE_SC	-	-	0.054	-
POST_CS	PRE_CS	+	0.37	6.8e-12	L
POST_CS	PRE_CT	+	0.25	3.8e-08	L
POST_CS	PRE_SCS	-	-	0.071	-
POST_CS	POST_CLS*	-	-	0.96	-
POST_CS	POST_CLE	-	-	0.063	-
POST_CS	POST_CAE	+	0.12	0.00024	M
POST_CS	POST_INV	+	0.13	0.00010	M
POST_CS	POST_TA**	-	-	0.35	-

Thus, table 4.21 shows an effect of the treatment on the post *curiosity state* (POST_CS) in favor of the control group, as we can see in the figure 4.4. In addition, we noticed six covariates affecting the result of post curiosity state: prior *relation to reality*, prior *interest*, prior *curiosity state*, prior *curiosity trait*, post *involvement* and *cognitive activation during the experiments*. We checked the independence of the covariates on the independent variable as explained in point (3) of section 4.5.1. Then we proceed with the main ANCOVA analysis, as indicated in point (4) of section 4.5.1, and we obtained that there was no effect of the treatment on post *curiosity state* after taking into account all covariates. The only surviving effect was prior *curiosity state* (see appendix 4 for the details of the results).

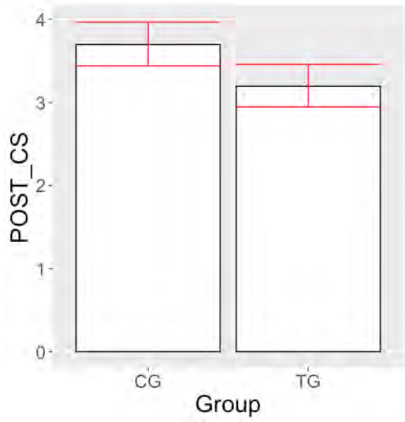


Figure 4.4: Mean value and standard deviation and of *curiosity state* in the post-test (POST_CS) for the control and the treatment group (CG or TG).

4.5.3. Effects of on learning

We proceeded with the same approach as in the previous section, starting by step (2) of section 4.5.1 and testing the effect of all possible predictors on the result of the *conceptual post-test* (LPO) with the one-way ANOVA. The results are reported in the table 4.22, showing the presence of a small effect of the treatment in favor of the control group (as shown on the left side of figure 4.5). There was also the effect of ten covariates: the result of the *conceptual pre-test* (LPR), *gender*, prior *grades in mathematics*, *physics* and *French*, the result of the *spatial abilities* test, prior *self-concept*, *cognitive load* and *cognitive activation during the experiments*, *involvement* and *teacher assessment.*

We noticed that

- The *conceptual post-test* outcome was correlated with *gender*: boys have higher results than girls (see right side of figure 4.5).

- Physics *conceptual learning* was also positively correlated with *self-concept* (figure 4.5, on the left), for which r = 0.26 corresponding to a Cohen's d = 0.54). This result confirmed a known result from previous research in physics education. For example, as we already observed in section 3.4, Hattie (2008) reports a correlation r = 0.43 corresponding to a Cohen's d = 0.95 for the effect of *self-concept* on *learning*. Moreover, a meta-analysis on psychological correlates of academic performance of undergraduate students [Richardson *et al*., 2012] reports a Cohen's d = 1.1 for *self-concept*, and d = 0.35 for *intrinsic motivation*. This indicates that *self-concept* is a stronger predictor of learning than motivation [see also Güdel *et al*., 2019]. A more recent meta-analysis on middle school students' science engagement by Aker & Ellis (2019) gives for the effect of "*feeling of competence*" an effect size g = 0.56.

As previously, the independence of the predictors on the independent variable (*treatment*) was tested before the main analysis, in point (4) of section 4.5.1, the main analysis, according to which the treatment has no effect on the result of the conceptual post-test. We took into account all the covariates, and the only surviving effects were the result of the *conceptual pre-test* (figure 4.6, on the left) and, in less strong way, *spatial abilities* (figure 4.6, on the right) and *gender*[3].

Table 4.22: Results of the one-way ANOVA for the effect of several predictors on the outcome *learning post-test*. *1 to 57 degrees of freedom (only for TG). ** Average on all group used as individual value, + : the correlation refer to a positive slope (Pearson r >0).

Outcome	DV/predictor	Type of correlation	adj. r^2	p-value	Effect
LPO	GROUP	CG > TG	0.053	0.011	S
LPO	LPR	+	0.23	1.87e-07	M
LPO	GENDER	M > F	0.064	0.006	S
LPO	USE_APP	-	-	>0.05	-
LPO	MA_GRADE_PRE	+	0.099	0.00074	M
LPO	PY_GRADE_PRE	+	0.14	7.76e-05	M
LPO	FR_GRADE_PRE	+	0.079	0.0025	S
LPO	SPATIAL_ABILITIES	+	0.071	0.0038	S
LPO	PRE_RR	-	-	>0.05	-
LPO	OS	-	-	>0.05	-
LPO	PRE_IN	-	-	>0.05	-
LPO	PRE_SC	+	0.068	0.0047	S
LPO	PRE_CS	-	-	>0.05	-
LPO	PRE_CT	-	-	>0.05	-
LPO	PRE_SCS	-	-	>0.05	-
LPO	POST_CLS*	-	-	>0.05	-
LPO	POST_CLE	+	0.056	0.0093	S
LPO	POST_CAE	+	0.031	0.043	S
LPO	POST_INV	+	0.10	0.00068	M
LPO	POST_TA**	+	0.031	0.043	S

As we already pointed out in section 3.4, we recall here that the effect of prior knowledge on learning is known in the literature (see[Hattie, 2009], where d = 0.8, and also [Kohl & Finkelstein, 2005 and 2006] and [Ainsworth, 2006]), just like that of spatial abilities (see e.g. [Wu & Shah, 2004], [Mayer & Moreno, 2003] or [Khine, 2017]) and the fact that girls' disaffection for physics sciences can lead to a negative impact on their results [Osborne *et al.*, 2003]. Regarding the impact of prior knowledge on learning, the phrase coined by David Ausubel describes it well: “The single most important factor influencing learning is what the learner already knows” (1978).

We also performed the same steps described above for the other learning variables (*physics* and *mathematics grades* at the end of the study), and we did not find any effects of the treatment. The details of the analysis are in appendix 4.

[3] See the appendix A21 for the details of the results.

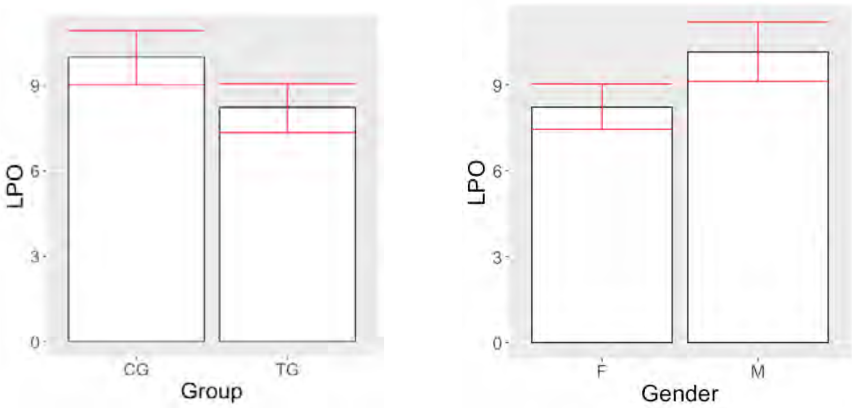


Figure 4.5: Histograms showing standard deviation of learning post-test mean score (LPO) versus group and gender.

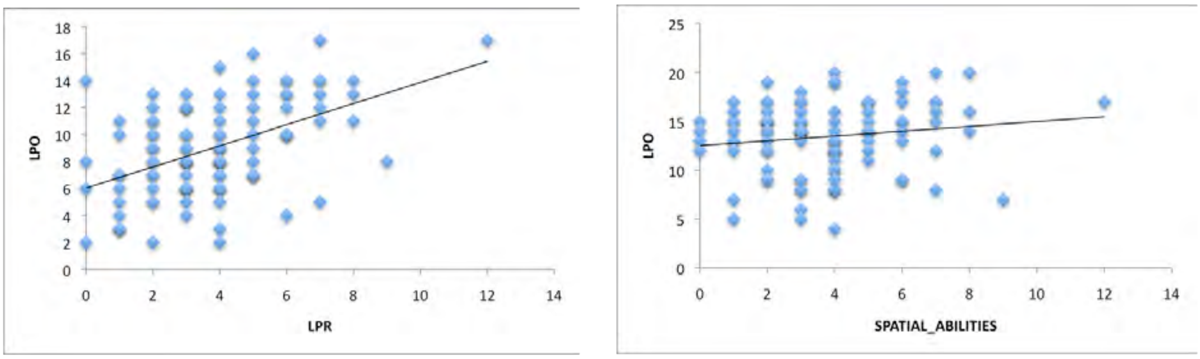


Figure 4.6: Learning post-test scores versus learning pre-test and versus the score of the spatial abilities test.

4.5.4. Effect on individual items of the conceptual learning test

Performing the one-way ANOVA analysis for each item of the conceptual post-test, we observed a p-value lower than 0.05 of the treatment only on three items: LPO2, LPO4 and LPO6. We recall that for LPO2, LPO7, LPO9 and LPO17 we observed a difference in the gains between the treatment group and the control group (see table 4.15). However, even with a simple one-way ANOVA, the treatment did not turn out to have any effect, neither on LPO7, nor LPO9 or LPO17. For LPO2, the effect observed with the one-way ANOVA was in favor of treatment group, while for LPO4 and LPO6 this effect was in favor of control group.

When evaluating the individual items effect using a single-interference procedure, it was necessary to control the rate of false positives to ensure that the effects noted are real and not only due to the probability of observing them when repeating the analysis independently many times (in this case 19 times). For this reason, we performed a *multiple significance testing* analysis (see section 3.2), in order to obtain a new set of corrected p-values, [Benjamini and Hochberg, 1995].

For each of the 19 items excluding LPO15, the corresponding standard p-value (empty circles) and the corrected p-value (filled dots) are shown in Figure 4.7. The item number ordered according to increasing p-value and the red line represents the threshold of significance set ($p < 0.05$). Thus, we could observe that the only surviving effect of the treatment was the one on LPO4.

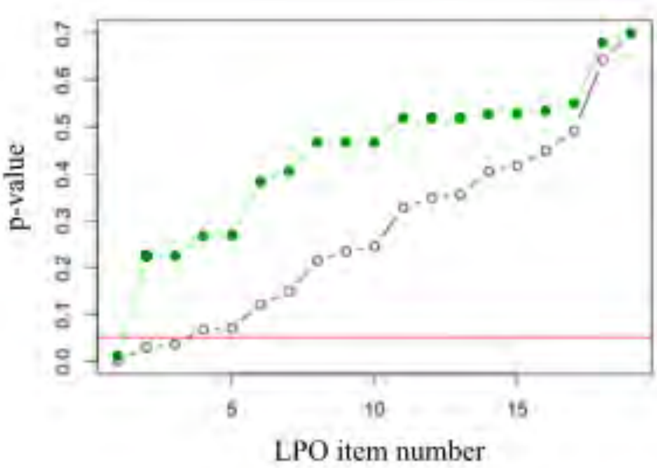


Figure 4.7: Standard p-values (black empty circles) and adjusted p-values (green filled dots) for the 19 items of the learning post-test ordered according to increasing p-value and excluding LPO15. The red line indicates the significance threshold ($p < 0.05$).

The standard and adjusted p-values of each item are as well numerically reported in the table 4.23: LPO2, LPO4 and LPO6 standard p-values were below the threshold 0,05. However their adjusted values were increased taking into account the false discovery rate, and only the p-value of LPO4 remained significant. Thus, we proceeded to the following steps of the ANCOVA analysis for the item LPO4, in order to determine if the observed effect persisted after taking into account the covariates. Note that, contrarily to many other items, LPO4 is not present in the conceptual pre-test, therefore we could not compare the result before and after the instruction.

The result of the one-way ANOVA (the step (2) of the analysis as described in section 4.5.1) is shown in table 4.24. Here we observed that the effect is in favor of the control group (see the figure 4.8) and indeed that the prior *grade in physics* was the only covariate having an effect on the outcome.

Table 4.23: Standard and adjusted p-values for LPO1, LPO2, …, LPO20 (excluding LPO15).

Outcome	IV/predictor	p-value	Effect	Adjusted p-value	Surviving effect
LPO1	TREATMENT	0.45	-	> 0.05	-
LPO2	TREATMENT	0.030	✔	0.22	-
LPO3	TREATMENT	0.071	-	> 0.05	-
LPO4	**TREATMENT**	**0.00054**	✔	**0.010**	✔
LPO5	TREATMENT	0.068	-	> 0.05	-
LPO6	TREATMENT	0.035	✔	0.22	-
LPO7	TREATMENT	0.70	-	> 0.05	-
LPO8	TREATMENT	0.23	-	> 0.05	-
LPO9	TREATMENT	0.15	-	> 0.05	-
LPO10	TREATMENT	0.25	-	> 0.05	-
LPO11	TREATMENT	0.21	-	> 0.05	-
LPO12	TREATMENT	0.40	-	> 0.05	-
LPO13	TREATMENT	0.36	-	> 0.05	-
LPO14	TREATMENT	0.64	-	> 0.05	-
LPO16	TREATMENT	0.49	-	> 0.05	-
LPO17	TREATMENT	0.35	-	> 0.05	-
LPO18	TREATMENT	0.12	-	> 0.05	-
LPR19	TREATMENT	0.33	-	> 0.05	-
LPO20	TREATMENT	0.42	-	> 0.05	-

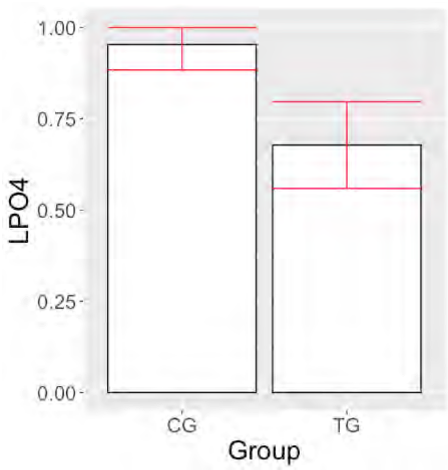


Figure 4.8: Histogram with standard deviation of LPO4 mean score versus group.

Table 4.24: Results of the one-way ANOVA for the effect of several predictors on the outcome *item n. 4* of the learning post-test (LPO4). *1 to 57 degree of freedom (only for TG); *1 to 57 DF (only TG); ** Average on all PY group used as individual value; + : the correlation refer to a positive slope.

DV (outcome)	DV (predictor)	Type of correlation	Adj. r^2	p-value	Effect
LPO4	GROUP	CG > TG	0.10	0.00054	M
LPO4	LPR	-	-	> 0.05	-
LPO4	GENDER	-	-	> 0.05	-
LPO4	USE_APP	-	-	> 0.05	-
LPO4	MA_GRADE_PRE	-	-	> 0.05	-
LPO4	PY_GRADE_PRE	+	0.036	0.032	S
LPO4	FR_GRADE_PRE	-	-	> 0.05	-
LPO4	SPATIAL_ABILITIES	-	-	> 0.05	-
LPO4	PRE_RR	-	-	> 0.05	-
LPO4	OS	-	-	> 0.05	-
LPO4	PRE_IN	-	-	> 0.05	-
LPO4	PRE_SC	-	-	> 0.05	-
LPO4	PRE_CS	-	-	> 0.05	-
LPO4	PRE_CT	-	-	> 0.05	-
LPO4	PRE_SCS	-	-	> 0.05	-
LPO4	POST_CLS*	-	-	> 0.05	-
LPO4	POST_CLE	-	-	> 0.05	-
LPO4	POST_CAE	-	-	> 0.05	-
LPO4	POST_INV	-	-	> 0.05	-
LPO4	POST_TA**	-	-	> 0.05	-

We proceed with the main analysis, as indicated in point (4) of section 4.5.1, and we found a surviving effect of the treatment on LPO4 in favor of the control group, taking into account the covariate *prior grade in physics*. The total eta squared $\eta_t^2 = 0.09$ indicated a medium effect, referring to the values criteria seen in section 3.2 [Cohen, 1988]. This is the only effect observed of the treatment on the dependent variables of the pilot study.

4.6. Discussion and conclusions

At the end of the pilot study the results were presented to the participating teachers. We discussed with them the experience they had made, the progress of the pilot study and the possible changes to be made in the main study. Overall, the teachers felt comfortable with the course and were able to complete the sequence and activities as planned. They showed curiosity about the results and were willing to participate in the main study. In addition, a fourth teacher interested in studying and using tablets joined this project and participated in the main study during the school year 2019-2020. However, the fourth teacher's classes belonged to a high school where the three levels program was covered in a different order with respect to the others. Indeed kinematics and dynamics were studied during the 3rd year in the high school of teacher 4, rather than in 2nd year, as is the case for teachers 1, 2 and 3.

4.6.1. Changes to the MDETs activities and teaching sequence

According to the results on the ANCOVA analysis performed in section 4.5, the only observed effect of the treatment on the dependent variables during the pilot study was a medium effect on the result of one particular item of the conceptual post-test (LPO4). This item was created for this study and it tests the notion of instantaneous velocity in a two-dimensional motion (tangent vector). LPO4 is relied to the MDETs activities n. 1 and n. 4 and, according to the results of sections 4.3.2 and 4.3.3 (see in particular the table 4.15) it was generally successful (overall $P = 0.79$). However, there was an important difference between the averages difficulties P of the control and the treatment group in the conceptual post-test. The former obtained $P = 0.95$, indicating that almost all of the pupils understood that velocity is represented with an arrow tangent to the trajectory. Although the result remained satisfactory for the treatment group ($P = 0.68$), a greater proportion of pupils gave the wrong answer. This item relates to the very first MDETs activity, which is supposed to introduce pupils to the basics of position and velocity vectors, without having the goal yet of describing parabolic motion (which is studied later in the school year, after having studied the uniform linear motion and the uniformly accelerated linear motion). Though, as for the second MDETs activity, the information about the motion given by the applications was beyond the skills of the pupils at this time of the year. In particular, they had access to the data of the two components of the motion (*x* and *y*) and they could see the relative graphs, before studying the simpler one-dimensional motions (uniform and uniformly accelerated linear motions). One possible explanation to the presence of this effect is therefore that the treatment pupils had to simultaneously

1. learn the concepts studied and
2. manage an excess of information given by the applications,

which may have caused cognitive overload (see section 2.3.3).

Taking this information into account, the four teachers participating to the main study agreed to drop the MDETs activities n. 1 and n. 4 and to begin with the MDETs activities n. 2 (return trip), in the form of a video common to all the pupils. In addition the teacher made a demonstration of the use of the applications during the first activity. The data of this first activity were thus given to the pupils without the graph of the motion. Thus, in the main study the first MDETs activity where pupils make the measurements was n. 3 (uniform linear motion, the one with the simpler graphs). This change had the advantage of reducing the cognitive load when using the tablets for the first time, and allowed pupils to better concentrate on the important notions related to the average speed during a return trip (activity n. 2) and of instant velocity on a two-dimensional motion (activity 1). The objective was on the one hand to observe an increase in the correct responses to the related items and, on the other hand, to reduce the cognitive load when studying the basics of velocity vector in a two-dimensional motion for the treatment group.

Furthermore, in order to complete the two-dimensional kinematics chapter, an activity on the projectile's motion (the activity n. 7 of appendix 2) was added to the teaching sequence of the main study. This activity was planned to be the last one, after studying the uniform linear motion and the uniformly accelerated linear motion, when pupils of the treatment group have already used the tablets several times.

<u>MDET activity n. 7: the projectile motion</u>

In this activity pupils trace the motion of a ball falling to the floor after rolling on a table (i. e. with an initial horizontal velocity). They first perform an analysis of the uniform linear motion (x-axis) and uniformly accelerated linear motion (y-axis) by calculating the velocity or the acceleration from the graph given by the application, as shown in the example in figure 4.9. Subsequently, pupils repeat the tracing for different initial speeds (see figure 4.10). Each time they measure the horizontal distance traveled by the ball during the flight and they establish a proportionality relation between this distance and the initial speed. This allows realizing that the fall time does not depend on the initial velocity but only on the height of the table.

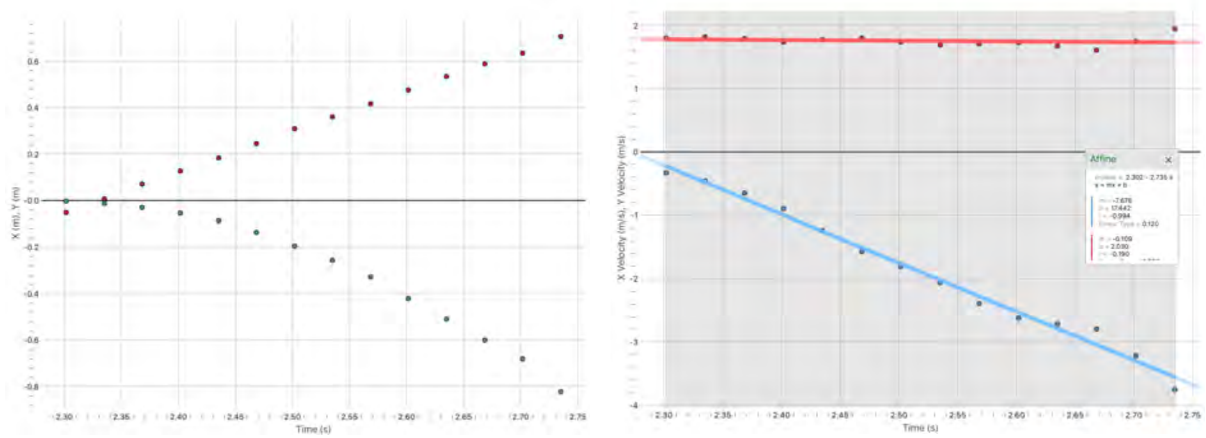


Figure 4.9: Graphics of the position (x in red, y in blue) and of the velocity (v_x in red, v_y in blue) as functions of time in a motion of a ball falling from a table.

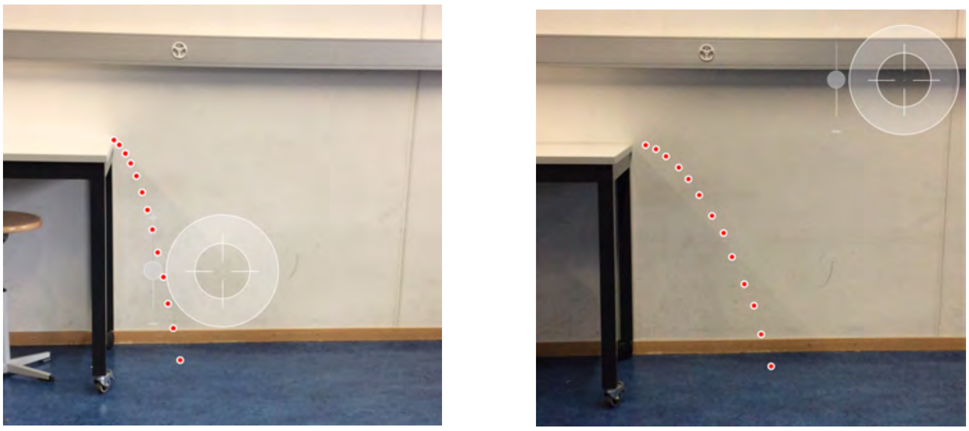


Figure 4.10: Tracing two motions with different initial velocities: the time of the flight does not depend on the initial speed (same number of points).

The equivalent traditional lab can be carried out by the control group, using a stopwatch chronometer and a ruler to measure the ball's initial velocity (from its diameter and passing time) and the horizontal distance from the table, when the ball hits the ground. However, the measure of the positions and velocities during the fall is not possible with a traditional setup.

Eventually, during the main study the pupils of the treatment group performed five MDETs activities: n. 2 (return trip), n. 3 (uniform linear motion), n. 5 (uniformly accelerated linear motion), n. 6 (jump) and n. 7 (projectile).

4.6.2. Changes to the conceptual learning test

Since MDETs activities n. 1 and n. 3 were not planned in the main study, the corresponding items were removed from the conceptual test (LPO4, LPO5 and LPO6 of the pilot study). Furthermore, two items on parabolic motion were added to the conceptual test, corresponding to MDETs activity n. 7. These are the items 12 and 14 of the Force Concept Inventory [Hestenes *et al.* 1992], and become new items LPO14 and LPO15 of the main study.

Moreover, as anticipated in section 4.3.2, the item LPO18 of the pilot study (on Newton 2nd law) was changed, because many pupils answered that, if you push with the same force two balls, one of which is 3 times less massive than the other, "the lightest reaches a speed approximately greater, but not *exactly* 3 times" (answer E), which was considered as false. Those pupils could have well understood the 2nd law of Newton, but still answered incorrectly because of the word "exactly".

Thus, for the main study, the word "exactly" were drop in answer B and C, as follows:

(B) "the heaviest reaches a speed ~~exactly~~ 3 times greater"

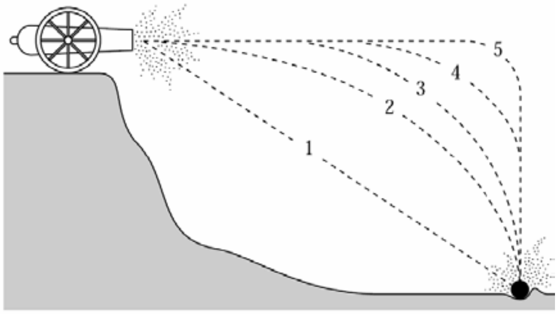
(C) "the lightest reaches a speed ~~exactly~~ 3 times greater"

The answers D and E ("the heaviest(D)/lightest(E) reaches a greater speed, but not exactly 3 times bigger") become "the heaviest(D)/lightest(E) reaches a speed 9 times bigger."

The full conceptual pre- and post-test of the main study, including the changes listed above, are the appendix 3.

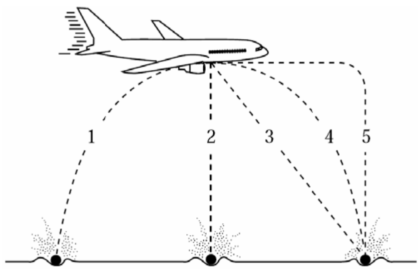
FCI 12: A ball is fired by a cannon from the top of a cliff as shown in the figure below. We neglect air friction. Which of the paths would the cannon ball most closely follow?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5



FCI 14: A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. We neglect air friction. As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5



4.6.3. Changes on tests for affective variables and spatial abilities

Regarding affective testing, we made the following changes:

- As we discussed in the item analysis of section 4.2.2, we replaced the word "comprendre" (understand) of CS2 of *curiosity state* by the word "approfondir" ("deepen"), because this word better conveys the idea of curiosity in French. This change is done in both pre- and post-test.

- In section 4.2.2 we analyzed INV5 of *involvement* of the post-test: "I was asked to explain how I solved problems". This item differs slightly from the others of the same scale, insofar as it concerns rather an extern factor leading the pupil's participation, and not a spontaneous participation. For example, the teacher could have asked the pupil how she/he solved a problem, and she/he might have given his explanation without the will to do that. Thus, we change INV5 into “I debated on the subjects covered in class” (“J’ai débattu sur les sujets traités en classe ”).

- Although all items of the dimension *teacher assessment* (TA) in the post-test worked well, it was considered appropriate to add an item assessing the teacher’s involvement. We then added an adaptation from [Vogt, 2010] « During the last physics classes, the teacher seemed to be more involved than usually ». We changed “*more involved than usually*” into “*particularly involved* ” (« Lors des derniers cours, l’enseignant semblait particulièrement engagé ». In order to maintain the same total number of items for this dimension, we removed item TA3, i.e. the one with the les satisfactory item analysis results.

- The affective dimensions worked well in the pilot study. Therefore, in order to optimize the time available without overloading the tests of the main study, we dropped some items, while paying attention to have at least five items for each dimension. The choice was made to drop the items with the items with poorer discrimination parameters or showing internal Cronbach scale consistency measure increased by omitting them (see section 3.2). We then removed
    - SC4, SC5, IN4, IN7, CT5, RR3 (pre- and post-test),
    - SCS4 (pre-test),
    - CLE3 (post-test),
    - CLS2, CLS7 (post-test, only treatment group).

- Indeed, there was no need to measure twice the scale *curiosity state* (in the pre- *and* in the post-test), and then we estimated this dimension only in the pre-test.

Across the instrument of all affective variables, we removed:
- 14 items from the treatment group post-test;
- 12 items from the control group post-test;
- 7 items from the common pre-test.

All the changes listed in this section are reported in table A.2 of appendix 1, summarizing the analysis of all affective variables.

The affective test for the main study is available in appendix 3:
- The affective pre-test;
- The affective post-test, including the anonymous questionnaire for the *teacher assessment* scale.

Finally, no change was made in the spatial abilities test.

5. RESULTS OF THE MAIN STUDY

Similarly to chapter 4, in this chapter we will present the results of the main study about:

1. The development of the tests (psychometric values, item and instrument analysis) and
2. The results of the participating pupils.

In addition, for a consistent reading, some specific explanations will be given directly following the presentation of certain results, while a general discussion will be given in chapter 6.

5.1. Implementation and progress

5.1.1. General remarks about the implementation

In this subsection we will present some specificities about the conduct of the main study and refer the reader to chapter 3 for the details on the sample, setting, design and methods and to section 4.6 on the modifications resulting from the pilot study.

The learning test was created based on the pilot study, by integrating the modifications shown in section 4.6.2. In particular, 3 items out of the 20 of the main study post-test were removed (on the vector quantities in the two-dimensional kinematics), and 2 items on the parabolic motion were added. Thus, the learning post-test of main study contains 19 items, while the conceptual pre-test learning contains only the items for which an answer could be given without instruction, i.e. 16 items. The affective and spatial abilities tests administered during the main study were modified from those of the pilot study according to the discussion in section 4.6.3. The pre- and post-test sessions were planned in the same way as in the pilot study and we refer to the section 4.1 for the details. As for the pilot study, all the tests are available in appendix 3.

5.1.2. Adaptations to the teaching during the covid19 lockdown

We remind that four teachers participated in the main study and all of them could complete the sequence and the test sessions. Nevertheless, teacher 3 (T3) fell a couple of weeks behind in the program and the post-test session for his group-classes took place in March, which was the first week of confinement because of the Covid19 pandemic. Thus, the pupils of groups 3 made the post-tests remotely, from their home, using a computer or their own Smartphone or a tablet during a test session that lasted about one hour. For each questionnaire (pre and post-test), a link was sent to pupils individually, which allowed them to complete the test within the dedicated time. The implementation of all the post-tests on a secure online platform had to be done suddenly because of the improvised announcement of the closure of face-to-face schools. Then it was a challenge of speed and efficiency, more than of collaboration between the teacher, the pupils and the researchers. At the very beginning of the lockdown, it was not clear how the remote assessments counted in the pupils' final grade, because the management of local schools had not yet clarified the evaluation methods during the lockdown. In order to motivate the pupils of group 3 to complete the conceptual post-test in an authentic way, a notice was displayed on the screen before the start of the test. This notice (available in appendix 3) explains the formative importance of the conceptual test, and that a feedback would be given on the evolution of the pupils' knowledge. They were asked to complete the post-tests individually, in a calm place, without interactions with other people (no personal messages) or with the course material, as if they were doing a classroom assessment. Teacher 3 was available by videoconference, for any questions of comprehension of the statement. The post-test session went as planned and all the pupils seem to have responded sincerely.

5.2. Affective outcomes

5.2.1. Pre-test

For each affective outcome of the pre-test, the analysis of the instrument, including the mean values and the range of values of the characteristic quantities, is shown in Table 5.1 shows.

Table 5.1: Instrument analysis of the affective outputs of the pre-test; 6-level items 1 = completely disagree, 6 = completely agree; N = 116; N_{TG} = 56; N_{CG} = 60.

Variable	Scale characteristics	Average value (confidence interval)	Range of values
Relation to reality	Mean	3,35(1,08)	[3,0 ; 3,84]
	Item-test correlation r_{it}	0,81(0,14)	[0,78 ; 0,84]
	Reliability (internal consistency) α	0,87(0,08)	-
Self-concept	Mean	3,56(1,01)	[3,16 ; 4,00]
	Item-test correlation r_{it}	0,80(0,14)	[0,71 ; 0,83]
	Reliability (internal consistency) α	0,85(0,09)	-
Interest	Mean	3,17(0,85)	[2,50 ; 3,66]
	Item-test correlation r_{it}	0,69(0,19)	[0,60 ; 0,80]
	Reliability (internal consistency) α	0,717(0,16)	-
Curiosity state	Mean	3,34(0,94)	[2,74 ; 3,63]
	Item-test correlation r_{it}	0,80(0,84)	[0,77 ; 0,83]
	Reliability (internal consistency) α	0,79(0,13)	-

The results of the item analysis from the affective dependent variables according to the analysis methods are explained in section 3.2. The details of the item analysis for the affective outcomes of the pre-test is available in the table A.6 of appendix 1, where the French version of each item is on the first left side column, and the relative mean value M (standard deviation), the individual item reliability r_{it} (confidence interval), and the variation of the Cronbach alpha α-α^* are given. Furthermore, compared to the pilot study, the modifications are reported and the deleted items are those we have dropped, following the discussion in section 4.6.3. According to the criteria on the value ranges explained in section 3.2, results shown in the table 5.1 for relation to reality (RR), interest (IN), curiosity state (CS) and self-concept (SC) are fully satisfactory, with values comparables with those of the affective tests of the pilot study and all the α increased compared to the pilot study, which indicates that the changes made are appropriate.

5.2.2. Post-test

As in the previous section, the instrument analysis for each dependent variable of the affective post-test, including the mean values and the range of values of the characteristic quantities is shown in table 5.2. While the results of the item analysis of the same test are available in table A.8 of appendix 1.

Table 5.2: Instrument analysis of the affective outputs of the post-test; 6-level items 1 = completely disagree, 6 = completely agree; N = 111; N_{TG} = 55; N_{CG} = 56.

Variable	Scale characteristics	Average value (confidence interval)	Range of values
Relation to reality	Mean	3,67(1,13)	[3,39 ; 4,37]
	Item-test correlation r_{it}	0,85(0,15)	[0,79 ; 0,90]
	Reliability (internal consistency) α	0,90(0,06)	-
Self-concept	Mean	3,60(1,15)	[3,18 ; 4,11]
	Item-test correlation r_{it}	0,84(0,19)	[0,75 ; 0,89]
	Reliability (internal consistency) α	0,89(0,06)	-
Interest	Mean	3,35(0,86)	[2,51 ; 3,93]
	Item-test correlation r_{it}	0,69(0,25)	[0,56 ; 0,76]
	Reliability (internal consistency) α	0,71(0,17)	-
Curiosity state	Mean	3,25(1,09)	[2,95 ; 3,43]
	Item-test correlation r_{it}	0,83(0,12)	[0,81 ; 0,86]
	Reliability (internal consistency) α	0,89(0,07)	-

As it was the case for the outcomes of the affective pre-test, in the post-test we obtained overall good results. The values of α are on average higher than in the affective post-test of the pilot study, despite the lower number of items in some dimensions. Furthermore, we did not observe problematic items (as is the case for CS2 in the affective tests of the pilot study), confirming that the modifications made are appropriate.

5.2.3. Comparison of pre- and post- results

Table 5.3 summarizes and compares the mean values of the affective outcomes, before and after the instruction, for the control group, for the treatment group as well as for all the participants in the main study. Furthermore, the Cohen's d values are also reported. We refer to section 3.2 for the usual thresholds of Cohen's d.

Table 5.3: Averages values (6-level items 1 = completely disagree, 6 = completely agree) of the affective pre- and post-tests for affective outcomes. Comparing the results for N = 111 pupils participating to the main study (N_{TG} = 55; N_{CG} = 56). In the last column, the Cohen's d values for the pre/post comparison are reported. The * indicates a small positive effect.

Example of item (Translated from French)	α pre/post		Average M ()			Difference	Cohen's d
			Group	PRE	POST		
SC: My classmates thought I was good at physics.	0,85	0,89	TG	3,52(1,07)	3,59(1,17)	+0,07	-
			CG	3,59(0,97)	3,61(1,15)	+0,03	-
			tot	3,56(1,01)	3,60(1,15)	+0,04	-
IN: I liked the physics class.	0,72	0,71	TG	3,10(0,88)	3,27(0,90)	+0,17	0,19*
			CG	3,24(0,82)	3,43(0,83)	+0,19	0,23*
			tot	3,17(0,85)	3,35(0,86)	+0,18	0,21*
CS: The course aroused my curiosity about the topics covered.	0,86	0,89	TG	3,40(1,04)	3,34(1.05)	-0,06	-
			CG	3,28(0,85)	3,17(1,13)	-0,11	
			tot	3,34(0.94)	3,25(1,09)	-0,09	-
RR: The subjects of the physics course are useful for everyday situations.	0,87	0,90	TG	3,44(1,04)	3,73(1,00)	+0,29	0,28*
			CG	3,25(1,12)	3,61(1,25)	+0,36	0,34*
			tot	3,35(1,08)	3,67(1,13)	+0,32	0,31*

We recall that in the equivalent table of the pilot study (table 4.5) the mean values were all higher in the control group compared to the treatment group, and that these differences were maintained throughout the pilot study. Moreover the variations of dependent variables, between the pre- and post-test, were slightly negative for all affective outcomes except for *relation to reality*, whose variation was positive for all groups, although the time-variations of all variables were insignificant (see section 4.2.3).

In the main study, firstly we did not observe that one group was regularly outperforming the other. Secondly, the pre/post variations were rather positive, and for the variables *interest* and *relation to reality* they turned out to be significant, both for the treatment and the control group. This indicates that the teaching had at least an overall beneficial effect on these variables. The last column of table 5.3 shows the calculated Cohen's d, quantifying the positive effect of the instruction during this study. So far, there does not seem to be a significant difference between the evolution of the dependent variables for the treatment and the control group. We will go into more details in section 5.5, dedicated to the ANCOVA analysis.

5.3. Conceptual test

5.3.1. Pre-test

The characteristics average and the range of values of the conceptual pre-test including all the items are shown in table 5.4. Based only on a dichotomous true/false analysis, without taking into account the possible misconceptions among the false answers, we found that several items have unsatisfactory psychometric values according to the criteria seen in section 3.2. As this is a conceptual test taken *before* the instruction, this result is not surprising: looking at the analysis of the individual items presented in table 5.5 (first line for each item), we observed that the questions with the worst psychometric values were also the most difficult. We therefore constructed a test with an item selection restricted to those with acceptable psychometric parameters. We then removed:

- The items having a unsatisfactory r_{it} and/or decreasing α (LPR9, LPR13 and LPR14);
- The items with lowest P: LPR10 (0.11) and LPR12 (0.03) corresponding to a strong misconception.

The same characteristics as table 5.4 for the restricted item selection are given in table 5.6. Here the psychometric indexes are satisfactory, as we can also see in the individual item analysis of table 5.5 (second line for each item). As in the pre-tests of the pilot study and of the validation phase, there are not only many incorrect answers, but also several known misconceptions, as analyzed in chapters 3 and 4. The strong presence of misconceptions before the instruction is visible in table 5.7 that shows the percent of pupils' answers (A, B, C, D, E or null answer) for each item of the conceptual pre-test of the main study. The underlined values are the most frequent wrong answers and correspond to the same misconceptions already present in the learning pre-test of the pilot study and in the validation phase. In addition, the answer A of the newly introduced item LPR12 (with respect to the pilot study) highlighted the misconception considering that a free falling object with an horizontal initial velocity does not maintain its horizontal uniform linear motion and its trajectory (with respect to the ground) is deflected backwards. In sum, for 10 out of 16 items, the most frequent answer option corresponds to a misconception known from previous research (see discussion of those misconceptions in section 5.3.3).

Table 5.4: Instrument analysis for the full conceptual pre-test of the main study. MCQ with 1 correct answer out of 5, k = 16 items and dichotomous scale level; N = 116; N_{TG} = 56; N_{CG} = 60.

Characteristics	Average value (confidence interval)	range of values
Item difficulty P	0,29(0,15)	[0,03 ; 0,52]
Item discrimination D	0,36	[0,01 ; 0,76]
Item-test correlation r_{it}	0,31(0,32)	[0,03 ; 0,55]
Reliability (internal consistency) α	0,37(0,34)	
$\Delta\alpha_C = \alpha - \alpha^*$ (after elimination)		[-0,086; +0,102]
Fergusons Delta δ	0,88	-

Table 5.5: Item analysis for the conceptual pre-test of the main study. Values in the full test (first line) and in the restricted test (second line), where items with too low r_{it} , decreasing α or too low P were excluded. MCQ with 1 correct answer out of 5; N = 116: N_{TG} = 56; N_{CG} = 60. Modified or new items with respect to the pilot study test are indicated with an *.

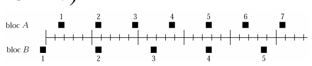
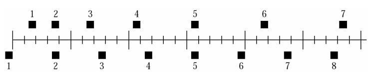
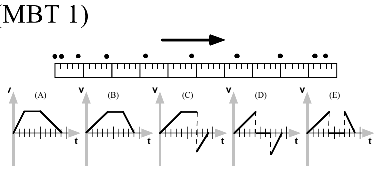
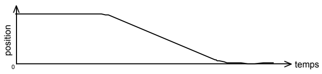
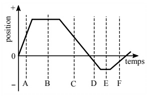
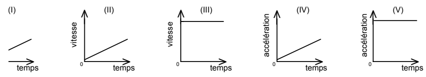
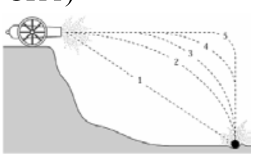
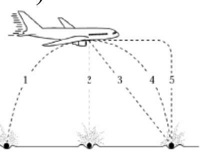
Item keywords (source)	P(SD)	D	r_{it}(CI)	α - α*
LPR1: Visualize acceleration from trajectory in LM (FCI 20) 	0,19 (0,39)	0,54 -------------------- 0,58	0,47(0,28) -------------------- 0,49(0,28)	+0,07 ---------------- +0,04
LPR2: Visualize velocity from trajectory in LM (FCI 19) 	0,43(0,50)	0,58 -------------------- 0,70	0,44(0,30) -------------------- 0,52(0,27)	+0,06 ---------------- +0,05
LPR3: Average speed and the average of two speeds.	0,16(0,36)	0,46 -------------------- 0,43	0,48(0,28) -------------------- 0,48(0,28)	+0,07 ---------------- +0,04
LPR4: Velocity diagram from trajectory in LM (MBT 1) 	0,39(0,49)	0,37 -------------------- 0,44	0,31(0,33) -------------------- 0,34(0,32)	+0,01 ---------------- -0,01

Table 5.5 continued

LPR5: Position-to-time diagram (TUG 8) 	0,17(0,38)	0,40 -------------------- 0,35	0,35(0,32) -------------------- 0,34(0,32)	+0,03 ---------------- +0,01
LPR6: Instant velocity as slope in the position to time diagram (MCT 30) 	0,28(0,45)	0,60 -------------------- 0,66	0,48(0,28) -------------------- 0,56(0,25)	+0,07 ---------------- +0,06
LPR7: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified) 	0,19(0,38)	0,60 -------------------- 0,55	0,51(0,27) -------------------- 0,52(0,27)	+0,08 ---------------- +0,05
LPR8: Kinematics of free falling different bodies – covered distance (FCI 1 – removed all the « about », no friction at all)	0,50(0,50)	0,76 -------------------- 0,83	0,55(0,26) -------------------- 0,55(0,26)	+0,10 ---------------- +0,06
LPR9: Quadratic relationship between distance and time in free fall: UALM (created from FCI 1)	0,48(0,50)	0,04 -------------------- -	0,03(0,36) -	-0,09 -
LPR10: *g* during a free fall with change in velocity's orientation (throwing a stone upward)	0,11(0,32)	0,15 -------------------- -	0,14(0,36) -	-0,01 -
LPR11: (FCI11)* 	0,46(0,50)	0,34 -------------------- 0,40	0,28(0,34) -------------------- 0,32(0,33)	-0,01 ---------------- -0,02
LPR12: (FCI 14)* 	0,03(0,16)	0,07 -------------------- -	0,13(0,36) -	- -------------- -
LPR13: 1st Newton's law and gravitation – lift at constant velocity (FCI 17, answer E modified)	0,22(0,42)	0,01 -------------------- -	0,05(0,36) -	-0,06 -
LPR14: 2nd Newton's law – acceleration is inversely proportional to the mass (created – acceleration of two different masses with the same net force)*	0,52(0,50)	0,22 -------------------- -	0,13(0,36) -	-0,06 -
LPR15: 3rd Newton's law – frontal collision (FCI 14)	0,34(0,48)	0,46 -------------------- 0,47	0,36(0,32) -------------------- 0,38(0,31)	+0,028 ---------------- +0,04
LPR16: 3rd Newton's law – accelerated system in contact (FCI 15, answer D modified)	0,21(0,41)	0,23 -------------------- 0,32	0,23(0,35) -------------------- 0,27(0,34)	-0,006 ---------------- -0,012

Looking at the individual items results in tables 5.5 and 5.7 we also observed that, although the pupils had not yet benefited from an instruction, certain items present rather high solution probabilities (difficulty index around 0.5). This is particularly the case for item LPR8 (which was excluded in the analysis of the pilot study) on the free fall time of two different masses. This item also had a high P in the pilot study, confirming that the associated misconception is not widespread at the secondary school level.

Table 5.6: Instrument analysis for the restricted conceptual learning pre-test of the main study, considering only the items with acceptable parameters. MCQ with 1 correct answer out of 5, k = 11 items and dichotomous scale level; N = 116 : N_{TG} = 56; N_{CG} = 60.

Characteristics	**Average value (confidence interval)**	**range of values**
Item difficulty P	0,30(0,15)	[0,16 ; 0,50]
Item discrimination D	0,52	[0,32 ; 0,83]
Item-test correlation r_{it}	0,43(0,29)	[0,27 ; 0,56]
Reliability (internal consistency) α	0,56(0,24)	-
$\Delta\alpha_C = \alpha - \alpha^*$ (after elimination of the item in question)	-	[-0,017; +0,061] (3 items)
Fergusons Delta δ	0,88	-

We noticed that the newly introduced item LPR11 on the projectile motion and LPR14 on the 2nd Newton's law were as well quite easy for a pre-test study. More generally, the results of the learning pre-tests (here and in chapter 4) showed that the pupils starting the physics course arrive with pre-existing conceptual constructs: some are correct, but for the most part they are wrong. This confirms findings known in physics education research for decades (see [Doktor & Mestre, 2014] and reference therein), as discussed in section 2.3.1.

Table 5.7: Percent of each answer option for the items of the conceptual pre-test. The first line is the number of the item (LPR). The right answer is indicated with *, the most frequent one is in bold characters, underlined when a misconception known from previous research is present (see table A.3 of appendix 1 for the items' validation and table 4.5 for the pilot study). The sum of the answers may be different from 100% because of rounding.

LPR	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
%A	21	14	**56**	37	16	29	19*	10	8	17	1	**56**	**37**	17	**56**	21*
%B	7	2	16*	**39***	18	2	10	6	4	18	**46***	35	22*	20	2	6
%C	**51**	4	6	3	**38**	28*	0	**50***	36	**47**	38	6	2	**52***	3	**62**
%D	19*	35	2	9	17*	1	4	28	**48***	**7**	**9**	3*	30	3	3	10
%E	2	**43***	20	10	9	**33**	**65**	6	3	11*	5	0	8	6	34*	0
% 0	1	2	1	3	1	7	2	0	0	0	1	0	0	1	2	1

Factor analysis

An exploratory factor analysis was carried out to examine whether some conceptual dimensions underlying the test are visible. We proceeded with the same considerations as explained in section 3.2 about analyses methods, concerning the limitations of this kind of analysis for the dichotomous data of a conceptual test, and those due to the minimum number of items required for each expected dimension, leading to underestimated or biased loadings (se the section 3.2.2 and the references thereby). For this conceptual pre-test, the case-to-item (see section 3.2) ratio is greater than 7:1, which is considered as sufficient compared to the previous studies [Osborne *et al*., 2008].

In order to have the least biased results possible, we only considered the items of the restricted version of the pre-test, i.e. excluding the items with unsatisfactory r_{it} and/or decreasing α and items whose difficulty is lower than 0.2 (see previous discussion), leading to the subset of 11 items indicated in the tables 5.5 and 5.6. Thus, although the test has been constructed based on five conceptual a priori dimensions, discarding the items with unsatisfying psychometric parameters (LPR9, LPR10, LPR12, LPR13 and LPR14), we eventually hypotized three possible sub-dimensions for the 11 items of the restricted version of the pre-test.

1) One-dimensional kinematics (and free fall): LPR1, LPR2, LPR3, LPR4, LPR5, LPR6, LPR7, LPR8;
2) Two-dimensional kinematics (and free fall): LPR11;
3) Newton 3rd law: LPR15, LPR16.

The average of KMO values of the 11 items of the restricted version of the test is 0.59, which is acceptable for carrying out the factor analysis (see section 3.2.2). Figure 5.1 shows the scree-plot of the resulting eigenvalues, and the relative highest loadings and cumulative variances are shown in the table 5.8. Six loadings were greater than 1 and the slope changes significantly between factor 2 and factor 4. We thus compared several solutions with three to six factors and rotated through oblique rotation to clarify and simplify the data structure, with the aim to identify the most suitable model.

The model with three factors showed the best agreement with three sub-dimensions hypotized above, as shown in table 5.9: one-dimension kinematics (factor 1), the 3rd Newton Law (factor 2) and the projectile motion (factor 3). Nevertheless, items LPR4 and LPR8 present rather low saturations in the dimension where they are expected, and LPR8 has an unexplained higher loading on the factor of LPR11. Indeed LPR8 is on the one-dimensional kinematics of free fall, and LPR11 on the projectile motion.

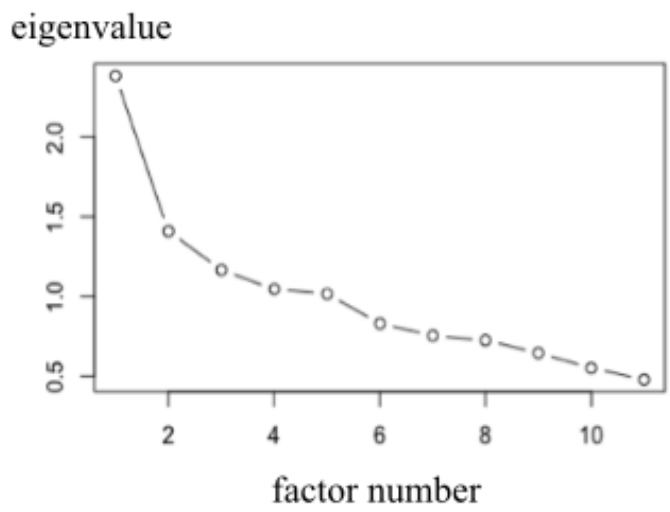


Figure 5.1: Scree-plot for the restricted version of the pre-test.

Table 5.8: Result of the factor analysis for the first seven dominant factors, including their eigenvalues, the proportion of the modeled and cumulative variance.

Factor	Eigenvalue	Modeled variance	Cumulative variance
1	2.46	0.15	0.15
2	1.66	0.10	0.26
3	1.47	0.09	0.35
4	1.25	0.08	0.43
5	1.08	0.07	0.50
6	1.06	0.07	0.56
7	0.99	0.06	0.62

Table 5.9: Loadings greater than 0.3 for the analysis with three factors after oblique rotation.

Item	F1	F2	F3
LPR1	0.63	-	-
LPR2	0.61	-	-
LPR3	0.50	-	0.39
LPR4	0.32	0.30	-
LPR5	0.44	-	-
LPR6	0.63	-	-
LPR7	0.65	-	-
LPR8	0.38	-	0.58
LPR11	-	-	0.61
LPR15	-	0.75	-
LPR16	-	0.80	-

We then performed a new item analysis for the eight items of the first sub-dimension “one-dimensional kinematics”: the only one containing more than three items. Table 5.10 shows the instrument analysis of this sub-dimension, which turns out not to be significantly different from the one of the restricted version of the test, with 11 items (table 5.6). Only the values of r_{it} and α slightly increase, being consistent with the fact that the first factor is dealing with the conceptual aspects only. The item analysis of this sub-dimension is available in table A.9 of appendix 1

Table 5.10: Instrument analysis of the restricted conceptual pre-test, for the 8 items of the first dimension of the exploratory factor analysis (one-dimensional kinematics). CMQ with 1 right answer out of 5, k = 8 items and dichotomous scale level; N = 116; N_{TG} = 56; N_{CG} = 60.

Characteristics	**Average value (confidence interval)**	**range of values**
Item difficulty P	0,29(0,15)	[0,16 ; 0,50]
Item discrimination D	0,52	[0,41 ; 0,81]
Item-test correlation r_{it}	0,53(0,26)	[0,35 ; 0,62]
Reliability (internal consistency) α	0,62(0,21)	
$\Delta\alpha_C = \alpha - \alpha^*$ (after elimination of the item in question)		[-0,038; +0,063] (1 tem)
Fergusons Delta δ	0,85	-

5.3.2. Post-test

The characteristics average and the range of values of the conceptual learning post-test (LPO) are showed in tables 5.11 and 5.12. The first table is about the analysis of the complete post-test (19 items), while the second one summarizes the analysis of the restricted version of the same test (16 items), i.e. dropping the items with unsatisfying r_{it} and/or decreasing α, that is LPO16 (=LPR13), LPO17 (=LPR14) and LPO19 (=LPR16). Comparing these two tables, we observed that the Ferguson δ value of the restricted version decreased and the average values of the psychometric parameters did not significantly change with respect the test with 19 items.

Table 5.11: Instrument analysis of the conceptual post-test of the main study. CMQ with 1 correct answer out of 5, k = 19 items and dichotomous scale level; N = 111: N_{TG} = 55; N_{CG} = 56.

Characteristics	**Average value (confidence interval)**	**Range of values**
Item difficulty P	0,43(0,19)	[0,16 ; 0,76]
Item discrimination D	0,41(0,22)	[-0,02 ; 0,77]
Item-test correlation r_{it}	0,34(0,14)	[0,04 ; 0,53]
Reliability (internal consistency) α	0,59(0,22)	
$\Delta\alpha_C = \alpha - \alpha^*$(after elimination)		[-0,036; +0,046]
Fergusons Delta δ	0,91	

Moreover in table 5.12 the minimum values of the ranges increased above the acceptability threshold and the standard deviations tightened. The details of the item analysis, for the full post-test as well as for the restricted version, are presented in table A.10 of appendix 1, where all the individual psychometric values are given. The individual item analysis will also be presented in the next section, when comparing the result of each item in the pre- and in the post-test (table 5.19).

Table 5.12: Instrument analysis of the restricted conceptual post-test of the main study, considering only items with acceptable parameters. CMQ with 1 correct answer out of 5, k = 16 items and dichotomous scale level; N = 111: N_{TG} = 55; N_{CG} = 56.

Characteristics	Average value (confidence interval)	range of values
Item difficulty P	0,46(0,18)	[0,16 ; 0,76]
Item discrimination D	0,48(0,14)	[0,27 ; 0,70]
Item-test correlation r_{it}	0,39(0,09)	[0,28 ; 0,50]
Reliability (internal consistency) α	0,67(0,19)	
$\Delta\alpha_C = \alpha - \alpha^*$(after elimination)		[-0,002; +0,035]
Fergusons Delta δ	0,80	

Similarly to the previous conceptual tests (see in particular table 5.7 of the pre-test of the main study), table 5.13 shows, for each item of the post-test, the percent of given answers (A, B, C, D, E or null answer). Most misconceptions are successfully removed between the pre- and the post-test: their number among the most frequent incorrect answers falls from 10 (out of 16) in the pre-test to 5 (out of 19) in the post-test. Thus, after the instruction, the remaining misconceptions are:

- LPO3: the average speed on a return trip (same distance) is the average between the speed of go and the speed of back.
- LPO13: in a free falling motion with a change in the velocity's orientation, the acceleration is not constant (it is maximal at the beginning and at the end of the flight).
- LPO15: an object falling from a moving body goes backward (new with respect to pilot study).
- LPO16: if a body moves with constant velocity, the resultant force on it is not zero and has the same orientation as its velocity.
- LPO20: during an interaction, the more massive object exerts a more intense force than the less massive object.

Apart from the misconception related to LPO15 (discussed in section 5.3.1), which concerns the newly introduced item on the projectile motion, we noticed in the main study the same persistent misconceptions that we already found in the pilot study. Furthermore, we observed highly frequent answers, like answer B and C of LPO6 indicating that a large proportion of pupils cannot interpret a graph of position as a function of time [Beichner, 1994]. Furthermore, the response C of LPO9 is also frequently given, without being linked to a known misconception. The results of the individual items of the post-test compared to the pre-test and the underlying misconceptions will be further and deeper discussed in section 5.3.3.

Table 5.13: Occurrences of each answer of the post-test in percent. The correct answer is indicated with *, the most given is in bold characters, underlined when a misconception is present. The item number of the post-test (LPO) and of the pre-test (LPR) are indicated in the first two lines. The sum of the answers may be different from 100% because of rounding.

LPO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
LPR	**1**	**2**	**3**	**4**	**-**	**5**	**6**	**7**	**-**	**-**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
%A	5	7	**45**	34	11	6	20	**53***	6	15	9	8	27	2	**49**	**47**	29	31	18*
%B	5	1	16*	**62***	7	29	1	20	14	**58***	5	10	8	**47***	23	27*	9	3	6
%C	37	3	7	2	24	**30**	**48***	2	**37**	10	**76***	26	**37**	40	6	0	**44***	0	**68**
%D	**50***	23	5	2	**43***	28*	**5**	**1**	26*	14	4	**54***	8	8	23*	21	8	**1**	**5**
%E	4	**66***	26	0	13	5	25	24	26	3	6	2	20*	4	0	5	10	**65***	3
%0	1	1	0	0	2	2	2	0	1	0	0	0	0	0	0	0	0	1	1

Factor analysis

The construction of the conceptual post-test of the main study was motivated by the educational objectives explained in chapter 3 and the changes following the discussion on the results of the pilot study in section 4.6. As a consequence, the items included in the instrument target different chapters and, at the same time, they are correlated in different ways. Thus, as it was the case for the previous conceptual tests (the tests of the pilot study and the pre-test of the main study), when performing a factor analysis, we did not expect to find a clear separation between subscales. Moreover, we remind that the reduction of the multiple-choice results to dichotomous data greatly reduces the possible correlations between the underlying conceptions (see section 3.2.2). Similarly to what have been done for the conceptual pre-test (section 5.3.1) and with the same considerations of caution, we performed an exploratory factor analysis. We excluded items with too low r_{it} , decreasing α and/or having a $P < 0.2$ (LPO3, LPO16, LPO17 and LPO19). For this test, $N = 111$ and $k = 19$ items, leads to the fair subject-to-item ratio of about 6:1.

We expected between 2 and 4 main a priori conceptual dimensions for this restricted version of the post-test:

1) One-dimensional kinematics: LPO1, LPO2, LPO4, LPO5, LPO6, LPO7, LPO8, LPO9 and LPO10;
2) One-dimensional free fall (also belonging to one-dimensional kinematics): LPO11,

LPO12 and LPO13;
3) Projectile motion (also belonging to two-dimensional kinematics and free fall): LPO14 and LPO15;
4) 3rd Newton's law: LPO18.

where:

- Dimensions 1) and 2) can be merged in "one-dimensional kinematics, including $a = g$";
- Dimensions 2) and 3) can be merged in "free fall";
- Dimensions 1), 2) and 3) can be merged in "kinematics".

Moreover, LPO13, LPO14 and LPO15 involve free falling bodies with change in the velocity orientation.

The average of the 15 KMO indices of this restricted version of the test is 0.63, which is considered as acceptable for performing the factor analysis (see section 3.2.2). The scree-plot of the resulting eigenvalues is shown in figure 5.2, and the relative highest loadings and cumulative variances can be observed in table 5.14. For the interpretation of this plot, we refer to section 3.2.2 and proceeded as in the previous factor analysis. We observed six eigenvalues greater or close to 1 and two changes in the slope: after the second and after the fourth eigenvalue. We identified the most suitable factorial structure by comparing several oblique rotated solutions between two and six factors. The model that better fitted the data resulted to be the oblique rotated six factors solution, shown in table 5.15.

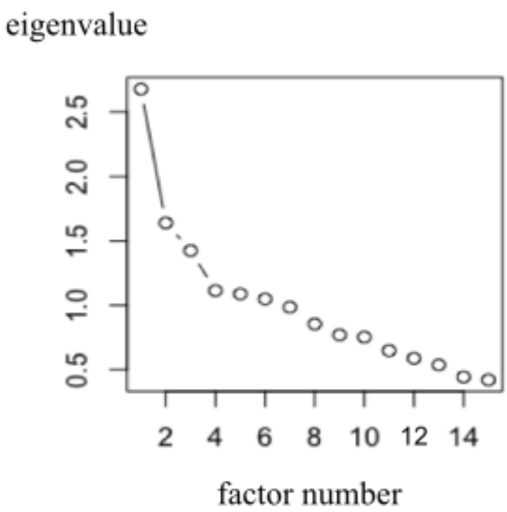


Figure 5.2: Scree-plot for the restricted version of the pre-test.

All the models between two and six dimensions showed the presence of the conceptual dimension "one-dimensional kinematics" as first factor, regrouping all the expected items except LPO4. Indeed, table 5.14 indicates that items LPO4 and LPO5 load together on one single factor (F3). These two items are linked because they originally constituted two questions about the same item (n. 1 of Mechanics Baseline Test [Hestenes *et al*. 1992]), therefore a coherence exists among the answers to the first and the second question, as the answer to the second (on the acceleration) depends on the answer to the first (velocity).

Table 5.14: Results of the factor analysis for the first six dominant factors, including their eigenvalues, the proportion of the modeled and cumulative variance.

Factor	Eigenvalue	Modeled variance	Cumulative variance
1	2.53	0.19	0.19
2	1.41	0.11	0.30
3	1.39	0.11	0.41
4	1.10	0.08	0.49
5	1.08	0.08	0.58
6	0.98	0.08	0.65

However, the factor analysis only takes into account "true or false" information, without considering the different conceptual (mis)understanding of the different "false" answers options. Thus, when answering LPO4 and LPO5, some pupils may have given the wrong answer to LPO4 (A instead of B, which is false just because of a detail in the graph interpretation), but have answered in a coherent way to LPO5. In the factor analysis those results are counted both as false, in the same way as a completely wrong or incoherent couple of answers for those two items (see sect. 3.2.2 for this methodological limitation of factor analysis).

Table 5.15: Loadings greater than 0.30 for the factors analysis with six dimensions, after applying an oblique rotation.

Item	F1	F2	F3	F4	F5	F6
LPO1	0.52					
LPO2	0.58					
LPO4		0.31	0.73			
LPO5	0.48		0.54			0.37
LPO6	0.41				0.43	
LPO7	0.43			0.30		
LPO8	0.55				0.31	
LPO9	0.35			0.32		
LPO10	0.61					
LPO11	0.39	0.48				
LPO12	0.30		0.31			
LPO13	0.34			0.41		
LPO14		0.35			0.65	
LPO15						0.70
LPO18	0.41	0.60				

We also noticed that LPO18 has the highest loading in F2 and dominates this factor, in agreement with the fact that it is the only item concerning dynamics. However, LPO18 also appears in the first dimension, and this can be explained because it is an application of the 3rd

Newton's law to a one-dimensional motion. Therefore, we can consider factor 1 as gathering all the items concerning the one-dimensional motion (kinematics and dynamics).

Despite the fact that items LPO14 and LPO15 relate to two-dimensional kinematics, they never appear in the same factor and almost each item seems to form a single factor (they have the highest loadings respectively in F5 and F6). This can be explained with the great difference of these two items' difficulties: LPO15 resulted to be more difficult because it also implies the understanding that the trajectory depends on the observer's frame of reference and that the uniform component of the horizontal motion keeps constant when free falling. Therefore LPO14 can be considered as only testing the projectile motion where the moving object and the observer are in the same reference frame, while LPO15 tests the projectile motion and the relativity of the trajectory.

We also performed the analysis excluding some particular items, to check the stability of the results:

- Excluding the items LPO14 and LPO15 at the time, both concerning "two-dimensional kinematics", or
- Excluding the item LPO18, the only one being about the Newton's laws, or
- Excluding LPO4: the only item dealing with "one-dimensional kinematics", which does not belong to the first factor.

However, none of these tests led to an association of LPO4 with the first dimension or the couple of items LPO14 and LPO15 to be merged in the same dimension. Therefore, the most suitable model presented in table 5.15 results to be quite robust. Finally, we noted that LPO13, belonging to the first factor, was also present with a higher loading on F4. LPO13 is the only item testing the understanding of acceleration in a uniformly accelerated linear motion (free fall) with a change of the orientation of velocity. As in the pilot study (chapter 4) and in the validation phase (chapter 3), this item was particularly difficult. This can be explained because LPO13 is specifically about the misconception confusing velocity and acceleration when they are opposite. In the pilot study[1], the difficulty index of this item did not exceed 0.10 both in the pre- and in the post-test, and the gain was zero for this item (see section 4.3.3). In the main study, P was 0.11 in the pre-test and 0.20 in the post-test: even though P remained low, there was a noticeable improvement, which we will discuss more in detail in section 5.3.3.

Table 5.16 presents the instrument analysis taking into account only the 12 items belonging to the first conceptual dimension, and the individual item analysis for the same sub-dimension can be found in the table A.11 of appendix 1. Comparing table 5.16 with tables 5.11 and 5.12, we observed that here the average values of the psychometric values improved slightly, and the values of individual items became satisfying to very good

[1] LPO13 corresponds to LPO14 in the pilot study (see chapter 4).

Table 5.16: Instrument analysis of the restricted version of the learning post-test, considering only the items of the first conceptual dimension (one dimensional kinematics). MCQ with 1 correct answer out of 5, k = 12 items and dichotomous scale level; N = 111; N_{TG} = 55; N_{CG} = 56.

Characteristics	**Average value (confidence interval)**	**range of values**
Item difficulty P	0,49(0,17)	[0,20 ; 0,76]
Item discrimination D	0,56(0,13)	[0,37 ; 0,75]
Item-test correlation r_{it}	0,45(0,08)	[0,35 ; 0,57]
Reliability (internal consistency) α	0,68(0,18)	
$\Delta\alpha_C = \alpha - \alpha^*$(after elimination)		[+0,013; +0,060]
Fergusons Delta δ	0,91	

5.3.3. Comparison of pre- and post- results

Tables 5.17 and 5.18 provide the psychometric characteristics of the full conceptual pre- and post-tests, respectively. As it was the case in the pilot study (see the section 4.3.3), the psychometric indices have improved in the post-test compared to the pre-test, as the instruction led to a better understanding, contributing to remove existing misconceptions to a large extent. In addition, contrarily to what was observed in the pilot study, the lower indices of difficulty in the values ranges increased too, which indicates an overall improvement of learning.

In order to better examine the evolution of the results of each item, table 5.19 compares the individual psychometric indices of items present in both the pre- and the post-test. Here we indicate the values of the psychometric parameters for the treatment group, the control group and total. The specific gain for each item is also indicated, in the last column.

Table 5.17: Characteristics average values of the full conceptual pre- and post-test.

Pre-test		N		α		δ	
Full test (k = 16)		116		0,37(0,34)		0,88	
Characteristic	**Average value (confidence interval) TG/CG/tot**			**Range of values TG/CG/tot**			
Difficulty P	0,32(0,14)	0,27(0,17)	0,29(0,15)	$0,02 \leq P_{TG} \leq 0,52$	$0,03 \leq P_{CG} \leq 0,53$	$0,03 \leq P \leq 0,52$	

Table 5.18: Characteristics average values of the full conceptual pre- and post-test.

Post-test		N		α		δ
Full test (k = 19)		111		0,59(0,22)		0,91
Characteristic	**Average value (confidence interval) TG/CG/tot**			**Range of values TG/CG/tot**		
Difficulty P	0,44(0,19)	0,43(0,19)	0,43(0,19)	$0,16 \leq P_{TG} \leq 0,76$	$0,14 \leq P_{CG} \leq 0,75$	$0,16 \leq P \leq 0,76$
Discrimination D	0,45(0,21)	0,38(0,25)	0,41(0,22)	$-0,01 \leq D_{TG} \leq 0,84$	$-0,04 \leq D_{CG} \leq 0,76$	$-0,02 \leq D \leq 0,77$
Item-test correlation r_{it}	0,37(0,14)	0,31(0,16)	0,34(0,14)	$0,03 \leq r_{itTG} \leq 0,62$	$0,04 \leq r_{itCG} \leq 0,60$	$0,05 \leq r_{it} \leq 0,54$

Table 5.19: Comparing the item parameters of the conceptual pre- and post-test. Difficulty indices P and gains are calculated for N = 111 (N_{TG} = 55 and N_{CG} = 56): only pupils who took both the pre- and the post-test. Discriminaton D, item-test correlation r_{it} and Cronbach's alpha α are calculated for N_{pre} = 116 and N_{post} = 111. In the 2nd and 3rd columns, the right answer is indicated with *, the most frequent is in bold characters, underlined when a misconception is present.

Item keywords (source)	% PRE A/B/C /D/E/0	% POST A/B/C /D/E/0	Analysis PRE(confidence interval)		Analysis POST(confidence interval)		Learning gain
LPO1 (LPR1): Visualize acceleration from trajectory in LM (FCI 20) CHRONOPHOTOGRAPHY	21 7 **51** 19* 2 1	5 5 37 **50*** 4 1	$P = 0{,}19(0{,}39)$ $D = 0{,}54$ $r_{it} = 0{,}47(0{,}28)$ $\alpha - \alpha^* = +0{,}072$	$P_{TG} = 0{,}27$ $P_{CG} = 0{,}12$	$P = 0{,}50(0{,}50)$ $D = 0{,}77$ $r_{it} = 0{,}53(0{,}27)$ $\alpha - \alpha^* = +0{,}044$	$P_{TG} = 0{,}49(0{,}50)$ $D_{TG} = 0{,}84$ $r_{itTG} = 0{,}62(0{,}33)$ $\alpha - \alpha^*_{TG} = +0{,}051$ $P_{CG} = 0{,}50(0{,}50)$ $D_{CG} = 0{,}59$ $r_{itCG} = 0{,}42(0{,}43)$ $\alpha - \alpha^*_{CG} = +0{,}033$	Gain for TG : 0,30 CG : 0,43 Tot: 0,38
LPO2 (LPR2) : Visualize velocity from trajectory in LM (FCI 19) CHRONOPHOTOGRAPHY	14 2 4 35 **43*** 2	7 1 3 23 **66*** 1	$P = 0{,}43(0{,}50)$ $D = 0{,}58$ $r_{it} = 0{,}44(0{,}30)$ $\alpha - \alpha^* = +0{,}055$	$P_{TG} = 0{,}43$ $P_{CG} = 0{,}43$	$P = 0{,}66(0{,}48)$ $D = 0{,}64$ $r_{it} = 0{,}49(0{,}28)$ $\alpha - \alpha^* = +0{,}038$	$P_{TG} = 0{,}65(0{,}48)$ $D_{TG} = 0{,}59$ $r_{itTG} = 0{,}45(0{,}43)$ $\alpha - \alpha^*_{TG} = +0{,}025$ $P_{CG} = 0{,}66(0{,}48)$ $D_{CG} = 0{,}74$ $r_{itCG} = 0{,}54(0{,}37)$ $\alpha - \alpha^*_{CG} = +0{,}062$	Gain for TG : 0,40 CG : 0,40 Tot: 0,40
LPO3 (LPR3) : Average speed and the average of two speeds (inspired by [Ree85] and [RS86])	**56** 16* 6 2 20 1	**45** 16* 7 5 26 0	$P = 0{,}16(0{,}36)$ $D = 0{,}46$ $r_{it} = 0{,}48(0{,}28)$ $\alpha - \alpha^* = +0{,}071$	$P_{TG} = 0{,}18$ $P_{CG} = 0{,}13$	$P = 0{,}16(0{,}37)$ $D = 0{,}26$ $r_{it} = 0{,}31(0{,}34)$ $\alpha - \alpha^* = +0{,}012$	$P_{TG} = 0{,}18(0{,}39)$ $D_{TG} = 0{,}31$ $r_{itTG} = 0{,}30(0{,}48)$ $\alpha - \alpha^*_{TG} = +0{,}009$ $P_{CG} = 0{,}14(0{,}35)$ $D_{CG} = 0{,}29$ $r_{itCG} = 0{,}32(0{,}46)$ $\alpha - \alpha^*_{CG} = +0{,}018$	Gain for TG : 0,00 CG : 0,01 Tot: 0,01
LPO4 (LPR4) : Velocity diagram from trajectory in LM (MBT 1) CHRONOPHOTOGRAPHY with choice of velocity diags	37 **39*** 3 9 10 3	34 **62*** 2 2 0 0	$P = 0{,}39(0{,}49)$ $D = 0{,}37$ $r_{it} = 0{,}31(0{,}33)$ $\alpha - \alpha^* = +0{,}006$	$P_{TG} = 0{,}43$ $P_{CG} = 0{,}35$	$P = 0{,}62(0{,}49)$ $D = 0{,}30$ $r_{it} = 0{,}28(0{,}34)$ $\alpha - \alpha^* = +0{,}002$	$P_{TG} = 0{,}64(0{,}49)$ $D_{TG} = 0{,}49$ $r_{itTG} = 0{,}36(0{,}47)$ $\alpha - \alpha^*_{TG} = +0{,}012$ $P_{CG} = 0{,}61(0{,}49)$ $D_{CG} = 0{,}27$ $r_{itCG} = 0{,}19(0{,}49)$ $\alpha - \alpha^*_{CG} = -0{,}014$	Gain for TG : 0,36 CG : 0,40 Tot: 0,38
LPO5: Acceleration diagram from trajectory in LM (MBT 1) CHRONOPHOTOGRAPHY with choice of acceleration diags	-	11 7 24 **43*** 13 2			$P = 0{,}43(0{,}50)$ $D = 0{,}58$ $r_{it} = 0{,}45(0{,}30)$ $\alpha - \alpha^* = +0{,}030$	$P_{TG} = 0{,}56(0{,}50)$ $D_{TG} = 0{,}57$ $r_{itTG} = 0{,}42(0{,}41)$ $\alpha - \alpha^*_{TG} = +0{,}019$ $P_{CG} = 0{,}30(0{,}46)$ $D_{CG} = 0{,}64$ $r_{itCG} = 0{,}52(0{,}38)$ $\alpha - \alpha^*_{CG} = +0{,}057$	-
LPO6 (LPR5) : Decreasing osition-to-time diagram (TUG 8) ("rolling down object")	16 18 **38** 17* 9 1	6 29 **30** 28* 5 2	$P = 0{,}17(0{,}38)$ $D = 0{,}40$ $r_{it} = 0{,}35(0{,}32)$ $\alpha - \alpha^* = +0{,}032$	$P_{TG} = 0{,}20$ $P_{CG} = 0{,}15$	$P = 0{,}28(0{,}45)$ $D = 0{,}46$ $r_{it} = 0{,}35(0{,}33)$ $\alpha - \alpha^* = +0{,}014$	$P_{TG} = 0{,}25(0{,}44)$ $D_{TG} = 0{,}52$ $r_{itTG} = 0{,}44(0{,}43)$ $\alpha - \alpha^*_{TG} = +0{,}024$ $P_{CG} = 0{,}30(0{,}46)$ $D_{CG} = 0{,}46$ $r_{itCG} = 0{,}25(0{,}48)$ $\alpha - \alpha^*_{CG} = 0{,}000$	Gain for TG : 0,07 CG : 0,18 Tot: 0,13

Table 5.18 continued

LPO7(LPR6) : Instant velocity as slope in the position to time diagram (MCT 30)	**29** 2 28* 1 **33** 7	20 1 **48*** 5 25 2	P = 0,28(0,45) D = 0,60 r_{it} = 0,48(0,28) α - α* = +0,074	P_{TG} = 0,34 P_{CG} = 0,23	P = 0,48(0,50) D = 0,51 r_{it} = 0,40(0,31) α - α* = +0,020	P_{TG} = 0,51(0,50) D_{TG} = 0,64 r_{itTG} = 0,45(0,43) α - $α*_{TG}$ = +0,025 P_{CG} = 0,45(0,50) D_{CG} = 0,33 r_{itCG} = 0,32(0,47) α - $α*_{CG}$ = +0,012	Gain for TG : 0,26 CG : 0,28 Tot: 0,27
LPO8(LPR7) : Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified)	19* 10 0 4 **65** 2	**53*** 20 2 **1** 24 0	P = 0,19(0,38) D = 0,60 r_{it} = 0,48(0,28) α - α* = +0,082	P_{TG} = 0,29 P_{CG} = 0,10	P = 0,53(0,50) D = 0,68 r_{it} = 0,49(0,28) α - α* = +0,038	P_{TG} = 0,49(0,50) D_{TG} = 0,66 r_{itTG} = 0,52(0,39) α - $α*_{TG}$ = +0,035 P_{CG} = 0,57(0,50) D_{CG} = 0,74 r_{itCG} = 0,46(0,40) α - $α*_{CG}$ = +0,044	Gain for TG : 0,29 CG : 0,52 Tot: 0,42
LPO9: Time diagram from velocity diagram (created)	-	6 14 **37** 26* 26 1			P = 0,26(0,44) D = 0,42 r_{it} = 0,34(0,33) α – α* = +0,013	P_{TG} = 0,31(0,47) D_{TG} = 0,63 r_{itTG} = 0,49(0,41) α – $α*_{TG}$ = +0,030 P_{CG} = 0,21(0,41) D_{CG} = 0,06 r_{itCG} = 0,14(0,50) α – $α*_{CG}$ = -0,014	-
LPO10: Acceleration diagram from velocity diagram (TUG 14)	-	15 **58*** 10 14 3 0			P = 0,58(0,50) D = 0,68 r_{it} = 0,54(0,27) α - α* = +0,047	P_{TG} = 0,58(0,50) D_{TG} = 0,59 r_{itTG} = 0,47(0,42) α - $α*_{TG}$ = +0,027 P_{CG} = 0,57(0,50) D_{CG} = 0,76 r_{itCG} = 0,62(0,33) α - $α*_{CG}$ = +0,083	-
LPO11(LPR8) : Kinematics of free falling different bodies – covered distance (FCI 1 – removed all the « about », no friction at all)	10 6 **50*** 28 6 0	9 5 **76*** 4 6 0	P = 0,50(0,50) D = 0,76 r_{it} = 0,55(0,26) α - α* = +0,102	P_{TG} = 0,50 P_{CG} = 0,50	P = 0,76(0,43) D = 0,48 r_{it} = 0,41(0,31) α - α* = +0,024	P_{TG} = 0,76(0,43) D_{TG} = 0,47 r_{itTG} = 0,37(0,46) α - $α*_{TG}$ = 0,015 P_{CG} = 0,75(0,44) D_{CG} = 0,44 r_{itCG} = 0,46(0,41) α - $α*_{CG}$ = +0,043	Gain for TG : 0,53 CG : 0,50 Tot: 0,51
LPO12(LPR9) : Quadratic relationship between distance and time in free fall : UALM (created from FCI 1)	8 4 36 **48*** 3 0	8 10 26 **54*** 2 0	P = 0,48(0,50) D = 0,04 r_{it} = 0,03(0,36) α - α* = -0,086	P_{TG} = 0,52 P_{CG} = 0,45	P = 0,54(0,50) D = 0,40 r_{it} = 0,32(0,33) α - α* = +0,006	P_{TG} = 0,56(0,50) D_{TG} = 0,36 r_{itTG} = 0,32(0,48) α - $α*_{TG}$ = +0,005 P_{CG} = 0,52(0,50) D_{CG} = 0,49 r_{itCG} = 0,31(0,46) α – $α*_{CG}$ = +0,009	Gain for TG : 0,09 CG : 0,12 Tot: 0,11
LPO13(LPR10) : *g* during a free fall with change in velocity's orientation *	17 18 **47** 7 11* 0	27 8 **37** 8 20 * 0	P = 0,11(0,32) D = 0,15 r_{it} = 0,14(0,36) α – α* = -0,011	P_{TG} = 0,16 P_{CG} = 0,07	P = 0,20(0,40) D = 0,30 r_{it} = 0,30(0,34) α – α* = +0,010	P_{TG} = 0,16(0,37) D_{TG} = 0,38 r_{itTG} = 0,41(0,45) α – $α*_{TG}$ = +0,020 P_{CG} = 0,23(0,43) D_{CG} = 0,21 r_{itCG} = 0,20(0,49) α - $α*_{CG}$ = -0,004	Gain for TG : 0,00 CG : 0,18 Tot: 0,10

Table 5.18 continued

LPO14(LPR11) : (FCI11) Projectile motion : cannon bullet	1 **46*** 38 9 5 1	2 **47*** 40 8 4 0	P = 0,46(0,50) D = 0,34 r_{it} = 0,28(0,34) α - α* = -0,009	P_{TG} = 0,41	P = 0,47(0,50) D = 0,31 r_{it} = 0,30(0,34) α - α* = +0,004	P_{TG} = 0,49(0,50) D_{TG} = 0,40 r_{itTG} = 0,35(0,47) α - $α*_{TG}$ = +0,009	Gain for TG : 0,14 CG : -0,11 Tot: 0,02
				P_{CG} = 0,50		P_{CG} = 0,45(0,50) D_{CG} = 0,10 r_{itCG} = 0,25(0,48) α - $α*_{CG}$ = -0,004	
LPO15 (LPR12) : (FCI 14) Projectile motion: object falling from an airplane	**56** 35 6 3* 0 0	**49** 23 6 23* 0 0	P = 0,03(0,16) D = 0,07 r_{it} = 0,13(0,36) α - α* = +0,002	P_{TG} = 0,02	P = 0,23(0,42) D = 0,30 r_{it} = 0,24(35) α - α* = +0,001	P_{TG} = 0,22(0,42) D_{TG} = 0,25 r_{itTG} = 0,25(0,50) α - $α*_{TG}$ = +0,002	Gain for TG : 0,20 CG : 0,21 Tot: 0,20
				P_{CG} = 0,03		P_{CG} = 0,23(0,43) D_{CG} = 0,27 r_{itCG} = 0,23(0,48) α - $α*_{CG}$ = +0,001	
LPO16(LPR13) : 1st Newton's law and gravitation – lift at constant velocity (FCI 17, answer E modified)	**37** 22* 2 30 8 0	**47** 27* 0 21 5 0	P = 0,22(0,42) D = 0,01 r_{it} = 0,05(0,36) α – α* = -0,055	P_{TG} = 0,23	P = 0,27(0,45) D = 0,26 r_{it} = 0,21(0,36) α – α* = -0,005	P_{TG} = 0,29(0,46) D_{TG} = 0,24 r_{itTG} = 0,23(0,51) α – $α*_{TG}$ = -0,003	Gain for TG : 0,08 CG : 0,04 Tot: 0,06
				P_{CG} = 0,22		P_{CG} = 0,25(0,44) D_{CG} = 0,33 r_{itCG} = 0,20(0,49) α – $α*_{CG}$ = -0,007	
LPO17(LPR14) : 2nd Newton's law – acceleration is inversely proportional to the mass (created – acceleration of two different masses with the same net force)	17 20 **52*** 3 6 1	29 9 **44*** 8 10 0	P = 0,52(0,50) D = 0,22 r_{it} = 0,13(0,36) α - α* = -0,057	P_{TG} = 0,50	P = 0,44(0,50) D = -0,01 r_{it} = 0,05(0,37) α - α* = -0,035	P_{TG} = 0,33(0,47) D_{TG} = 0,05 r_{itTG} = 0,04(0,53) α - $α*_{TG}$ = -0,025	Gain for TG : -0,35 CG : 0,04 Tot: -0,16
				P_{CG} = 0,53		P_{CG} = 0,55(0,50) D_{CG} = -0,04 r_{itCG} = 0,07(0,51) α – $α*_{CG}$ = -0,038	
LPO18 (LPR15): 3rd Newton's law – frontal collision between a big truck and a small car (FCI 14)	**56** 2 3 **3** 34* 2	31 3 0 **1** **65*** 1	P = 0,34(0,48) D = 0,46 r_{it} = 0,36(0,32) α - α* = +0,028	P_{TG} = 0,39	P = 0,65(0,48) D = 0,51 r_{it} = 0,42(0,31) α - α* = +0,025	P_{TG} = 0,62(0,49) D_{TG} = 0,47 r_{itTG} = 0,39(0,45) α - $α*_{TG}$ = +0,016	Gain for TG : 0,37 CG : 0,54 Tot: 0,46
				P_{CG} = 0,30		P_{CG} = 0,68(0,47) D_{CG} = 0,47 r_{itCG} = 0,45(0,41) α - $α*_{CG}$ = +0,041	
LPO19 (LPR16): 3rd Newton's law – accelerated system in contact (FCI 15, answer D modified)	21* 6 **62** 10 0 1	18* 6 **68** 5 3 1	P = 0,21(0,41) D = 0,23 r_{it} = 0,23(0,35) α - α* = -0,006	P_{TG} = 0,23	P = 0,18(0,39) D = -0,02 r_{it} = 0,06(0,37) α - α* = -0,019	P_{TG} = 0,16(0,37) D_{TG} = -0,001 r_{itTG} = 0,08(0,53) α - $α*_{TG}$ = -0,011	Gain for TG : -0,09 CG : 0,02 Tot: -0,03
				P_{CG} = 0,18		P_{CG} = 0,20(0,40) D_{CG} = 0,00 r_{itCG} = 0,03(0,51) α - $α*_{CG}$ = -0,028	

Referring to table 5.19, we first some noteworthy results concerning pre-post comparing of the results of individual items:

- LPO1: The misconception confusing velocity and acceleration (answer C) was present in the pre-test and diminished in the post-test, where the most frequent answer was the correct one (D). This item involves the chronophotography of the motion, similar to the representation given by the apps of video analysis. Then pupils in the treatment group might have been expected to answer this question better than pupils on the treatment group. However in the main study the control group had a greater gain than pupils on the treatment group. This indicates that the treatment did not improve the understanding of the interpretation of the motion's chronophotography.

- LPO2: Despite the fact that the majority of pupils gave the correct answer at the beginning and at the end of the study (answer D: the speed is the same at an instant between 3 and 4), a significant proportion of pupils confused velocity and position. They answered that the velocity is the same at time 2 (answer B) or at time 5 (answer C). Nevertheless, the proportion of wrong answers decreased in the post-test. Remind that in the pilot study the treatment group performed better than the control group (see section 4.3.3 and in particular the table 4.15), as one could expect for this kind of item involving the chronophotography representation of the motion. However, this difference did not turn out to be significant after ANCOVA and multiple testing analysis (see section 4.5.4 and, in particular, table 4.23). Contrarily to the result of the pilot study, in the main study the gain was the same for both groups.

- LPO3: As we analyzed during the construction of the conceptual test (section 3.5) and in the pilot study (section 4.3.3) this question tests a classic misconception, relied to the "availability heuristic" (see section 2.3.1 and [Reed *et al*., 1985 and 1986]). Before and after the instruction, the same proportion of pupils gave the correct answer (B: the average speed on a return trip is lower than the mathematical average between the speed on the outward journey and the return). This low proportion (16%) is comparable to the results given by Reed *et al*. (1985). If we only take into account the percent of correct answers, no progression is present between the pre-test and the post-test. However, looking at the evolution the distribution of wrong answers, we observe that while in the pre-test 56% of pupils asserted that the speed is equal to the arithmetic average between the speed to go and the one to return (A), this proportion decreased by more than 10% in the post-test. Moreover, the number of answers stating: "there is not enough information to answer the question" (E) increased. Although from a strictly dichotomist point of view ("true or false") no progression was present, a conceptual change could take place that could indeed be analyzed in more depth. Finally, contrary to what we observed in the pilot study, where the treatment group performed worse than the control group (see section 4.3.3), in the main study there was no difference in gain between the two groups. This suggests that the changes made in the order of MDETs activities (see section 4.6.1) resolved a possible cognitive overload for pupils of the treatment group.

- As discussed in section 5.3.2 on factor analysis, LPO4 and LPO5 are linked because they question the graph of $v(t)$ (LPO4) and $a(t)$ (LPO5) for the same chronophotography. They both belong to item 1 in the MBT [Hestenes *et al*., 1992]. LPO4 was already in the pre-test and, for this item, a comparable gain was verified in both groups. For LPO4, in addition to the gain because a part of the pupils who did not answer correctly in the pre-test gave the good answer in the post-test, there was a part of the pupils that gave an answer completely wrong (C, D or E) in the pre-test, and changed for a “not so wrong” answer in the post-test. Indeed, answers A and B are very close: they only differ in the slope of the graphs, which is correct only for answer B. In other words, about 25% of pupils that gave a completely wrong answer in the pre-test (C, D or E) changed for a “better” answer in the post-test (A or B), even though answer A was considered as wrong. LPO5 was only present in the post-test, for this item the ratio of right answers for treatment group is almost double that for the control group (56% against 30%) whereas the control group clearly outperformed the treatment group in the pre-test.

- LPO17: This item particularly malfunctioned, not only because the percent of correct answers decreased, but also because the proportion of the wrong responses associating the same force with the same velocity (instead of acceleration) increased (answer A). This is particularly the case for the treatment group, which had a negative gain of -35%, while the control group did not show any change. For this item, the discrimination index D and item-test correlation r_{it} are low, and it decreases the alpha. The fact that many pupils associated the same net force with the same velocity may come from the correction to the misconception that “different masses free falling from the same height have different acceleration, then hit the ground with different velocities”. This misconception is more widespread among younger pupils, while among high school pupils this is less the case. As the results of LPO11 show, here pupils know that different masses free falling from the same height hit the ground with the same velocities. Thus, pupils who gave the answer A may have made a wrong application of the “piece of knowledge” valid in the case of the free fall to the case of equal net forces. In this case they did not understand that the same acceleration of the free falling bodies is explained by the fact that the gravitational forces acting on different masses are different, because they are proportional to the (gravitational) mass. This proportionality simplifies when dividing by the (inertial) mass.

Secondly, we carry out overall comments on the other items:

- LPO6: The correct answer (D) for the interpretation of the graph of *x(t)* is in competition with two misconceptions. The first concerns the confusion between time diagram and trajectory: this is present in answer A ("the object first rolls on a flat surface, then it rolls down a slope" rather than "the object is motionless then backs up") or in answer B ("the object does not move and then rolls down a slope"). The second misconception concerns the confusion between the graph of *x(t)* with that of *v(t)* (answer C: "the object goes at constant velocity then it slows down", rather than "the object is motionless then backs up"). These misconceptions, and in particular the one linked to response C, persisted in the post-test. Although the correct answers (D) increased by 11% and the proportion of answers A and C decreased overall, answer C remained the most frequent. This highlights the strong persistence of the misconception in question. Note that the gain of this item is greater for the control group (18%) than for the treatment group (7%).

- LPO7: The answers associating the same velocity to points with the same position but opposite velocities (points A and C in answer (A) and points D and F in answer (E)) are clearly in the majority for the pre-test. They are still present in the post-test, but in the minority. Note that even adding the percent of responses A and E in the post-test (20% + 25%) we obtain a smaller proportion with respect to the correct answer (48%, answer C).

- LPO8: The responses showing a confusion between the graphs of *x(t)* and *a(t)* for a uniform linear motion (answer E) decreased sharply between the pre-test and the post-test. Most choices were in favor of the correct answer (53%, answer A) but also of the answer showing a confusion between the graph *x(t)* and *v(t)*, even if only marginally (20%). The gain was greater for the control group than for the treatment group (respectively 52% versus 29%).

- LPO10 was not in the pre-test and did not reveal particular misconceptions. About 60% of students gave the correct answer (B) by associating the correct graph of *a(t)* with that of *v(t),* composed by three motions: first with $a < 0$, then with $a = 0$ and eventually with $a > 0$. About 10% of the pupils associated the same pattern for *a(t)* and for *v(t)* (responses A and C) or did not recognize a negative acceleration in the first part of the movement (response D). The results were similar for treatment group and control group.

- LPO11 was a fairly easy item, also in the pre-test ($P_{pretest} = 0{,}5$), testing a classic misconception (answer C: “the heavier body reaches in first on the ground, even without frictions”). There was still a general gain for this item and the misconception almost disappeared in the post-test, passing from 28% to 4% of the answers. The results were comparable for treatment group and control group. We remark that in the pilot study we had to exclude this item because of especially bad psychometrics parameters.

- LPO13: Similarly to the previous two items, this question concerns the free fall. However here the motion has not a zero initial velocity (the initial velocity is upward, opposite to the acceleration). When asked: “when is the acceleration maximum?” most pupils confused acceleration and speed (answer A) or acceleration and velocity (answers B or C). This misconception decreased in the post-test, and the correct answers (E) passed from 11% to 20%. However, it was found to be persistent in most students. Note the difference between the treatment group, which had zero gain (P = 0,16 in the pre-test and in the post-test), and the control group, where the difficulty index passed from 0,07 to 0,23, corresponding to a gain of 18%. We remind that during the pilot study, both treatment group and control group had zero gain and the index P was below the 0,1 for this item.

- LPO14 and LPO15 are both questions on the trajectory of a projectile motion. LPO15 is more difficult, because the trajectory is requested for an observer who is not in the same reference frame as the body launching the projectile (the airplane). For LPO15, we observe a high proportion (35% in the pre-test) of the responses referring to the motion seen from the aircraft's frame rather than from the observer on the ground. This proportion decreased in the post-test (up to 23%) and the correct answers increased from 3% to 23%. The gain was 20%, and almost the same for treatment group and control group. LPO14 was simpler and the most given answer was the correct one, as it was already the case in the pre-test (46%). However, for this item we notice a gain of only 14% for the control group and a negative gain for the treatment group (-11%).

- LPO16: Despite the fact that the number of correct answers increased slightly, from 22% in the pre-test to 27% in the post-test (answer B: "the intensity of the cable force equal to that of the force of gravity"), there was also a consolidation of the misconception underlying the idea that a non-vanishing net force is necessary to keep an object at a constant velocity (answer A: "the intensity of the force of the cable is greater than the intensity of the force of gravity") passing from 37% to 47%. Moreover, there was a decrease in the number of pupils who answered that "the intensity of the force of the cable is greater than the intensity of the force of gravity and of the air" (answer D). This suggests that, in the post-test, pupils could better understand the statement "all friction is negligible". The gain was small, between 4% and 8% and this item shows a low r_{it}. In this case, the misconception associating a resulting non-zero resultant force with a motion at constant velocity remained strongly rooted.

- LPO18 is on Newton's 3rd law in the case of a frontal collision between two objects of different masses. The answers concerning the misconception believing that the more massive body acts with a greater force (response A) decreased, passing from 56% in the pre-test to 31% in the post-test. The gain was 37% for the treatment group and 54% for the control group.

We finally point out some remaining open questions:

- LPO9 asks to associate the graph of *x(t)* with that of *v(t)* in a composition of constant velocity and constant acceleration motions ($a > 0$ between t_0 and t_1, $a < 0$ between t_1 and t_2 and $a = 0$ after t_2). This item was not in the pre-test. The response C is false within the three time intervals; it was however the most frequently given answer, with a proportion of 37%. We could not find a satisfactory interpretation of this on the basis of the available information. The responses D and E differ only after t_2: the response D (26%) is correct because there is a straight line associated with uniform linear motion (v = constant) after t_2, while in the response E (26%) the parabola (with $a < 0$) maintains a constant concavity then a constant acceleration. As for LPO5, the treatment group (P = 0,31) obtained better results than the control group (P = 0,21) for this item.

- LPO12: This item tests the quadratic relationship between the covered distance and the time in the free fall. In the post-test the results were better than in the pre-test and the proportion of pupils who attributed a linear relation between x and t decreased (answer C). However, there was a small increase in the percentage of pupils who replied that "two marbles thrown from two different heights hit the ground at the same time" (answer B).

Although this can be explained by a wrong application of the "piece of knowledge" for the case of free fall from the same height, we have no clear explanation for this increase.

- LPO19: As for the item LPO18, here the Newton's 3rd law is tested, but in the case of two bodies in contact and accelerating. This item was difficult because of the confusion between 2nd law and 3rd law of Newton, which lead pupils to conclude that the force of the car on the truck (which is in the direction of acceleration) is greater than the force of the truck on the car, "otherwise the system car+truck would not accelerate" (answer C). In the post-test, this misconception was accentuated, while the percentage of correct answers (A) slightly decreased. Note that discrimination and item-test correlation r_{it} is low and this item decreases the alpha. Nevertheless, we could not find satisfactory explanations for the increasing of the frequency of the answers linked to this misconception.

In general, the evolution between the pre and post results of several items was not the same for the test group and the control group. In section 6 dedicated to ANCOVA analysis, we will examine whether such differences are significant.

5.3.4. Learning gain

We will see in section 5.5 on ANCOVA analysis that in the main study there have been significant variations on affective and learning outputs depending on the teacher. In particular, we recall that the group 3 made the post-tests on-line (see the section 5.1). These different conditions may have had an effect on the results of pupils of the group 3 and this is the reason why in section 5.5 we will carry out the ANCOVA analysis separately for the groups 1, 2, 3 and 4, more than for the whole sample. Here we calculated the learning gain (see section 3.2) for the each group and for the whole sample.

The learning gains (see section 3.2) for individual groups 1, 2, 3 and 4 (see table 3.2) and for the whole sample are shown in table 5.20. The difficulty index P for the pre-test, for the full post-test (19 items) and for the post-test taking only into account items present in the pre-test (16 items) with relative standard deviations are also reported. Moreover, the pre/post Cohen's d coefficients are given. We observe that, whether 16 or 19 items are considered for the post-test, the gains of the different groups remain quite stable. On the other hand, significant variations exist between groups of different teachers. In particular the low P and the small gain of the students of group 3 stands out. Teacher 3 affirmed that he noticed the initial learning difficulties of this group and in particular of control class-group CG3 (see table 3.2), mainly because of lack of personal work. For this reason, a ritual of weekly formative evaluations was set up in CG3, with the aim to motivate pupils to make more efforts. This is consistent with the fact that, although the results of the post-test are relatively low and similar for both CG3 and TG3, we see in table 5.20 that pupils of the control class-group 3 obtained lower results than the treatment class-group 3 in the pre-test. Thus, their learning gain was higher and the size effect twice as large (the Cohen's d passed from 0.6 to 1.2). We will come back and further analyze the question of the difference in learning results between groups 1, 2, 3 and 4 in section 5.5 on the ANCOVA analysis and the subsequent discussion (chapter 6).

Table 5.20: Average difficulties with relative standard deviations, Cohen's d and the average learning gains for the different groups, including treatment groups and control groups. The gains are given taking into account only the items present both in the pre- and in the post-test (16 to 16 items) and for the full tests (16 to 19 items).

Group	N	<P> PRE 16 items (SD)	<P> POST 16 items (SD)	<P> POST 19 items (SD)	Cohen's d 16 ->19	Gain of av. 16 -> 16	Gain of av. 16 -> 19	Av. of gain 16 -> 16	Av. of gain 16 -> 19
TG1	13	0,36(,17)	0,47(,17)	0,47(,17)	0,7	18%	17%	19%	18%
CG1	14	0,24(,11)	0,52(,11)	0,50(,11)	2,3	37%	35%	36%	34%
Tot G1	27	0,28(,15)	0,50(,14)	0,49(,14)	1,4	29%	27%	28%	26%
TG2	14	0,28(,08)	0,40(,17)	0,42(,17)	1,1	17%	20%	15%	18%
CG2	12	0,26(,08)	0,47(,14)	0,44(,14)	1,4	28%	25%	28%	25%
Tot G2	26	0,27(,08)	0,43(,14)	0,43(,16)	1,3	22%	22%	21%	22%
TG3	13	0,28(,10)	0,31(,18)	0,32(,18)	0,3	4,7%	5,7%	5%	6%
CG3	14	0,21(,10)	0,32(,14)	0,31(,14)	0,8	14%	12%	13%	11%
Tot G3	27	0,25(,11)	0,32(,16)	0,32(,16)	0,5	9,5%	9,3%	9%	9%
TG4	15	0,35(,15)	0,51(,13)	0,52(,13)	1,2	25%	27%	23%	25%
CG4	16	0,37(,14)	0,46(,14)	0,46(,14)	0,6	15%	15%	14%	14%
Tot G4	31	0,36(,14)	0,48(,13)	0,49(,14)	0,9	20%	21%	18%	19%
TG	55	0,31(,13)	0,43(,17)	0,44(,17)	0,9	16%	17%	15%	17%
CG	56	0,27(,13)	0,44(,15)	0,43(,15)	1,1	23%	21%	22%	21%
Tot	111	0,29(,13)	0,43(,16)	0,43(,16)	1,0	20%	20%	19%	19%

5.4. Characteristics of covariates

5.4.1 Affective test

The instrument analysis and the mean values of each covariate for the treatment and the control group is reported in table 5.21. The item analysis for these variables can be found in table A.12 of appendix 1. Referring to the values ranges of section 3.2, we observe overall satisfactory to good results. The mean values (in a 6-level scale) were higher than in the pilot study (see tables 4.17 and 4.18) just as the values of α, and this despite the lower number of items. Indeed, contrarily to the pilot study, the item of the perceived self-*involvement* scale INV5 showed good results here. Note also the sharp increase in the α for the *teacher assessment* (AT) dimension, which went from 0.74 in the pilot study to 0.83 in the main study. Thus, those results indicate that the modifications made taking into account the results of pilot study were consistent (see section 4.6.3).

Table 5.21: Instrument analysis of the affective control variables of the main study. The means for the treatment and the control group are also given. N = 111; N_{TG} = 55; N_{CG} = 56; 6-level items 1 = completely disagree, 6 = completely agree.

Variable	Scale characteristics	Average value (confidence interval)		Range of values
Curiosity trait	Mean	Tot: 4,62(0,71)		[3,79 ; 5,22]
		TG: 4,72 (0,73)	CG: 4,53(0,69)	
	Item-test correlation r_{it}	0,73(0,17)		[0,66 ; 0,76]
	Reliability α	0,77(0,13)		-
Cognitive load experiment	Mean	Tot: 4,06(0,82)		[3,40 ; 4,68]
		TG: 4,10(0,87)	CG: 4,03(0,78)	
	Item-test correlation r_{it}	0,65(0,24)		[0,51 ; 0,75]
	Reliability α	0,66(0,20)		-
Cognitive activation experiment	Mean	Tot: 4,16(0,73)		[3,84 ; 4,59]
		TG: 4,07(0,73)	CG: 4,24(0,74)	
	Item-test correlation r_{it}	0,62(0,23)		[0,51 ; 0,75]
	Reliability α	0,59(0,24)		-
Involvement	Mean	Tot: 3,60(0,95)		[3,19 ; 3,99]
		TG: 3,56(0,93)	CG: 3,63(0,99)	
	Item-test correlation r_{it}	0,71(0,19)		[0,66 ; 0,75]
	Reliability α	0,75(0,15)		-
Self-concept Smartphones	Mean	Tot: 4,48(0,88)		[4,19 ; 4,79]
		TG: 4,40(0,84)	CG: 4,55(0,92)	
	Item-test correlation r_{it}	0,67(0,21)		[0,43 ; 0,78]
	Reliability α	0,69(0,18)		-
Cognitive load apps Smartphone	Mean	Only TG: 4,35(1,15)		[3,78 ; 4,76]
	Item-test correlation r_{it}	0,82(0,28)		[0,73 ; 0,92]
	Reliability α	0,88(0,10)		-
Teacher assessment	Mean	Tot: 4,91(0,43)		[4,46 ; 5,24]
		TG: 4,88(0,56)	CG: 4,93(0,27)	
	Item-test correlation r_{it}	0,77(0,11)		[0,59 ; 0,85]
	Reliability (internal consistency) α	0,83(0,10)		-

It should first be noted that the dimensions *cognitive load during the experiments* and *cognitive activation during the experiments* had lower alpha values than the other covariates, while remaining acceptable. However, as in the pilot study, these values did not call into question the internal consistency of the test (see section 4.4.5)

As in the affective tests of the pilot study, the dimensions *cognitive load* and *cognitive activation during the experiments* stayed around $\alpha \approx 0.6$, and yet we see in table A.12 that they do not consist of items with particularly unsatisfying psychometric parameters. In this regard, we recall the considerations already made in the section 4.4.1: although the α is considered as an important indicator for the consistency of a test, it should always be considered with all the other parameters and here the item-test correlations r_{it} are good for all items of those dimensions. Indeed, Sijtsma (2009) showed that, taken individually, the α is not a measure of internal consistency or of the degree of unidimensionality of a test and its unique value can lead to underestimating the reliability (see also [Lord & Novick, 1968; Zimmermann 1972]). Note also in table 5.21, that the mean values are comparable for the treatment group and for the control group for all these variables, and in particular for the *cognitive load during the experiment*. This result, which was already observed in the pilot study, is important because it indicates that during the activities with the MDETs, the pupils did not perceive a cognitive overload.

5.4.2 Spatial abilities

The averages and the range of values of the psychometrics characteristics for the *spatial abilities* test are presented in the table 5.22, and the individual item analysis of this test is available in the table A.13 of the appendix 1. This is the same test given in the pilot study, ("Paper Folding" test from [Elkstrom *et al.*, 1976], pp. 176, validated from previous research) and it showed again satisfactory results (see section 4.4.2).

Table 5.22: Instrument analysis of the spatial abilities test in pilot study, k = 20 items, one right answer on five. N = 116.

Characteristics	Average value (confidence interval)	range of values
Item difficulty P	0,57(0,28)	[0,10 ; 0,98]
Item discrimination D	0,50(0,22)	[0,07 ; 0,91]
Item-test correlation r_{it}	0,42(0,13)	[0,20 ; 0,68]
Reliability (internal consistency), α	0,78(0,12)	
$\Delta\alpha_C = \alpha - \alpha^*$ (after elimination of the item in question)		[-0,003; +0,026]
Fergusons Delta δ	0,92	

Note that here, as in the pilot study (see section 4.4.2), some items have a low discrimination index (D < 0,20) slightly decreasing the value of α, due to their particularly high difficulty index (P > 0,95). In the main study these are the two items at the beginning of each series of 10 of the test, and their easiness is explained by their initial place in the test, with the aim to familiarize pupils with this kind of visual-spatial questions, which they have never done before.

Lastly, table 5.23 shows, for each item of the same test, the number of the given answers (A, B, C, D, E or null answer). As it was the case the spatial abilities test (table 5.41) in the pilot study, here the correct answer was always the most frequent also for the items whose difficulty is lower than about 0.5 (except for item 9 where most pupils did not answered). On the contrary, in the conceptual tests (see tables 5.15 and 5.20) many incorrect answers showed particularly high occurrences, corresponding to misconceptions.

Table 5.23: Occurrences of each answer. The right answer is indicated with *, the most frequent is in bold characters. The item number of the test (SA) is indicated in the first line.

SA	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	**96***	16	2	20	17	0	**28***	3	3	3	0	2	**93***	2	3	**81***	2	5	8	16
B	0	10	**70***	2	**60***	0	16	5	16	3	1	**85***	2	9	**38***	6	14	12	5	12
C	1	6	7	4	6	1	5	**58***	5	3	**99***	9	4	3	8	1	0	24	6	14*
D	0	**66***	0	**60***	4	1	13	0	11	12	0	1	0	3	3	0	9	17*	**54***	11
E	4	1	8	1	1	**84***	8	1	10*	**33***	0	3	1	**79***	32	8	**68***	5	3	6
0	0	3	14	14	12	15	31	33	**56**	47	1	1	1	6	17	5	9	**37**	24	**42**

5.5. ANCOVA analysis

5.5.1. Implementation

The ANCOVA analysis (see section 3.2) was carried out by collecting in the same electronic annexed file (Data_ANCOVA_MS.txt) all the data corresponding to the variables in the table A.2 of appendix 1, for the 111 pupils participating in the whole semester of the main study. As it was the case for the pilot study, the schools provided the grades of mathematics, physics and French at the beginning and at the end of the semester, and the specific option discipline chosen by the pupil. The ANCOVA analysis was conceived in several steps using R studio [R Core Team, 2014] on the basis of the same approach explained in section 4.5.1 of the pilot study.

In the next sections, we present the significant results obtained on the whole sample participating in the main study (N = 111, N_{CG} = 56, N_{TG} = 55), before analyzing the groups 1, 2, 3 and 4 separately. We will skip the description of all details of steps (1), (2) and (3) described in section 4.5.1 and directly provide the significant results of the main analysis (step (4)), the detailed analysis being available in appendix 4.

5.5.2. Effects on global affective outcomes

We performed the procedure as explained in the previous paragraph and found the following results:

- No effect of treatment (i.e. the use of MDETs) was found on all the affective dependent variables, i.e. on *self-concept*, *curiosity state*, *interest* or *relation to reality* at the end of the semester.

- However, an effect of the variable *group* (1, 2, 3, 4 corresponding to each participating teacher) and *teacher assessment* was found on *interest* in the post-test. With *group* as independent variable, the influence of the following covariates was tested: prior *interest*, *curiosity state*, *curiosity trait*, *involvement*, *cognitive load* and *cognitive activation during the experiments* (we did not consider *teacher assessment* as a covariate, too close and correlated with *group*). The analysis showed a surviving effect of the independent variable, after removing the effect of all the covariates. Although the effect of *involvement* resulted to be the most important and, in a less strong way, the impact of *cognitive activation during the experiments* was surviving as well, the effect of the variable *group* on *post interest* remained, yet with a small effect size of η_t^2 = 0.04 (see section 3.2 for the values of η_t^2). Figure 5.3 shows the histograms representing the mean values of *post interest* and the significant covariates for the four groups. We observe a significant difference between the lowest mean value of post *interest* (2,72 ± 0,77) and the highest one (3,59 ± 0,94). Although less pronounced, this difference is also visible for some of the covariates taken into consideration.

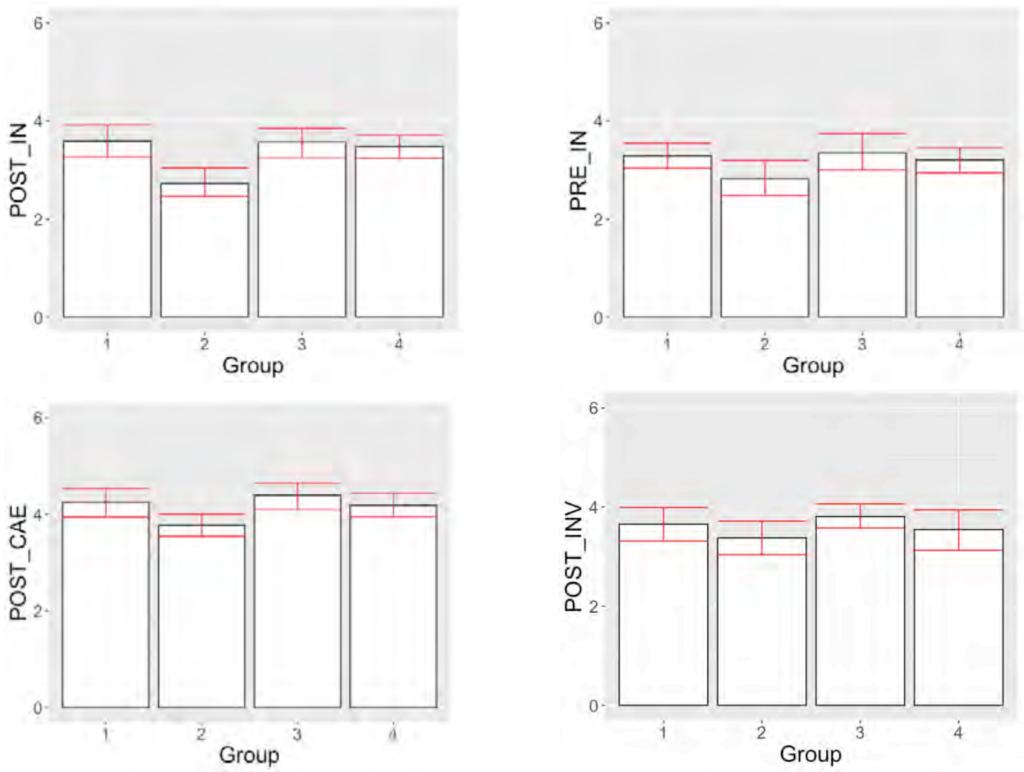


Figure 5.3: Histograms representing the mean score and standard deviation of pre- and post-interest (PRE_IN and POST_IN) and of the two significant covariates, i.e. cognitive activation (POST_CAE) and involvement (POST_INV), on the bottom versus the group.

- A small effect of the variable *gender* on *self-concept* was also observed, with $\eta_t^2 = 0.03$. This effect remains present after controlling for all covariates: prior *self-concept*, *interest*, *curiosity state*, *self-concept regarding smartphones*, *teacher*, *spatial abilities*, post *grade on physics* and *mathematics*, *involvement*, *cognitive load* and *cognitive activation during the experiments*, *cognitive load regarding apps for smartphones*. We remark that, among these covariates, the impact of prior *self-concept* and post *physics grade* remained significant. As we highlighted in section 3.4 on covariates, the effect of *gender* on *self-concept* have already been observed in physics education research (see e.g. [Lee & Burkam, 1996], [Murphy & Whitelegg, 2006], [Kost *et al.*, 2009], [Louis & Mistele, 2012] and [Madsen *et al.*, 2013]). Although girls were on average no less interested or less efficient in physics, they generally had a self-concept significantly lower than boys, as confirmed in figure 5.4.

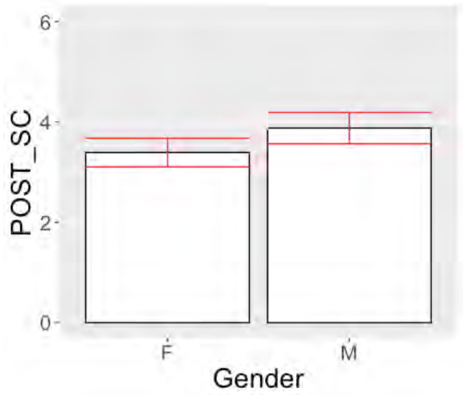


Figure 5.4: Histogram representing the mean score and standard deviation of post self-concept (POST_SC) versus gender.

5.5.3. Effects on global learning

According to the procedure explained in section 4.5.1, the following results were obtained:

- No effects of the treatment on the global result of the *learning post-test* or the post *physics grade* were observed.

- An indication of a possible effect of the treatment on the post *average grade in mathematics* in favor of the treatment group was found, as shown in figure 5.5, representing the average math grade before (left) and after (right) the treatment for both groups. Although the p-value of 0.09 for this hypothetical effect exceeded the significance threshold ($p < 0.05$), it is worth considering the possibility of such an effect, as we will discuss in chapter 6. The main analysis took into account six covariates, whose independence on the variable *group* was tested: they are the result of the *learning pre-test* (LPR), the prior *grade on mathematics*, *physics* and *French*, *spatial abilities*, and *involvement*. The surviving effects are those of *involvement* and prior *math grade*.

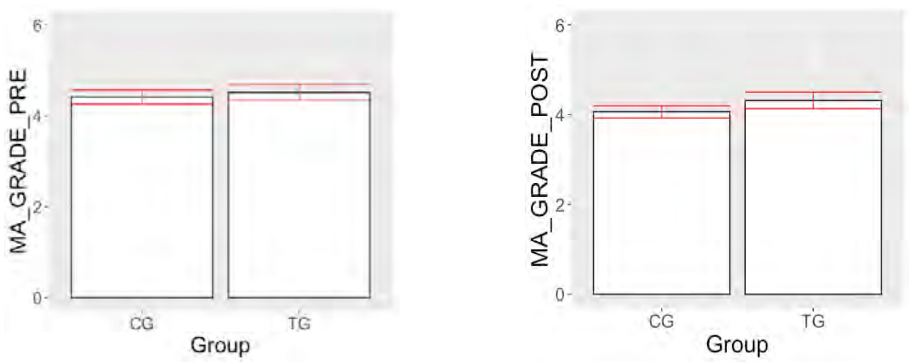


Figure 5.5: Histograms representing the mean score and standard deviation of the prior and post grade of mathematics (MA_GRADE_PRE and MA_GRADE_POST) versus the treatment and control group.

- An effect of the variable *group* (1, 2, 3 and 4) on the result of the *learning post-test* (LPO) was observed. Taking into account six covariates (prior *self-concept*, *grade on mathematics*, result of the *learning pre-test*, *spatial abilities*, *specific option* and *cognitive load during the experiments*), the main analysis indicated a medium effect with η_t^2 = 0.10. Note that, more than the variable *group* (1, 2, 3, or 4, which here was considered as the independent variable) the only surviving effects were those of *learning pre-test* and of *specific option*. As expected from what observed in section 5.3 (see in particular table 5.20), figure 5.6 shows that group 3 obtained the lowest average value.

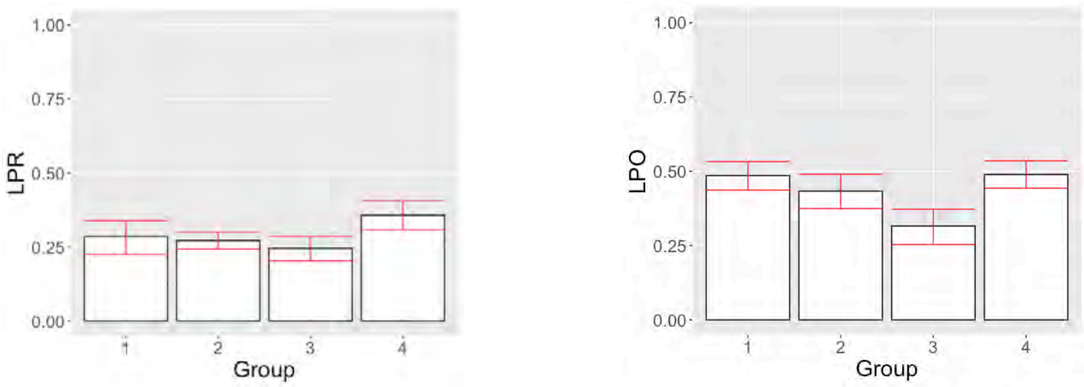


Figure 5.6: Histograms representing the averages difficulties P and standard deviation of the conceptual pre- and post-test (resp. LPR and LPO) versus the group.

A more fine-grained analysis may be carried out, however this possibility is beyond the scope of our research and was not explored here.

- No significant surviving effect of the treatment on the individual items of the learning post-test was eventually observed. By performing a simple one-way ANOVA, out of the 19 items of the post-test, the effect of the treatment presented a p-value lower than the set threshold of 0.05 only for items LPO5 and LPO17, as shown in table A.14 in appendix 1. However, when evaluating the individual items effect by carrying out a *multiple significance testing analysis* introduced in section 3.2 (see also section 4.5.4 on the ANCOVA analysis of the pilot study), no effect on individual items survived. The figure 5.7 shows, for each of the 19 items (LPO item number ordered according to increasing p-value), the corresponding standard calculated p-value (empty circles) and the corrected p-value (filled dots). The p-values of the 19 items are in ascending order and the red line is the threshold of significance of an effect. The corrected p-values are available in table A.14 of appendix 1.

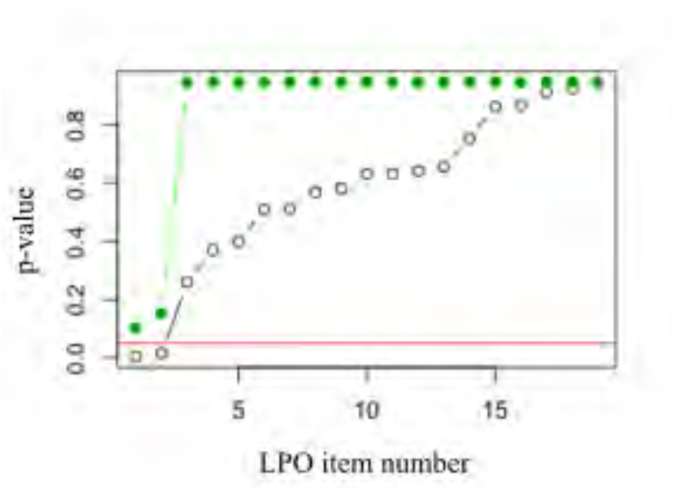


Figure 5.7: Standard p-values (empty circles) and corrected p-values (filled dots) for the 19 items of the learning post-test ordered according to increasing p-value. The red line indicates the significance threshold ($p < 0.05$).

5.5.4. Effects on separate groups

In the previous sections of this chapter, by carrying out the item and ANCOVA analysis across the whole sample, we observed some important differences between the four groups of pupils. In particular, the variable *group* turned out to have an influence both on the affective (*learning post-test*) and cognitive (*interest*) outcomes. Unlike in the pilot study, in the main study several factors might lead to these differences, notably the difference in level of group 4 and the covid19 confinement during the post-test session of group 3. For these reasons, we performed the ANCOVA analysis separately for the four groups of participants. In the following, we will summarize the significant results and let the reader refer to appendix 4 for the details of these analyzes.

<u>Group 1</u> (N_{CG}=14 ; N_{TG}=13)

- No effect of the treatment was observed on the affective dependent variables and on learning (conceptual post-test, mathematics and physics grades) for pupils of group 1.

- After carrying out the correction for multiple testing (see sections 3.2 and 5.5.3), no significant effect on the individual item level remained for pupils of group 1.

<u>Group 2</u> (N_{CG}=12 ; N_{TG}=14)

- No effect of the treatment was observed on the affective dependent variables and on learning averages results (conceptual post-test, mathematics and physics grades).

- Nevertheless, we observed an effect of the treatment on the item LPO17 of the conceptual post-test (corresponding to LPR14 in the pre-test) in favor of the control group 2. When performing a simple one-way ANOVA, out of the 19 items of the post-test, only the effect LPO17 presented a p-value below the significance threshold of 0.05 (p-value = 0.00078). As previously, after the multiple significance testing analysis, we obtained for this item the corrected p-value $p_{corr} = 0.015$. Figure 5.9, shows that this value kept being below the significance threshold. We then proceeded with the main analysis, and took into account four covariates affecting the result of LPO17 (*physics grade*, *self-concept regarding the apps*, *specific option* and *cognitive activation during the experiments*). The first two covariates had an impact on the final outcome. The result is that there was indeed a surviving effect of the treatment on the result of the item LPO17, with $\eta_t^2 = 0.10$ indicating a medium size. The figure 5.10 shows that this effect is in favor of the control group 2.

  Note that the effect observed in group 2 can explain the low p-value of the one-way ANOVA for the same item in the analysis for the whole group (last point in section 5.5.3), which eventually turned out not to be relevant, after the multiple testing analysis: this effect was stronger, then relevant, for group 2.

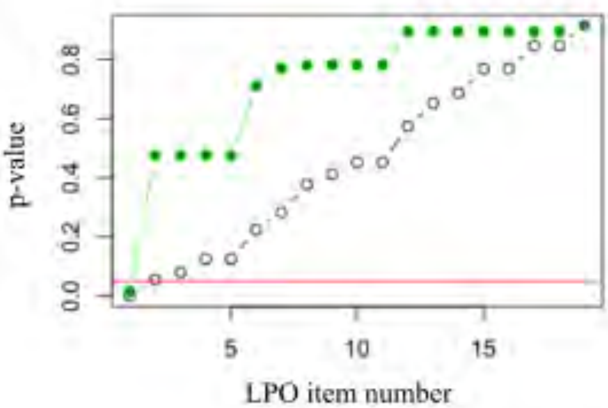


Figure 5.9: Standard p-values (black empty circles) and corrected p-values (green filled dots) for the 19 items of the learning post-test ordered according to increasing p-value, for group 2. The red line indicates the significance threshold ($p < 0.05$) and the p-values.

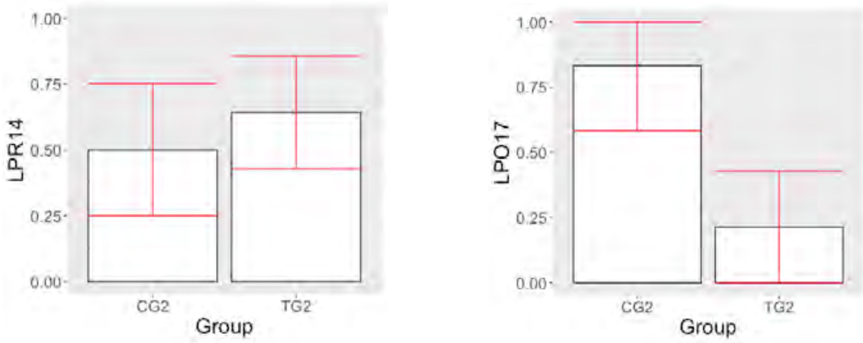


Figure 5.10: Histograms representing the mean score and standard deviation of difficulty of LPR14 and LPO17 (the same item in the pre- and in the post-test) versus the treatment and control group 2.

Group 3 (N_{CG}=14 ; N_{TG}=13)

- We observed a medium effect of the treatment on *interest* in favor of the control group 3, as shown in the figure 5.11. The one-way ANOVA included six covariates: prior *interest*, *curiosity state*, *curiosity trait*, post *involvement*, *cognitive load* and *cognitive activation during the experiments*, of which only *curiosity trait* affected the final result of the main analysis. Taking into account all the predictors, we obtained a significant effect of the treatment on post *interest*, whose η_t^2 = 0.12 indicates a medium size.

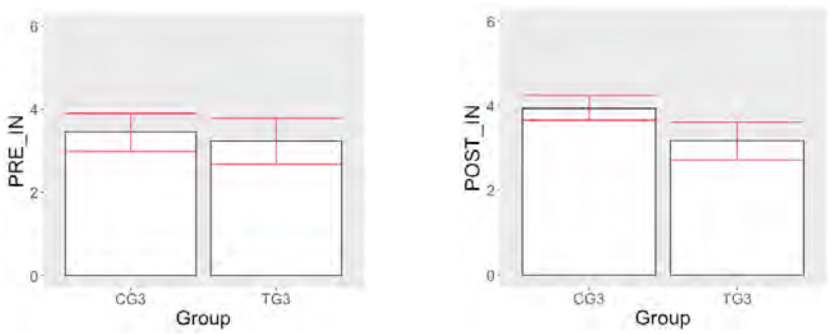


Figure 5.11: Histograms representing the mean value and standard deviation of pre- and post-interest (resp. PRE_IN and POST_IN) versus the treatment and control group 3.

- No more effect on global learning and affective dependent variables was observed for group 3.

Group 4 (N_{CG} =16; N_{TG} = 15)

- No effect of the treatment was observed on the affective dependent variables and on learning (conceptual post-test, mathematics and physics grades) for pupils of group 4.

- After carrying out the correction for multiple testing (see sections 3.2 and 5.5.3), no significant effect on the individual item level remained for pupils of group 4.

6. DISCUSSION

In this study we tested the effect of Mobile Devices as Experimental Tools (MDETs) in the physics courses for one semester (about 18 weeks) on physics and mathematics learning of pupils. Additionally, we also investigated the impact of these devices on motivation and self-concept in physics. With this aim, we replaced several classic laboratory sessions with MDETs activities, perfectly adapted to the curriculum, so that the treatment group and the control group could benefit from the same proportion of time devoted to manipulation for experiments and the same proposal of exercises or activities having an authentic topical context (see section 2.2.2). 111 pupils divided into 4 groups (G1, G2, G3 and G4, taught by 4 different teachers) participated in the main study. Each teacher taught one treatment class-group and one control class-group.

In this section, we will discuss:

1. The global effects on pupil's learning (physics and mathematics) observed;
2. The effects on learning in different groups (G1, G2, G3, G4);
3. The global effects on affective dependent variables: *interest*, *curiosity state*, *relation to reality* and *self-concept*;
4. The effects on affective dependent in different groups;
5. Some raw qualitative results from the teachers' interviews;

We then will present the limitations resulting from our study, as well as some recommendations for classroom practice and for future research.

6.1. Learning outcomes

In chapter 2, on one hand we hypothesized the idea that the use of MDETs during the physics classes could have a positive effect on the physics' learning, due to:

- The multiple representations provided by the apps of video analysis, capable of reducing the extraneous cognitive load [Seufert, 2003; Mayer, 2005; Mayer, 1989] (section 2.3.4);

- The real-time representations of the collected data, facilitating the linking of the different representations of the studied motion in the learner's memory, and promoting his or her germane cognitive load [Mokros, 1987; Thornton, 1986] (section 2.4.1);

- The interactive and mobile learning possibilities of those devices (see section 2.4.1 and references therein);

- The indirect positive effect on motivation and self-concept regarding physics learning, thanks to the Context Based Science Education (CBSE) and Science-Technology-Society (STS) approaches [Bennett *et al.,* 2007] (see sections 2.2.1 and 2.2.2).

On the other hand, the requirements for the handling of the MDETs also could overload the learner's working memory, and thus have a negative effect on learning [Van Bruggen *et al*., 2002] (section 2.3.4). Moreover, arguments exist indicating the potential distractor effect of MDETs [Beland and Murphy, 2015] [Tossell *et al*. 2014] (see section 2.4.3).

6.1.1. Physics and conceptual understanding

Our first research question was (section 2.5):

"Does long-term use of MDETs improve the learning of mechanics among high school pupils?"

Table 5.20 shows that the global learning gain after the instruction was of about 20% with a pre/post effect size around 1, indicating a large size effect. The beneficial effect of the instruction on conceptual learning also occurred separately in groups 1, 2, 3 and 4, and for all individual class-groups. However, although an overall strong learning gain of conceptual understanding of mechanics was observed both for treatment and control group, the results of chapter 5 indicate that there is no significant difference in physics learning between the treatment group and the control group (table 5.20 and section 5.5.3).

The results of the ANCOVA analysis of the main study carried out in chapter 5 confirmed what also emerged from the pilot study (chapter 4), namely that the treatment (the use of MDETs) had no impact on the global conceptual understanding of mechanics (conceptual test) or on the overall physics' grade during the semester. This result differs from those of previous analogous studies by Hochberg *et al*. (2020) and Klein *et al.* (2018), discussed in chapter 2 (see in particular section 2.5). This can be explained by the differences in the sample studied in our research compared to the two previously mentioned. Here we examined high school pupils of non-specialized physics classes, while

- In Hochberg *et al*. (2020) pupils who benefited from positive effects were from high school specialized physics classes, and
- In Klein *et al.* (2018) the observed positive effects refer rather to university level physics' students.

Secondly, similarly to what found by Hochberg *et al*. (2018 and 2020) and Klein *et al.* (2018), here the use of MDETs did not increase the perceived *cognitive load during the experiments* (see table 5.21), and in this study the participating teachers reported no such distractor effects in their classes. In addition, the observed values of perceived *cognitive load during the experiments* were also similar to those of *cognitive activation during the experiments* and perceived *cognitive load due to the use of apps* (table 5.21). Although this would argue in favor of an absence of a cognitive overload or distracting effects of these devices, such conclusions based solely on the results of the *perceived* cognitive load is not obvious, and the interpretation of these values requires caution. Indeed, although the perceived cognitive load was comparable for treatment and control group also in the pilot study (see table 4.18), pupils of the treatment group had a significantly worse understanding of instant velocity vector in a two-dimensional motion, as tested by the conceptual item related to the *first* MDETs activity (see table 4.15 and the result of the ANCOVA analysis in section 4.5.4). In section 4.6.1, we argued that one possible explanation for the presence of this effect is that the pupils of the treatment group had to simultaneously learn the concepts studied, how using the apps and managing the information provided by the multiple representations for the first time. This may have caused and increased extraneous cognitive load at the expense of germane cognitive load, while keeping the total load unchanged (see section 2.3.3) at the beginning of the pilot study. Following this result of the pilot study, in the main study some modifications were made to the structure of the sequence and to the conceptual test. This allowed the pupils of the treatment group to get acquainted more gradually with the apps and the multiple representations and functionalities provided them (see sections 4.6.1 and 4.6.2). Thus, in the main study we did not observe the same kind of effect, showing that the modifications made were consistent. As explained in section 2.3.3, empirically differentiating between the different types of cognitive load (as is done e.g. in [DeLeeuw & Mayer, 2008]) is beyond the scope of this investigation. It would however be a good avenue of future research on the implications of the use of MDETs in the learning of physics.

Furthermore, an effect of the different leaner group (see table 3.2) on the result of the conceptual test had to be stated (see the paragraph 5.5.3), with a total explained variance η_t^2 = 0,10, indicating a medium size. This effect was not present during the pilot study and it can be explained in the main study mainly for two reasons:

- First, the pupils of the group 3, obtaining the lower results on learning (see the figure 5.6 and table 5.20), completed the post-tests during the first covid19 lockdown as a formative assessment, without influence on the final grade. This can have had an effect on pupils' learning investment before the conceptual post-test.

- Secondly, the pupils of group 4 were in their 3rd year, while the pupils of the other groups were in their 2nd year (in the Geneva high school there are some differences in the order of the curriculum's subjects). This means that on the one hand the pupils of group 4 had a significantly better knowledge of the mathematics necessary in learning mechanics and, on the other hand, contrarily to the pupils in their 2nd year, they studied kinematics later in their physics curriculum at the high school. Indeed, they already had seen the chapters on energy (heat), waves and optics before the beginning of the study (during the second year). This can explain the ceiling effect observed for the pupils of group 4.

6.1.2. Mathematics learning

Following the considerations made in section 2.3.3 on the link between the learning of physics and mathematics, our second research question was (section 2.5):

"Does the long-term use of MDETs improve the learning of the related mathematics content among high school pupils?"

Indeed, the representations provided by the apps of video analysis are based on the mastery of the mathematics content treated in parallel math classes (see section 2.3.3).

Although previous research generally documented effect in the opposite direction, i.e. the positive effect of knowledge of mathematics for learning of physics (see e.g. [Thorndike, 1946], [Meltzer, 2002] or [Karam, 2015]), in our study we could observe the possibility of a positive effect of the use of MDETs in the physics course on mathematics learning. Indeed, the results of section 5.5.3 showed that pupils of the treatment group obtained a higher *mathematics grade* than those of the control group, and this difference could be significant. Despite the fact that the p-value observed was of 0.089 (therefore above the threshold set of 0.05) and that the effect found was small, this finding on the interaction between the learning of physics and mathematics deserves to be considered in future research.

On the one hand, learning to use and coordinate the multiple representations provided by the video analysis apps requires a cognitive effort from the learner at the high school level (see section 6.1.1). This is the reason why teaching using these apps should be planned with the necessary precautions, so that the learner can gradually assimilate the information and make the linking between the learned notions (see section 2.3.3) without overload of the working memory. This is done more easily for higher-level students (undergraduate or upper secondary 2 specialized physics classes), which would explain the positive learning results observed by Klein *et al.* (2018).

On the other hand, we argue that the effort provided for the learning of mathematics, necessary for the use of video analysis apps can also be at the origin of the increase of the cognitive germane load, responsible for a better learning of the mathematics underlying the targeted physics concepts. This explanation is in line, not only with the idea advanced in section 2.3.2, that a better knowledge of mathematics affects positively the learning of physics, but also that the training and the application of the mathematic language in the context of physics learning leads to a better learning of mathematics (see e.g. [Sherin, 2001], [Tuminaro & Redish, 2007]).

6.1.3. Effects on individual groups

Since the variable *group* was found to be a significant predictor of learning in the main study, we proceeded to analyze the effects on learning for the pupils of each group separately, i.e.

groups 1, 2, 3 and 4 (we remind that each teacher taught one treatment class-group and one control class-group, each of 13 to 16 pupils, see table 3.2). No significant results were found, except for an effect in favor of the control class-group 2 on the result of one item (LPO17 of the conceptual post-test; LPR14 in the pre-test), with $\eta_t^2 = 0.10$ indicating a medium-sized effect (see section 5.5.4). This item concerns the Newton second law, and the fact that acceleration is inversely proportional to mass for equal applied forces. This item decreased the α of the conceptual post-test and its parameters discrimination D and reliability item-test r_{it} are particularly low (see section 5.3.3 on the item analysis of the conceptual test and in particular table 5.19). LPO17 was critical especially for pupils of group 2, not only because there was a decrease in the proportion of correct answers, but there was also an increase in the response associating the same resultant force with the same final velocity. This was particularly the case for the treatment group, which presented an overall negative gain (-35%), while the control group did not show any change. Associating the same resultant force with the same variation of velocity may come from the wrong application of the correction to the misconception that "different masses, which are free falling from the same height, have different acceleration, then hit the ground with different velocities". This misconception is more widespread among younger pupils, while among high school pupils this is less the case (in the pilot study, the item related to this misconception had a difficulty index so high that the discrimination index and reliability item-test were particularly low, the α was decreased and we had to exclude this items from the analysis, see tables 4.10 and A.5). This lead to think that many pupils did not understand the difference between the situation of LPO17 (equal resultant forces on different masses) and that of different masses in free fall. Indeed, free falling bodies with the same initial velocity reach the same final velocities because the gravitational forces acting on different bodies are not the same, but they are proportional to the mass (gravitational). This proportionality simplifies when dividing by the mass (inertial). This simplification does not apply in the situation of item LPO17.

6.2. Affective outcomes

In chapter 2, we hypothesized a positive effect of the use of the MDETs on the attitude of pupils with regard to the physics course. Indeed, the advantageous characteristics of these devices (mobility, practicality, interactivity, familiarity, see figure 2.4)

- Make them authentic instruments for pupils, creating a material context and

- Make it possible to create activities with new situations, perceived as more related to the pupils' real life, and creating a topical context [Hochberg, 2017].

The design of this study used these two contexts in a perfectly integrated way during the physics course, which is recognized to have positive effects on the motivation of pupils towards the subjects studied [Bennett *et al.*, 2007; Gilbert *et al.*, 2011; Müller *et al.*, 2014] (see section 2.2).

6.2.1. Global effects

Our third research question was (section 2.5):

"Does the long-term use of MDETs improve levels of interest, perceived relation to reality, self-concept and curiosity related to the studied topics, among high school pupils?"

Table 5.3 shows that the impact of the instruction was similar for the treatment group and the control group concerning affective independent variables. The pre/post variations of the situational *relation to reality, self-concept*, *interest* and *curiosity state* in physics are similar for both groups and, in addition, they were all slightly positive in the main study (contrarily to the pilot study, see table 4.5). For *relation to reality* and *interest* this variation is even significant for both treatment and control groups, with a small effect size (Cohen's d between 0.28 and 0.30 for *relation to reality,* and between 0.19 and 0.23 for *interest*). This result confirmed that it was possible to maintain an effective topical context even without the use of MDETs.

The ANCOVA analysis did not show any significant impact of the use of MDETs on any affective output (section 5.5). This is in line with the impressions of teachers that the possible first phase of interest around the activities with the tablets ends up fading during the semester (see section 6.3 below).

However, we observed an effect of the variable *group* (i.e. group 1, 2, 3, 4, see table 3.2) on the variable *interest*. The $\eta_t^2 = 0.04$ indicates a small effect size (see section 5.5.2).

6.2.2. Effects on individual groups

As for learning, the fact that the group (i.e. group 1, 2, 3, 4, see table 3.2) had an influence on the pupils' interest led us to carry out a separate analysis for each group. Eventually, we only found a medium effect size ($\eta_t^2 = 0.12$) of the group on the *interest* in favor of the control class-group 3 (section 5.5.4). This effect is reinforced by the observation of a decrease in the standard deviation, which accompanies the increase in the mean of interest of the control group 3 (see figure 5.11). Teacher 3 explained that, starting from the middle of the semester, short assessments (of about 10'-15') were carried out at each lesson only in the control class-group (CG3), because a large proportion of pupils in this class-group showed difficulties in their engagement for learning at the beginning of the semester, causing an alarming drop in their marks. Thus, the fact of being obliged to provide more work and more regularly, may have had an effect on the interest shown in the subject studied, more than an improvement in learning. Teacher 3 stated that the marks of this group did improve thereafter and, after the end of the study, they even increased compared to the beginning of the year. This explanation was confirmed by the difference in learning gain between the control class-group 3 (ranging from12% to14%) and the treatment class-group 3 (from 5% to 6%) observed in table 5.20. Although the two groups had on average similar results of the conceptual post-test, the pupils of the control class-group 3 have been weaker than those of the treatment class-group 3 at the start of the semester. This effect is an example of how, for individual groups, even maintaining the same teacher, interventions justified by educational reasons specific to the profile of one class-group can have a significant impact.

Finally, we emphasize that, although the attitudes of the four teachers towards MDETs were very different, and one of the teachers was the author of this research, the results concerning the impact of MDETs on learning and motivation of pupils were very consistent across the participating teachers.

6.3. Teachers' perception

We presented the results to the teachers who participated in the study. Physics teachers know the 2nd year mathematics curriculum that pupils follow alongside the mechanics course. It covers topics such as the study of functions, reading and interpreting graphs of polynomial and fractional functions, equations and inequalities with polynomials and trigonometry. From the teachers' perspective, the multiple representations given by the applications of the tablets for the motions studied during the physics lessons could actually have had an important role in the learning of these notions in mathematics. Teacher 3 declared that, beyond the use of tablets, by going through the mechanics' program with his classes, the pupils regularly affirmed that "*seeing these notions (i.e. linear and quadratic functions and graphics) in the physics course allows them to better understand what a function is*". Teacher 1 shared this point of view and added that often these affirmations by pupils are accompanied by a greater awareness, by their experience, of the close link between the two disciplines and how they rely on each other to move forward. Teacher 3 affirmed that other questions then arose from pupils, on the sidelines of the physics course, such as "*So, mathematics is used to understand nature?* ". Teacher 1 believes that, beyond this study, more generally, the links between mathematics and physics lessons could be strengthened in high school. Teacher 4 shared what affirmed by his two colleagues and, for his part, he affirmed to be surprised that the effects on the learning of the pupils have not been more important, especially in physics. He stated that pupils who did not choose physics as specific option of their maturity only have one lesson of physics per week, which is not enough to be in depth in the concepts learned and often doing one lab session may complicate the learning process. He is therefore convinced that the fact of benefiting from applications for tablets allows a real simplification when taking and analyzing measurements by pupils, and that this allows more time to be freed to focus on the concepts studied. In addition, since the beginning of the study, the teacher 4 was the most enthusiastic about using MDETs, compared to his colleagues. The four teachers agreed on the practicality and simplicity of the MDETs in the laboratory sessions of physics lessons and declared that they wish to use them subsequently for certain experiments, beyond the study. Teachers 1 and 3 have been shown to be more cautious insofar as they also see drawbacks, which cannot be overlooked.

Teacher 4 was the most optimistic about the possibility of a positive effect of tablets both on learning and on motivation, while teachers 1 and 3 expressed a more mixed opinion: they appreciated the practicality and the new possibilities offered by MDETs for teaching, without however expecting a large effect on the pupils' motivation or learning on the medium term. Teacher 1 and 3 also indicated the fact that MDETs remain double-edged tools: they can have positive aspects, but on the condition that the pupils have already learned to master the applications and the functioning of the tablets (take of stable videos, tracing, ...) and that the teachers have carefully prepared the activity, taking into account all possible cognitive obstacles. Teacher 2 rather highlighted the limitations of MDETs and, if during the pilot study his opinion was divided, during the main study his overall assessment was rather negative. Teacher 2 also claimed to have had poorly motivated pupils in general during the main study. We suppose that the different attitudes of teachers towards MDETs could have had an influence on the impact that the latter have on students.

6.4. Limitations

This study confirmed that MDETs constitute an excellent alternative to traditional experiences in physics classes, namely for the mechanics' course taught in high school, given that the activities carried out are inserted in a coherent and harmonious way in the teaching sequence and that the multiple representations provided by the applications are within the reach of pupils' level.

All the participating teachers noticed the practicality and flexibility of setting up and carrying out activities with MDETs, which makes these devices an interesting opportunity for teaching in any case, as indeed they have no negative effects on pupils. Teachers claimed to have a feeling of relief, whether from the pupil's point of view or from the teacher's point of view, because for both there is a real reduction in repetitive tasks to be performed during the experiments. For example, the experiments on uniform linear motion or on uniformly accelerated linear motion (activities n. 3 and 4 in appendix 2) can each be performed in a single teaching period (45') with the MDETs, while they take two periods with traditional setups. In addition, pupils can perform experiments that simply would not be possible with traditional equipment, such as the activity of the jump (activity n. 6 in appendix 2).

Nonetheless, some limitations should be considered when teaching with MDETs with high school pupils, especially when the video analysis' apps are used.

- First, there is a phase of appropriation of the mobile device (tablet or Smartphone) and of the apps. It is generally not easy for pupils to make a video of sufficiently good quality for the tracing by the app to be possible: they have to be stable during the recording, enough contrast between the studied object and the background is needed, the angular speed (pixel speed) cannot be too high, the tracing circle has to be chosen with an appropriate width, ... All these requirements take time to be learned and mastered, which is not evident for pupils and frequently for the teachers too – although they almost all own a Smartphone. Among the four teachers who participated in the study, one had difficulties. Moreover, it's worth to notice that many teachers who did not participate in the study ever took into consideration to use these devices in their lessons, because they affirmed that they could not master them with sufficient ease. This confirms what has emerged in previous investigations on the difficulties of integrating technologies in schools, including human factors or other barriers due to the technologies [Kenttälä, 2019].

- Second, beyond the practical mastery of the technological object, and as the theoretical arguments of sections 2.3.3 and 2.3.4 anticipated, the use of MDETs can cause cognitive overload if pupils do not master the mathematics underlying the representations provided by the apps used during the experiments. For example, in the pilot study we had indications that difficulties were present when showing pupils the motion time-diagram of the round trip activity (activity n. 2 in appendix 2), as they were never taught before what a time diagram was. This resulted in an overload of working memory and therefore the impossibility for pupils to focus on the notion of average speed. As a consequence, the treatment group result in the corresponding item of the conceptual learning test was lower than that of the control group (see item LPO3 in the table 4.11: the gain of the treatment group is negative for the treatment group, and is of 0.16 for the control group), although this difference was eventually not significant according to the ANCOVA analysis of chapter 4.
  A similar fact occurred, again during the pilot study, with the activity n. 1. Pupils accessed all the representations of the two-dimensional motion already in the very first activity (data table and time-diagrams), and they could not concentrate on the notion to be learned, i.e. the instant velocity vector. Then, the treatment group obtained lower results than the control group at the corresponding item of the conceptual learning test (see item LPO4 in table 4.11: $P_{TG} = 0.68$ and $P_{CG} = 0.95$ and this item was not present in the pre-test), with a medium effect in favor of the control group noted according the ANCOVA analysis ($\eta_t^2 = 0.09$, see paragraph 4.5.4).
  Eventually, on the one hand familiarizing with the different mathematical representations of a physical phenomenon requires an effort from the pupils: teachers observe this during the physics lessons, also without the use of MDETs. On the other hand, this suggests that it is precisely this effort that gives a better knowledge of mathematics. Thus, when planning a teaching sequence, a balance should always be maintained between the efforts for learning without overloading the working memory.

- Third, despite the intentions, it was not possible to let the pupils make MDETs activities as homework, because, for that, they would have had to bring the tablets home, which was not manageable from an organizational point of view, for the limited availability of these devices (several classes in parallel used the same set of tablets furnished) and for the security of their use. Pupils of the treatment group were asked to take videos in their daily life in order to use them in class, for example a slide video for MDETs activity n. 4 on the inclined plane. However, none of them had ever uploaded a video.

- The possibility of using the pupils' private Smartphones for the MDETs activities was not explored in this study, as in the Geneva schools the use of private smartphones during the lessons is prohibited and, moreover, this idea raises many questions from different points of view, which would have radically changed the intentions of this research. First, from a learning point of view, the private Smartphones' distractor effect should be considered more than if the MDETs are provided by the institution. Secondly, although Smartphones and tablets are very widespread, some pupils can afford models that perform better than others and some pupils do not have any at all, therefore the question of equal treatment should also be considered. Furthermore, the apps used in the study are only available for a brand of high-end devices and there are no similar apps for all models of tablets or Smartphones. Asking the families of all pupils to buy apps for their phone is problematic: families can be opposed, many pupils do not have the right brand and, to date, no similar free-to-access video tracking apps is available.

- In a perspective of generalized use of MDETs in education, it should be taken into account that, depending on the country, difficulties may arise in the support of tablets by schools, taking into account the maintenance and the technical assistance they request. It may seem trivial, but for example having a wi-fi network or a bluetooth printer in each classroom is not obvious (these are political decisions). Updates are constantly needed and these high-tech objects become obsolete in few years, faster than standard lab equipment like rails, timers or dynamometers. Furthermore, we cannot neglect the planned obsolescence of these devices and their cost in environmental and durability terms. All these factors should be put on a balance with hindsight, taking into account the global context and the fact that we imagine a scientific education sustainable and accessible to all the community.

6.5. Recommendations

6.5.1. Classroom practice

Overall, the intervention is as good but not better than a quite effective conventional learning in physics. However, the use of MDETs offers interesting prospects for physics teaching in high school classes for various reasons. The main conclusions of this study for the teaching practices are summarized below.

- Despite the limitations and cautions listed above, the use of MDETs remains recommended in physics lessons, not as a replacement but complementarily with traditional setups. When possible, the easiness and practicality of the preparation of the experiences by the teacher constitutes a clear advantage: for the same content as a conventional activity, MDETs activities allow a faster implementation with a handy and light device, allowing to save precious time for other teaching moments. This advantage is highly regarded by teachers, regardless of the effects on students.

- If students are at the limit of mastering the mathematics of the different forms of representations provided by the apps, it is important to plan the lesson so that learning new contents in mathematics applied to physics is possible without cognitive overload. In particular, the use of video analysis is recommended to students who are familiar with the concepts relied to functions graphs and their interpretation, regressions, and know how to apply them to physical quantities. With these conditions, the use of video analysis can result in an improvement in the learning of the underlying mathematics. Moreover, pupils have the possibility to save time when taking data and when producing representations (graphs, tables, regressions).

- The study showed that learning how to use video analysis apps during the physics lessons is an interesting opportunity for better learning the underlying mathematics. In this sense, it becomes interesting to create closer interactions between the MDETs activities carried out during physics lessons and mathematics lessons. For example, the math teacher could use representations obtained in physics experiments to illustrate examples of applications mathematics notion to the real world. In the physics course, the presence of mathematics content can only have a positive impact on the student's overall learning of physics and the language of sciences. More generally, the interdisciplinarity of these two disciplines should be further encouraged.

- Teachers appreciate the flexibility of MDETs activities: depending on the class-group and the planning of the course, pupils can take measurements and analyze them (experimental activity), or the data can be given from the measurement by a single student or by the teacher and used by the whole class (semi-experimental activity). In the latter case, the strict data ownership and the real-time data capture are lacking, but the possibility of learning on authentic situations is more frequent, as the video may be recorded outside the classroom (playground, Luna park, home, etc. ...).

- For some course contents, it is possible to choose whether to do an experiment with traditional instruments or with MDETs (for example the activities n. 2, 4 and 5 of appendix 2), while for other contents only the traditional activity or only the MDETs activity is possible (for example the activity n. 6 of appendix 2, the "jump").

- Pupils might carry out activities at home, for example as homework, or when the lessons are given at a distance. This has not be possible within the framework of this study (see section 6.4), however this possibility remains open and new modalities could be explored, namely following the development of e-learning experiences within the framework of the 2019-2020 confinement.

In conclusion, even if the MDETs do not replace the traditional laboratories in physics, they prove to be a complementary tool, supplementing the possibilities and the richness of the available teaching tools.

6.5.2. Research

Although we did not observe any positive effect on pupils' physics learning or on motivation of middle-term use of MDETs, no negative effects has been highlighted either and, in particular, we did not observe an increased or decreased cognitive load of the treatment group with respect to the control group. An effective teaching of mechanics has been maintained by four different teachers, each of them having varying attitudes and expectations with regard to these devices.

In addition, the possibility of a positive effect on the mathematics results of using the apps of video analysis, which has been pointed out, is an interesting result and should be further investigated, as should the effect of these devices on affective variables in relation to mathematics learning (i.e. situational *self-concept* or motivation variables regarding mathematics). Indeed, with regard to physics, this study only assessed the effect of MDETs on the overall grade and on conceptual knowledge, but it would also be interesting to know what are the consequences of the use of MDETs on the learning of the mathematics applied to physics. As already mentioned in the previous sections of this chapter and in chapter 2, the use of the video analysis apps should be reserved for students who already have the basics to understand the provided representations, and this audience corresponds especially to the level from the last years of high school or undergraduate students.

Beyond the effects of MDETs, this study confirmed some known previous results in education research and/or highlighted certain facts:

- The importance of mathematical knowledge in the learning of physics, which confirms the strong link between the learning of these two disciplines (see sections 2.3.2 and 3.4 and references therein). This result of the use of MDETs in physics lessons both on mathematics learning should be more deeply investigated in the future, together with the impact on the variables of motivation and self-concept in mathematics. On the one hand, investigations in this direction would allow to better understand the mechanisms of the interaction between learning in physics and in mathematics. On the other hand, knowing to what extent the physics understanding have an effect in the learning of the linked mathematics contents could enrich and complete the existing research inquiring on the impact of prior mathematical knowledge in physics learning (see sections 2.3.2 and 3.4). In addition, collaborations between teachers of mathematics and physics could be established in the schools in a more multidisciplinary vision of the training of these disciplines.

- The teacher has a fundamental impact both on learning and on motivation in physics; this confirms the findings of the previous literature (see paragraph 3.4). In particular, we had the indication that the attitude of the teacher towards the treatment can strongly influence the impact of this same treatment on pupils. The qualitative part of the interviews with the teachers had only a relative importance in this study, because we discussed with the teachers mainly to ensure the good progress of the study and to better interpret the results obtained. Nevertheless, the teachers' point of view should systematically be considered, as their sincere appreciation of a new educational tool can prove to have an important issue in the results of empirical research, their interpretation, and in the practical applicability of the following prescriptions. Indeed, the involvement of teachers helps strengthening the link between educational research and what really happens in the classrooms.

- This investigation did not indicate empirical evidence of any effects of treatment on the evolution of affective variables, which indeed resulted to be overall positive for *interest* and for *relation to reality* in both groups ($d_{IN} \approx 0.2$ and $d_{RR} \approx 0.3$, according to table 5.11). This result indicated on the one hand that the effect of MDETs on the motivation variables, while it can exist after a point-wise use of those devices [Hochberg *et al.*, 2018], is not maintained over time. On the other hand, the efforts made to implement a sequence with as much situation context as possible in the two groups for this study have been effective, showing that it is possible to provide quality authentic mechanics lessons both with and without the use of MDETs.

7. CONCLUSION

In this research, we analyze the effect of the use of Mobile Devices used as Experimental Tools (MDETs) in physics laboratory sessions during one semester on situational *interest*, *curiosity state*, *relation to reality*, *self-concept* and *learning* in physics (conceptual and overall grade) and in related mathematics (grade) of pupils of the Geneva high school not specialized in physics. With this aim, several traditional laboratory sessions and exercises were replaced by MDETs activities, so that the treatment group and the control group benefit from the same proportion of time devoted to manipulation for experiments and the same proposal of exercises or activities with a situation context. The novel contribution of this study lies mainly in the technological learning tool used (familiar, hands-on and with high potentiality), in the specific learner group (non specialized pupils on secondary level), and in the integration of treatment activities in a regular teaching setting over the duration of a whole semester.

The year 2017-2018 was devoted to the preparation of the pilot study, by the creation of many MDETs video analysis activities, specifically adapted to the Geneva high school physics curriculum, and taking into account the constraints of the academic track options of the local school system. In particular, pupils who did not choose physics-mathematics applications as specific option follow a basic general physics curriculum at the beginning of the high-school course, before acquiring the necessary prerequisites in mathematics (i.e. vectors, functions, trigonometry and algebra) and, as a consequence, they have to learn the necessary mathematics at the same time as physics. Therefore, the issue of effectively improving students' learning and motivation in physics is all the more important in this context. In the same year, the questionnaires used as instruments were also produced, both for affective variables and learning, starting from the previous research and carefully adapting it to the targeted content and public.

During the school year 2018-2019, 102 pupils participated in the pilot study ($N_{TG} = 59$; $N_{CG} = 43$), belonging to 7 physics class-groups taught by three different teachers, while in 2019-2020, four teachers participated in the main study, each with one treatment group class and one control group class, with a total of 111 pupils.

The pilot study worked well overall, and the quality of the instruments could be validated resp. improved for the main study: only a few modifications in the planning of the sequence and the developed activities were necessary. A fair and good general progression was observed, both in treatment group and control group (the average gains have been between 24% and 32%, see table 4.16), and the affective outcomes presented a comparable evolution (see table 4.5). However no effects of the treatment were observed.

The main study could be completed under good working conditions, although one of the four groups (one control and one treatment class-group) made the post-tests session during the first week of confinement, due to the pandemic covid19 (March 2020). This unforeseen event reasonably partially explains the observed medium to large effect on the physics learning (conceptual test) of those pupils. No effect of MDETs on the physics learning was observed.

Despite this, the gain on physics learning was generally good for all groups, going from 17% to 21% (see table 5.20). Moreover, table 5.3 shows that, as for learning, the instruction was similar for treatment group and control group also for the affective independent variables: the pre/post variations of *self-concept* in physics, *interest*, *curiosity state* and *relation to reality* are similar for both control and treatment group, and they are all slightly positive. For *relation to reality* and *interest* this variation was even significant for the both groups, with a similar small size effect (Cohen's d between 0.28 and 0.30 for *relation to reality*, and between 0.19 and 0.23 for *interest*). This result confirms that it was possible to maintain an effective authentic situation context even without MDETs, while fully adhering to the objectives of the program to be taught and with the means available in the school.

The ANCOVA analysis highlighted a small effect on the average mathematics mark in favor of the treatment group (see section 5.5.3), confirming the link between the learning of physics and mathematics. This result should be considered in future research and that the impact of MDETs in physics lessons on mathematics learning should be more deeply investigated, together with their possible effect on variables of motivation and self-concept in mathematics underlying physics. This kind of investigation could complete the existing research, which mainly explores the impact of prior knowledge of mathematics on physics learning (see section 2.3.2). On the one hand, investigations in this direction would allow to better understand the mechanisms of the interaction between learning in physics and in mathematics: for example, to what extent the physics' understanding have an effect in the learning of the linked mathematics contents. On the other hand, collaborations between teachers of mathematics and physics could be established in the schools in a more multidisciplinary vision of the training of these two disciplines.

Finally, taken as a whole, the intervention was as good but not better than a quite effective conventional physics' course. However the use of the video analysis apps of MDETs offers some interesting issues for teaching of mechanics in high school classes when their use is carefully introduced. Indeed, the multiple representations and functionalities provided should not generate an extraneous cognitive load, but rather contribute to its reduction, while stimulating the germane cognitive load and leaving the total load unchanged. It is therefore necessary to ensure that the pupils master the use of the apps (recording suitable videos, tracking an object, handling the apps, …), and the mathematical prerequisites necessary for the interpretation of the many representations provided by the video analysis apps. These skills are more often acquired by undergraduates or upper secondary level students of specialized physics classes, and can improve the math learning of secondary school pupils who are learning these contents in the math classes. With those warnings, the practicality and ease of setting up MDETs activities allows on the one hand a relief and gain in time in the preparation of experiments for the teacher and, on the other hand, efficiency when taking of data and in making repetitive tasks such as the production of tables and graphs for pupils. Furthermore, from a practical point of view, the question of maintenance, accessibility, availability and durability of such devices is also to be considered for their generalized use in teaching.

For several reasons the possibility of using the pupils' private Smartphones for the MDETs activities was not investigated in this study, for example in view of an equal treatment for pupils. Furthermore, the use of private smartphones is still largely prohibited in Swiss secondary schools. Indeed, the presence of many applications for leisure, directly available during lessons (chat, music, video games, social networks, ...), would lead to consider the distracting effect differently from what done in this study. Nevertheless, the availability and hands-on nature of these devices led pupils going on using the apps seen in the classroom for private use with their personal mobile device, and this allowed them to more easily relate the subjects studied in physics - often perceived as abstract - to their daily lives. Besides, the possibility of letting pupils use these devices for homework remains unexplored.

The implementation of the teaching materials and of the study as a whole has been only possible thanks to the close collaboration and the very good mutual understanding between the researcher, the teachers (not only the participating teachers) and the laboratory assistants from schools throughout the process. Thus, on the one hand, over the months, the teachers participating were able to take an active part in the questioning of the study, and could learn about the methods and the results of the research in physics education. This enriched their practice as well as their critical view of the current teaching system. On the other hand, the concerns, difficulties, expectations but also the peculiarity of each teacher could be taken into account and discussed in the research framework, bringing to this study a remarkable wealth of elements and perspectives directly from the daily reality of school. Thus, this collaboration was able to benefit both science education research and teaching practice and to connect them. We hope that the results can contribute to the good progress of each other in the near future.

Table A.1 : MDETs Activities – Kinematics & Dynamics. Abbreviations: CL = Classic Laboratory ; RL = Real Life Laboratory; 1D or 2D = one or two-dimensional

Activity	Mobile apps.	Exercise(s): Notions/links with the curriculum (course chapter)	Relied item(s) of the validation concept test	Remarks	Activities selected for the pilot study
1. Pendulum (CL) 2. Ball throw – displacement + vector *v* (RL)	Video Physics + Graphical	– Position, displacement 2D – Average velocity and speed 2D – Instant velocity 2D	2, 5, 7, 8	– Possibility to work with given data as first activity – Possibility to use the same video and data for activity 9. (“The ball throw – vector *a*”)	Ball throw: displacement + vector v (Activity 1) For “the ball throw”, the difference between travelled distance and displacement is bigger than for pendulum (imprecision)
3. Gmap (RL)	Video Physics + Gaia GPS	Vector displacement, vector average velocity and scalar speed 2D	2, 5, 7, 8	-	Not ready
4. Ping-pong ball (RL)	Oscilloscope	Average speed in linear motion	-	– The average speed is a notion pretty well understood using classical exercises, contrarily to the notion of average and instant velocity, or the average between two speeds (i.e. in the return trip).	Interesting for lower level pupils. Not relevant concept item related for high school
5. Return trip (RL)	Video Physics + Graphical	– Vectors in 1D kinematics (+ and – sign versus magnitude); – Total average speed and versus mathematical average of two speeds (time weighted average)	11	– Very rooted misconception. – Small difference between the average speed and the mathematical average between two speeds.	Return trip (Activity 2) Rooted misconception. [Reed & Saavedra,1986]
6. Trolley on the rail + chronometer (CL) 7. Toy train (RL) 8. Projector roll (RL)	Video Physics + Graphical	Uniform linear motion, slope, intercept, proportionality, time equation, time diagram	12, 13, 16, 17 (replaced), 21	– Requires using studied mathematical concepts applied to physics, as giving a physical meaning and unit to a symbol. (a competence in itself).	The projector roll (Activity 3)
9. Ball throw – vector a (RL)	Video Physics + Graphical	– Draw the instant velocity vector 2D – Average acceleration vector 2D	7, 9, 23	– Instant velocity and average acceleration are perceived as a very difficult notions by pupils: I estimate that, at the end of the semester, less than 10% of them can draw these vectors for a given a trajectory. – This experience is also used for the notions of average velocity, position and displacement: possibility of using the same video and data as activity b. (“The ball’s throw – displacement + vector v”)	Ball throw – vector acceleration (Activity 4)

Table A.1 – continued

13. Trolley on the rail + chronometer (CL) 14. Slide (RL)	Video Physics + Graphical	Uniformly accelerated linear motion	12, 13, 14, 15, 16, 19, 20, 22, 23, 24, 25	– Can be adapted to study the dynamics of the motion on an inclined plane (ch.8), although often there's not time enough to do this chapter, at the end of the semester, because in January pupils must start the chapter on energy.	Slide – Inclined rail (Activity 5)
10. Vertical jump (RL)	Video Physics + Graphical	– Uniformly accelerated linear motion – Newton's laws – Free fall with changing sign velocity	14, 15, 19, 20, 22, 23, 24, 25, 27, 28, 29, 30, 31	– Activity divided into two parts: the first during the thrust: forces' balance, prediction of the force of the ground (use Sparkvue to verify the prediction?); the second is a free fall (a=g) with a change of the velocity's orientation, prediction of the maximal height (exercise of the "Geneva fountain").	Vertical jump (Activity 6) This activity is a good recapitulative of all the contents seen during the semester, with analysis, previsions and internal check
11. Balloon fall (RL)	Video Physics + Graphical	– Newton's laws – Free fall with resistance, – Estimate of the covered distance starting from the surface under the velocity plot	14, 15, 18, 19, 20, 22, 31	Good recap. of all the contents seen during the semester, with analysis, previsions and internal check. The plateau in the velocity plot is not perfect (deviation from electrostatics, balloon's rotations unless correctly released…)	Not done by all the teachers or done after the end of the winter semester (after the end of the study)
12. Helium balloon (RL)	Video Physics + Graphical	– Newton's laws, – Linear motion with resistance, – Archimedes' force (curriculum of the first year)	14, 15, 18, 19, 20, 22, 31	Good recap. of all the contents seen during the semester (and the first year too!), with analysis, previsions and internal check. The plateau in the velocity plot is not perfect (deviation from electrostatics, balloon's rotations unless correctly released…)	Not done by all the teachers or done after the end of the winter semester (after the end of the study)

Table A.2: Affective and predictor variables. Scales: O = ordinal, D = dichotomous, I = interval, N = nominal without order. For each scale, the items selected for the pilot study or for the main study (indicated with ✓) are distinguished during by their number (eg IN1, IN2, ..., IN7).

Acronym	Variable	Independent (IV) Dependent (DV) Covariate/ Control (CV)	Scale	Examples/Operationalisation: Existing literature items	Examples/Operationalisation: Translation French version/adaptation	Examples/Operationalisation: Created items	Source (teacher /school/ pupil)	# Items pre	# Items post
IN	Interest	CV (pre) DV(post)	O	1) Pendant les derniers mois, j'ai investi plus d'effort lors des heures de physique que dans les autres matières. 2) Pendant les derniers mois, résoudre un problème dans le cours de physique m'a bien plu. 3) Pendant les derniers mois, j'ai souvent parlé du cours de physique avec mes amis ou en famille. 4) La physique est ma matière préférée. 5) Les derniers mois, le cours de physique m'a plu. 6) Quand j'essaie de résoudre un problème de physique il m'arrive de ne pas sentir le temps passer. 7) À la maison, je fais des recherches dans des livres, sur le web, etc. pour en savoir plus sur les thèmes du cours de physique des derniers mois. 8) Dans mon temps libre je consacre du temps, en plus des devoirs, aux thèmes abordés dans le cours de physique des derniers mois. [Kuhn & Müller, 2015 ; Hoffmann *et al*., 1997; Pawek, 2009]	1) Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières. ✓IN1 1) (inspired) Au cours des derniers mois j'ai commencé à m'investir plus qu'auparavant en physique. 2) Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique. ✓IN2 5) Pendant les derniers mois, j'ai bien aimé le cours de physique. ✓IN3 **Not necessarily at home** 7) J'ai fait des recherches dans des livres, dans les journaux, sur le web, etc. pour en savoir plus sur les sujets traités dans le cours de physique des derniers mois. ✓IN4 **Removed from MS** 8) En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.✓IN5	**« Negative » items** 9) Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique. ✓IN6 10) Je ai trouvé le cours de physique des derniers mois inintéressant. 11) Pendant les heures du cours de physique des derniers mois je me suis ennuyé. ✓IN7 Removed from MS 12) Je ne trouve pas le cours de physique des derniers mois intéressant. 13) Je ne trouve pas intéressant de discuter des sujets traités au cours de physique des derniers mois en dehors de l'école.	P	7	7
SC	Self-concept	CV(pre) DV(post)	O	1) Les derniers mois du cours de physique m'ont plu. 2) Je suis toujours parvenu(e) à résoudre les exercices des derniers mois du cours de physique. 3) J'attendais toujours avec impatience le cours de physique. **No, trop « fort » en français.** 4) J'étais concentré(e) lors des heures du cours de physique des derniers mois. 5) Les exercices des derniers mois du cours de physique m'ont permis de mieux comprendre le sujet traité. **No, « course assessment »** 6) Je pense que mes camarades de classe ont trouvé que j'étais fort(e) lors des heures du cours de physique du dernier semestre. 7) Le sujet des dernières heures du cours physique était compréhensible. 8) Mes résultats lors des derniers mois du cours de physique étaient satisfaisants pour moi. 9) J'ai participé activement aux derniers mois du cours de physique. **-> « active participation »** 10) Je m'attends à ce que mes résultats dans les cours de physique soient bons à l'avenir. [Kuhn & Müller, 2015 ; Hoffmann *et al*., 1997; Pawek, 2009; Marsh, 1990]	1) Le cours de physique des derniers mois m'a bien plu. **= item IN 5)** 2) J'ai pu résoudre les problèmes de physique pendant les derniers mois de cours. ✓SC1 6) Je pense que, pendant les derniers mois, mes camarades ont trouvé que j'étais bon(ne) en physique. ✓SC2 7) J'ai bien compris les sujets traités au cours de physique des derniers mois. ✓SC3 8) Les derniers mois, mes résultats en physique ont été satisfaisants pour moi. ✓SC4 **Removed from MS** 9) J'ai participé activement pendant les heures de physique des derniers mois. 10) Je m'attends à ce que mes résultats en physique soient bons à l'avenir. ✓SC5 **Removed from MS**	**« Negative » items** 11) Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique. ✓SC6 12) Pendant le dernier semestre, les exercices de physique me reboutaient. 13) Je suis nul(le) en physique. ✓SC7	P	7	7

Table A.2 – continued

CT	Curiosity as a trait	CV (pre)	O	1) I find fascinating to learn new things. 2) I feel curious about new things. 3) I like to learn things that are new to me. 4) I find new things inspiring. 5) When I hear something new, I want to know more. 6) New situations capture my attention. 7) The prospect of learning new things excites me. 8) I like to enquire about things I don't understand. 9) I like to try to solve problems that puzzle me. 10) I want to probe deeply into things.. [Naylor, 1981; Litman & Spielberg, 2005]	1) Je trouve fascinant d'apprendre -de nouvelles choses. ✓CT1 2) Je suis curieux pour les nouvelles choses. 3) J'aime apprendre des choses que je ne connais pas. ✓CT2 4) Les nouveautés sont pour moi une source d'inspiration. 5) Lorsque j'apprends quelque chose de nouveau, je veux en savoir davantage sur ce sujet. ✓CT3 6) Les situations nouvelles capturent mon attention. 7) L'idée d'apprendre quelque chose de nouveau m'enthousiasme. 8) J'aime faire des recherches sur les choses que je ne comprends pas. ✓CT4 9) J'aime essayer de résoudre des problèmes qui m'intriguent. ✓CT5 **Removed from MS** 10) Je veux toujours examiner les choses en profondeur. ✓CT6		P	6	-
CS	Curiosity as a state related to content of the course	CV (pre) DV(post)	O	1) I want to inquire further/know more about this subject. 2) I feel personal connection with this subject. 3) I want to understand better. 4) I find it fascinating. 5) The last lessons made me curious to learn more about this subject. 6) I am more curious about this subject now, after the last activities. 7) I want to understand this topic better. 8) I find it fascinating to spend time on this subject. [Kuhn & Müller, 2015 ; Hoffmann *et al*., 1997; Pawek, 2009]	1) Je voudrais en savoir davantage sur les sujets triâtes dans le cours de physique des derniers mois. ✓CS1 2) Je suis personnellement (Je me sens) en lien avec les sujets traités dans le cours de physique des derniers mois. **Sounds weird in French.** 3) Je voudrais mieux comprendre les sujets traités dans le cours de physique des derniers mois. ✓CS2 **MS : comprendre -> approfondir** 4) Je trouve fascinants les sujets traités au cours de physique des derniers mois. ✓CS3 5) Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités. CS4✓ 6) cf. item 1) 7) cf. item 3) 8) Je trouve fascinant de passer du temps sur les sujets traités en physique les derniers mois.	8) J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois. CS5✓	P	5	5
CLE	Cognitive load related to the experiment	CV (Post)	O	1) I could well concentrate/focus on experiments, without "struggling" with the equipment/apparatus. 2) I could rapidly begin with the experiments. 3) I received enough information for doing the experiment. 4) It was difficult to use the equipment. 5) I felt overwhelmed by the features provided by the equipment. 6) It was hard for me to understand the instructions. 7) I had problems understanding the physics principles of the experiments. **-> Self-concept** 8) I had problems with using the equipment to make observations. Primary sources: [Orion *et al*., 1997]; [Yunker, 2010] (SOLEI instrument); [Paas, *et al*., 1994]; [Kuhn, 2010] Adapted from [Cors, 2016] ; [Hirth, 2019] ; [Woithe, 2020]	1) Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec le matériel ou sa mise en place. ✓CLE1 2) Lors du cours de physique des derniers mois, j'ai pu démarrer les activités rapidement. ✓CLE2 3) Lors du cours de physique des derniers mois, j'ai reçu des informations suffisantes pour effectuer les expériences. ✓CLE3 **Removed from MS** 4) Lors des expériences du cours de physique des derniers mois, le matériel était difficile à utiliser. 5) Lors des expériences du cours de physique des derniers mois, j'ai été débordé(e) par les fonctionnalités du matériel. 6) Lors des expériences du cours de physique des derniers mois, j'ai trouvé difficile de comprendre les instructions. 7) Lors du cours de physique des derniers mois, j'ai eu de la peine à comprendre les notions de physique des expériences. ✓CLE5**-> Self concept** 8) Lors des expériences du cours de physique des derniers mois, j'ai eu des problèmes à utiliser les instruments de mesure. ✓CLE6	**Other formulations:** **(Not only begin, but also doing the experiment)** 2) Les activités expérimentales du cours de physique des derniers mois étaient simples à effectuer. ✓CLE4 2) Les expériences du cours de physique des derniers mois étaient rapides à mettre en place/effectuer. **(More personal, less course judgement)** 6) Lors des expériences du cours de physique des derniers mois, je n'étais pas au clair avec les tâches demandées.	P	-	7

Table A.2 – continued

CLS	Cognitive load related to the apps of the Smart-phones	CV (Post, only TG)	O	1) I could well concentrate/focus on experiments, without “struggling” with the app. 2) I received enough information for using the app. 3) It was difficult to use this instrument. 4) I felt overwhelmed by the features provided by the equipment. 5) It was hard for me to understand the instructions. 6) I had problems with using the equipment to make observations. Same sources as CLE : - Primary sources: [Orion *et al.*, 1997]; [Yunker, 2010] (SOLEI instrument); [Paas, *et al.*, 1994]; [Kuhn, 2010]. - Adapted from [Cors, 2016] ; [Hirth, 2019] ; [Woithe, 2020].]	1) Lors du cours de physique des derniers mois, j’ai pu bien me concentrer sur les activités, sans avoir à me battre avec l’utilisation des applications pour tablettes. ✓CLS1 2) Lors des activités de physique des derniers mois, j’ai reçu des informations suffisantes pour l’utilisation des applications pour les tablettes. ✓CLS2 **Removed from MS** 3) Lors des activités de physique des derniers mois, les applications pour tablettes étaient difficiles à utiliser. ✓CLS3 3) J’ai du fournir un effort pour utiliser les applications des tablettes lors des activités de physique des derniers mois. 4) Lors des activités du cours de physique des derniers mois, j’ai été débordé(e) en essayant de comprendre le fonctionnement des applications pour tablettes. 4) J’ai eu de la peine à utiliser les apps pour tablettes lors du cours de physique des derniers mois. **-> SCS** 5) Lors les activités de physique des derniers mois, j’ai trouvé difficile de comprendre les instructions pour utiliser les applications pour tablettes. ✓CLS4 7) Lors des activités de physique des derniers mois, j’ai eu des problèmes en effectuant les mesures avec les tablettes. ✓CLS5	1) Lors du cours de physique des derniers mois, j’ai pu bien me concentrer sur les activités, l’utilisation des applications ne m’a pas pris trop de concentration. 8) Je trouve pratique d’utiliser des tablettes pour les activités de physique. ✓CLS6 9) L’utilisation des tablettes m’a aidé à mieux comprendre les sujets traités dans le cours de physique des derniers mois. ✓+1 **Removed from MS**	P (only TG)	-	6+1 (TG)
CAE	Cognitive activation during the experiment	CV (Post)		1) I was focused when doing the experiments in … 2) I was actively involved in doing the experiments … 3) I took a critical look at new ideas or material. 4) I tried to distinguish between important and unimportant things when doing the experiments. 5) During the experiments I tried to connect what I was learning with my previous physics knowledge. [Hänze & Berger, 2007 ; Wild, 2000]	1) J’étais concentré lors des expériences de physique des derniers mois. ✓CAE1 2) Je me suis engagé activement lors des expériences de physique des derniers mois. ✓CAE2 3) Lors des expériences de physique des derniers mois, j’ai eu un regard critique sur les idées testées. ✓CAE3 4) Lors des expériences de physique des derniers mois, j’ai essayé de différencier les choses importantes de celles moins importantes. ✓CAE4 5) Lors des activités de physique des derniers mois, j’ai essayé de relier ce que j’étais en train d’apprendre à mes connaissances antérieures de phys. ✓CAE5	**« Negative » items** 6) Lors des activités de physique du dernier semestre, je n’arrivais pas à me concentrer sur les taches assignées.		-	5
INV	Involve-ment	CV (post)	O	1) I discuss ideas in class. 2) I give my opinions during class discussions. 3) The teacher asks me questions. **-> Teacher assessment** 4) My ideas and suggestions are used during classroom discussions. 5) I ask the teacher questions. 6) I explain my ideas to other students. 7) Students discuss with me how to go about solving problems. 8) I am asked to explain how I solve problems. [Dorman, 2003; Fraser *et al.*, 1996] 9) J’ai participé activement pendant les cours de physique des derniers mois. ✓INV1 [Kuhn & Müller, 2015 ; Hoffmann *et al.*, 1997]	1) Pendant les heures de cours de physique des derniers mois, j’ai débattu sur les sujets traités en classe. **Ok for MS (new INV5)** 2) Pendant le cours de physique des derniers mois, j’ai donné mon opinion dans les discussions en classe. 4) Mes idées et/ou mes suggestions ont été prises en compte lors du cours de physique des derniers mois. 5) Pendant les cours de physique des derniers mois, j’ai posé souvent des questions. ✓ INV2 6) Pendant les derniers mois, j’ai expliqué mes idées sur les sujets du cours de physique à mes camarades. ✓INV3 7) Pendant les derniers mois, j’ai souvent discuté avec des camarades sur la résolution des problèmes de physique✓INV4 8) Pendant les derniers mois, on m’a demandé d’expliquer comment j’avais résolu des problèmes de physique. ✓INV5 **Removed from MS**	**« Negative » items** 10) Pendant le cours de physique du dernier semestre, je n’ai pas osé poser des questions.	P	-	5

Table A.2 – continued

SCS	Self-concept regarding apps for Smart-phone	CV (pre, only TG)	O	1) [Using smartphones apps] is easy. [SCE2] 2) I am good [using the apps for Smartphones and tablets.] [SCE3] 3) [Smartphones' apps] help me understanding things. [SCE9] [Marsh, 1990] 4) To me, the computer seems too unreliable to use as learning tool. 5) Sometimes computers do things I do not understand. 6) If I have computer problems while I am working, I feel helpless. 7) When work with a computer, I feel that the computer does what it wants. 8) The computer is an important entertainment medium in my life. [Richter *et al.*, 2000] 9) I would rather watch someone work with a complicated technological thing instead of trying to do it myself. 10) I always seem to do something wrong when I try to use technological things. 11) When I see a new technological thing, the first thing I want to do is play around with it to see what it can do. 12) I would rather play around with a technological thing than waste time reading instructions about how to do it. [Luckay & Brandon, 2011] 13) I use the device: very often / often / rather often / rather rarely / rarely/ very rarely [Hochberg *et al.*, 2017]	1) Je trouve les applications pour smartphones et tablettes faciles à utiliser. 2) Je suis à l'aise avec l'utilisation des applications pour smartphones et tablettes. ✓SCS1 3) Les applications pour smartphones et tablettes m'aident à comprendre des choses. ✓SCS2 4) Les apps pour tablettes et Smartphones me semblent trop peu fiables pour être utilisés comme outils d'apprentissage. Or 4) Les applications pour tablettes ou smartphones ne me semblent pas utiles pour apprendre. ✓SCS3 5) Parfois, les applications pour tablettes ou smartphones font des choses que je ne comprends pas. ✓SCS4 **Removed from MS** 6) Si j'ai des problèmes avec les applications pour tablettes ou Smartphones pendant que je les utilise, je me sens démuni(e). ✓SCS5 7) Quand j'utilise des tablettes ou Smartphones, j'ai l'impression que les applications font ce qu'elles veulent. 8) Mon Smartphone/ma tablette est un important moyen de divertissement pour moi. 9) Je préfère regarder quelqu'un utiliser une nouvelle application à la place d'essayer moi-même. 10) J'ai l'impression de faire toujours quelque chose de faux quand j'utilise une app pour Smartphone ou tablette. 11) Lorsque je vois une nouvelle application, la première chose que j'ai envie de faire est de jouer avec pour voir ce qu'on peut faire. 12) Je préfère jouer avec une novelle app, plutôt que gaspiller du temps en lisant le « mode d'emploi ». 13) J'utilise des applications pour Smartphones ou tablettes : très souvent/souvent/de temps en temps/ rarement/ pratiquement jamais ✓+1	**Use of apps to measure** 13) J'utilise des applications pour Smartphones/tablettes pour effectuer des mesures, comme le temps (chronomètre), le nombre de pas (entrainement physique), etc.✓ « SCS » 6	P	7 (TG)	-
RR	Relation to reality	CV (pre) DV(post)	O	1) Les thèmes (le contenu) du cours de physique des derniers mois sont utiles pour la vie quotidienne. 2) Les exercices du cours de physique des derniers mois sont utiles pour des choses auxquelles je suis confronté(e) en dehors de l'école. 3) Ce que nous avons appris en physique dans les derniers mois est utile pour la vie quotidienne. 4) Les exercices du cours de physique des derniers mois sont utiles dans la vie quotidienne. 5) Le cours de physique des derniers mois a traité de choses de la vie quotidienne. 6) Les thèmes (le contenu) du cours de physique des derniers mois sont utiles pour des choses auxquelles je suis confronté(e) en dehors de l'école. 7) Les exercices du cours de physique des derniers mois sont utiles pour la vie quotidienne. 8) Les exercices du cours de physique des derniers mois se réfèrent à la vie quotidienne. [Kuhn & Müller, 2015]	1) Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne. ✓RR2 2) Les problèmes du cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école. ✓RR1 5) Le cours de physique des derniers mois a traité des situations de la vie quotidienne. ✓RR3 **Removed from MS** 6) Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école. ✓RR4 8) Les problèmes du cours de physique des derniers mois se réfèrent à des situations de la vie quotidienne.	**Personal "sudden" impression** 9) Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne. ✓RR5 **« Negative » items** 10) Je ne vois pas de liens entre les sujets traités dans le cours de physique et la vie de tous les jours. ✓RR6	P	6	6

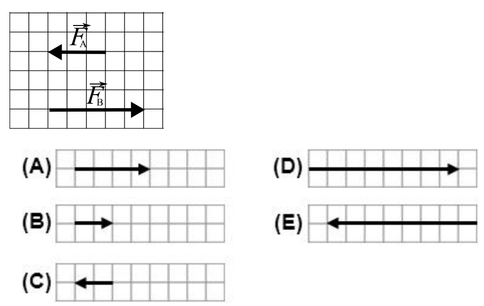
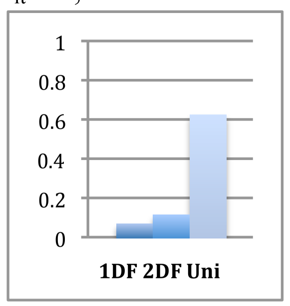
Table A.2 – continued

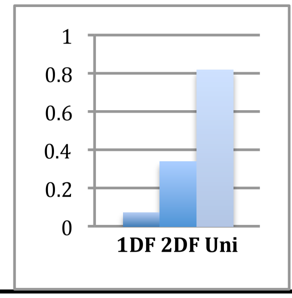
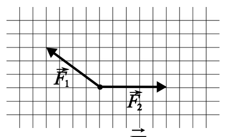
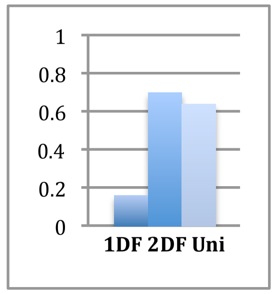
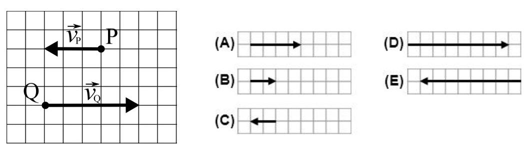
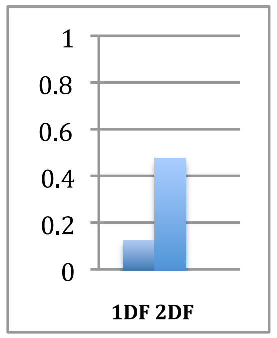
TA	Personal assessment of teacher	CV(post)	O	1) The teacher goes out of his/her way to help me. 2) The teacher helps me when I have trouble with the work. 3) The teacher talks with me. 4) The teacher's questions help me to understand. 5) The teacher moves about the class to talk with me. [Dorman, 2003; Fraser *et al.,* 1996 (WIHIC)] 6) I had the feeling that the teacher is fascinated by physics. 7) The teacher responded to my questions and comments. 8) Out teacher is/was motivating me. *Hochberg, Kuhn & Müller (2017)* 9) In the last physics classes, the teacher seemed to be more involved than usually [Vogt, 2010]	1) Pendant le cours de physique des derniers mois, l'enseignant(e) s'est donné(e) de la peine pour nous aider. 2) Pendant le cours de physique des derniers mois, l'enseignant(e) a pris du temps pour nous aider quand nous avions des problèmes avec les tâches assignées. ✓AT1 3) Pendant le cours de physique des derniers mois, l'enseignant(e) a discuté avec moi. 4) Pendant le cours de physique des derniers mois, les explications de l'enseignant(e) nous ont aidé à mieux comprendre les sujets traités. ✓AT2 5) Pendant le cours de physique des derniers mois, l'enseignant(e) s'est déplacé(e) dans la classe pour répondre aux questions. 6) Pendant le cours de physique des derniers mois, l'enseignant(e) donnait l'impression d'être passionné(e) par la physique. ✓AT3 **Removed from MS** 7) Pendant le cours de physique des derniers mois, l'enseignant(e) a répondu à nos questions. 8) Pendant le cours de physique des derniers mois, l'enseignant(e) nous encourageait. ✓AT4 9) Pendant le cours de physique des derniers mois, l'enseignant(e) semblait particulièrement engagé. **New item 3 for the MS AT3**	**Other formulation (not confusing with involvement or active participation)** 5) Pendant le cours de physique des derniers mois, l'enseignant(e) s'est déplacé(e) dans la classe pour répondre à nos questions. ✓AT5	P	-	5
SA	Spatial abilities / non verbal intelligence	CV (pre)	O	Mental Rotation test [Albaret & Aubert, 1996] Paper folding test ✓ [Elkstrom *et al.*, 1976]	-		P	2	
RC	Reading comprehension	-	I	French average grade	-	-	S	-	-
GE	Gender	CV	D	Male or female M or F	-	-	S	-	-
PG	Physics average grade	CV (pre) DV(post)	I	Problem solving tests average grade	-		S	-	-
GR	Group	IV	D	Treatment or control group (TG or CG)	-		S	-	-
LPR LPO	Concept learning achievement (QCM)	CV (pre) DV(post)	D	Concept test	-		Concept test	-	-
MG	Math average grade	CV (pre) DV(post)	I	Mathematics average grade	-		S	-	-
OS	Specific option	CV	N	English, Spanish, Latin, Bio-Chemistry, Economy, Visual Arts	-		S	-	-
T	Teacher	CV		Teacher 1, 2, 3, 4	-		S		
							Total (PS)	40 +2 SA	62

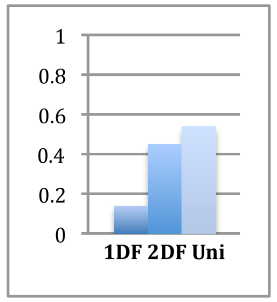
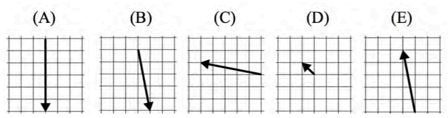
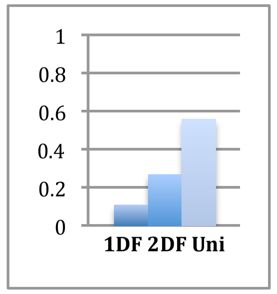
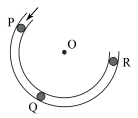
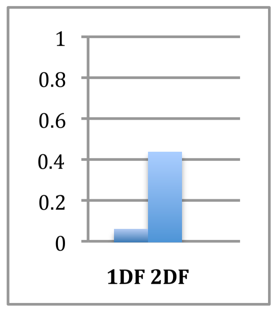
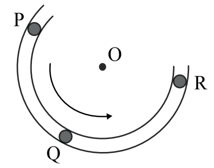
Table A.3: Instrument and tem analysis of the validation concept test (see explanation in section 3.5). The multiple choice question are either taken as is (14 items), or adapted (7 items) from existing tests in the literature, or created for this study (10 items). Analysis for the restrained post-test means taking only into account a selection of items composing the post-test of the pilot study. Abbreviations: FCI = Force Concept Inventory [Hestenes *et al.,* 1992]; TUG = Test of Understanding Graphs in Kinematics [Beichner, 1994]; TUV = Test of Understanding Vectors (TUV) [Barinol *et al.* 2014]; MBL = Mechanic Baseline test [Hestenes *et al*., 1992]; 1D and 2D = one- or two-dimensional motion.

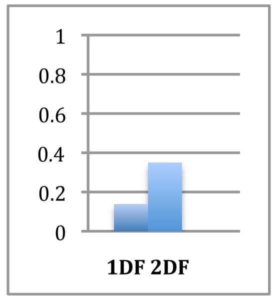
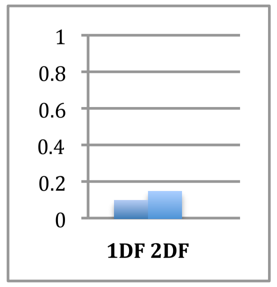
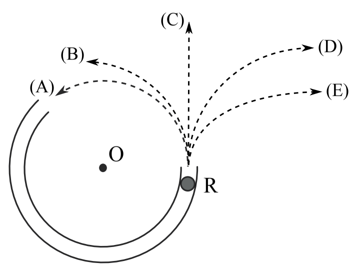
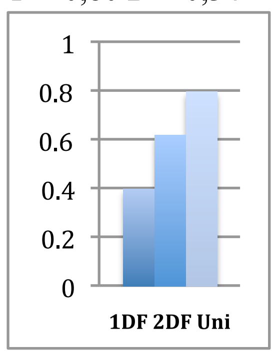
Validation analysis as pre-test (total of 31 items)	**Validation analysis as post-test (total of 31 items)**	**Validation analysis as restrained post-test, i.e. containing only the items selected for the pilot study (17 items)**
(25 items for test A with N=96 + 25 items for test B with N=68) : Item analysis: - 19 commons items (N=145; k=19) $\alpha_C = 0{,}50$; $\delta = 0{,}89$ - 6 items only for test A (N=96; k=25) $\alpha_C = 0{,}40$; $\delta = 0{,}88$ - 6 items only for test B (N=68; k=25) $\alpha_C = 0{,}71$; $\delta = 0{,}90$	25 items for test A (N=61) + 25 items for test B (N=50) : Item analysis: - 19 commons items (N=111; k=19) $\alpha_C = 0{,}71$; $\delta = 0{,}93$ - 6 items only for test A (N=61; k=25) $\alpha_C = 0{,}74$; $\delta = 0{,}92$ - 6 items only for test B (N=50; k=25) $\alpha_C = 0{,}77$; $\delta = 0{,}91$	25 items for test A (N=61) + 25 items for test B (N=50) : Item analysis: - 11 commons items (N=111; k=11) $\alpha_C = 0{,}67$; $\delta = 0{,}89$ - 2 items only for test A (N=61; k=13) $\alpha_C = 0{,}68$; $\delta = 0{,}91$ - 4 items only for test B (N=50; k=15) $\alpha_C = 0{,}74$; $\delta = 0{,}92$ + 3 items selected for the pilot study hors analysis: 2 items only for test A (items 8 and 9) + new item (item 17 replaced by item 30 MCT)

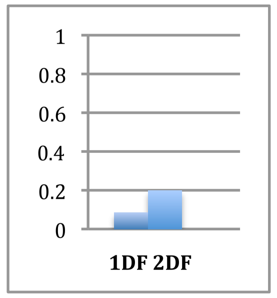
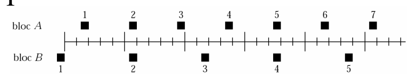
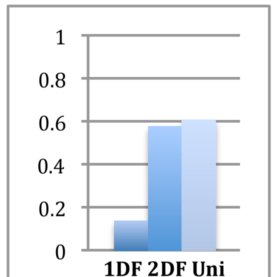
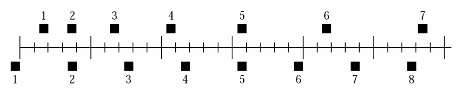
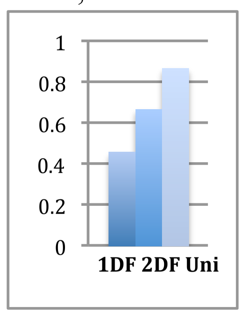
For the 19 common items as post-test (N=111, k=19)	**Mean value**	**Range of values**	**Desired range**	**For the 11 selected common items as post-test (N=111, k=11)**	**Mean value**	**Range of values**	**Desired range**
Difficulty P	0,54	$0{,}20 \le P \le 0{,}89$	$0{,}3 \le P \le 0{,}9$	Difficulty P	0,46	$0{,}20 \le P \le 0{,}77$	$0{,}3 \le P \le 0{,}9$
Discrimination D	0,47	$0{,}19 \le D \le 0{,}75$	$D \ge 0{,}3$	Discrimination D	0,56	$0{,}30 \le D \le 0{,}79$	$D \ge 0{,}3$
Item-test correlation r_{it}	0,40	$0{,}22 \le r_{it} \le 0{,}58$	$r_{it} \ge 0{,}2$	Item-test correlation r_{it}	0,48	$0{,}30 \le r_{it} \le 0{,}62$	$r_{it} \ge 0{,}2$

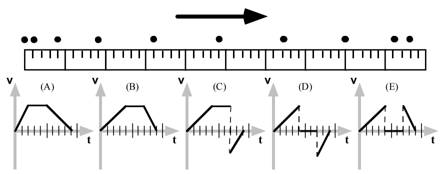
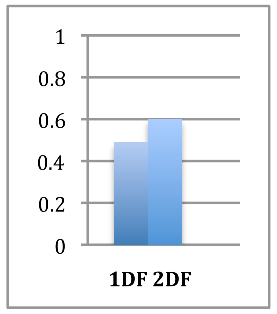
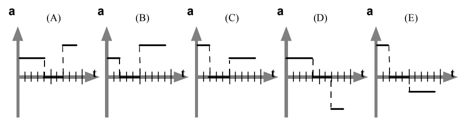
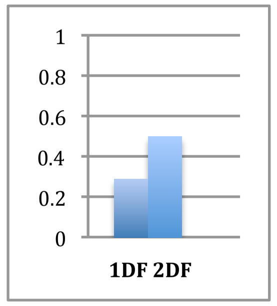
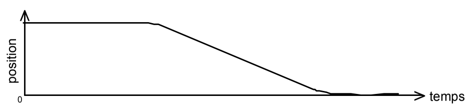
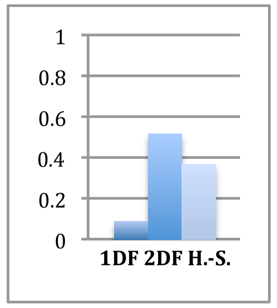
Item	**Corresp. item from literature**	**Tested concepts + *Reason(s) to change or create***	**Answers as pre-test**	**Answers as post-test (relied misconception)**	**Analysis as pre-test**	**Analysis As post-test**	**Difficulty P in previous analysis on high school (H. S.) or University students (Uni) & comparing histogram**	**$\alpha_{without\ item}$ (test) α_{test}**	**MDETs activity connected (see table A.1) + Remarks + Selected for pilot study (Yes or No) + Possible modifications**	**Replacing by an item from MCT**	**Analysis for restrained post-test**	**$\alpha_{without\ item}$ restrained post-test (items selected for the pilot study) $\alpha_{restr.\ test}$**
			*** = Right answer Bold = most given <u>Underlined</u> = misconception**									
1) La figure ci-contre représente les deux vecteurs $\vec{F}_A$ et $\vec{F}_B$. Parmi les options ci-dessous, choisissez celle qui représente le vecteur différence $\vec{F}_A - \vec{F}_B$. 	Adapted from 19 of TUV Goes with item 4	Difference between vectors (1D) *Change vectors A and B with forces F_A and F_B*	A: 1 B: **<u>42</u>** C: 11 D: 3 E: 5* 0: 6	A: 0 B: **<u>34</u>** (confuse A-B/A+B) C: 10 D: 0 (confuse A-B/B-A) E: 6* 0: 0	Test B P = 0,074 D = 0,045 $r_{it} = 0{,}14$	Test B P = 0,12 D = 0,21 $r_{it} = 0{,}23$	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,63 D = 0,65 $r_{it} = 0{,}54$ 	0,764392 (Test B) 0,765257	No MDETs activity directly connected (see table A.1). Low P No	-	-	-

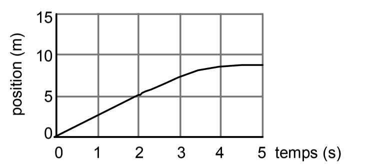
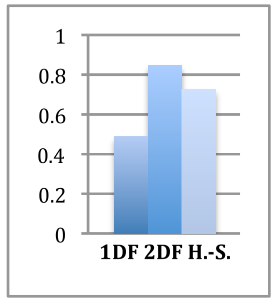
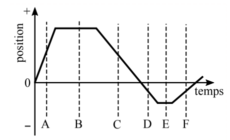
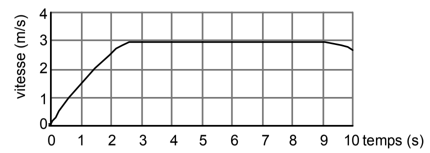
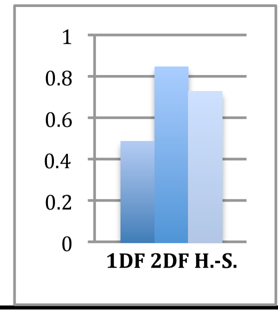
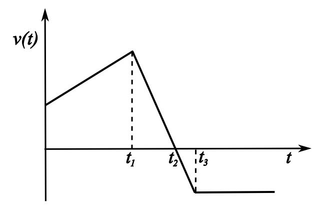
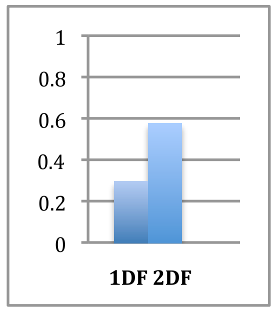
2) Dans un repère orthonormé du plan gradué en mètres (m), un point P est caractérisé par sa position $\vec{r} = (2\text{m}; 2\text{m})$. Parmi les options ci-dessous, laquelle exprime la norme de ce vecteur ? (A)2m; (B)$\sqrt{8}$m; (C)4m; (D)(2 ; 2); (E)8m^2	Adapted from 20 of TUV	Magnitude of a position vector (2D) *Add a physical value and units to mathematical quantities*	A: 18 B: 12* C: 31 **<u>D: 83</u>** E: 0 0: 20	A: 12 B: 38* C: 16 D: **<u>40</u>** (confuse magnitude and coordinates) E: 2 0: 3	Test comm. P = 0,073 D = 0,12 r_{it} = 0,24	Test comm. P = 0,34 D = 0,54 r_{it} = 0,46	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,82 D = 0,43 r_{it} = 0,45  	0,695103 (Test comm.) 0,71204	Activity 1 MDETs (see table A.1). Not directly present in the kinematics or dynamics curriculum. No	-			-
3) Un objet subit les deux forces représentées dans la figure ci-contre. Ces deux forces ont la même intensité. Dans ces conditions, la force résultante sur l'objet est  (A) plus intense que $\vec{F}_1$, et cela se déduit en utilisant le théorème de Pythagore (B) est moins intense que $\vec{F}_1$, parce que en faisant la somme graphiquement on trouve un vecteur plus petit. (C) est plus intense que $\vec{F}_1$, parce que la somme de deux vecteurs donne toujours un vecteur plus grand que les vecteurs qui sont additionnés. (D) a la même intensité que $\vec{F}_1$, et cela se déduit en utilisant le théorème de Pythagore. (E) est plus intense que $\vec{F}_1$, parce que la distance entre les deux bouts des flèches est plus grande que la longueur du vecteur $\vec{F}_1$.	Adapted from 16 of TUV	Net resultant force (vector sum) *Add a physical value and units to mathematical quantities*	A: 10 B: 26* **<u>C: 35</u>** D: 30 E: 31 0: 32	A: 3 **B: 78*** C: 10 (magnitude of a sum of vectors is equal to the sum of magnitudes) D: E: 10 0: 1	Test comm. P = 0,16 D = 0,12 r_{it} = 0,24	Test comm. P = 0,70 D = 0,52 r_{it} = 0,39	Barinol & Zavala 2014 (Uni 1st year) P = 0,64 D = 0,60 r_{it} = 0,50  	0,70230 (Test comm..) 0,71204	No MDETs activity directly connected (see table A.1). Not directly present in the 2nd year kinematics or dynamics curriculum. No	-			-
4) La figure ci-dessous représente les vitesses de deux corps à un instant donné, le premier au point P et le deuxième au point Q. Parmi les options ci-dessous, choisissez celle qui représente la vitesse avec laquelle le corps en P voit se déplacer le corps en Q.  	Adapted from 19 of TUV Goes with item 1	Relative velocity 1D - Difference between velocity vectors *Add a physical value to mathematical quantities*	A: 8 **<u>B: 27</u>** C: 7 D: 9* E: 7 0: 10	A: 1 B: 19 (confuse A-B/A+B) C: 1 **D: 24*** E: 5 (confuse A-B/B-A) 0: 0	Test B P = 0,13 D = 0,27 r_{it} = 0,31	Test B P = 0,48 D = 0,39 r_{it} = 0,25 Better P than item 1 (0,12)!	-  	0,76796 (Test B) 0,76526	No MDETs activity directly connected (see table A.1). Relative velocity => not covered by all the teachers Decreasing alpha No	-			-

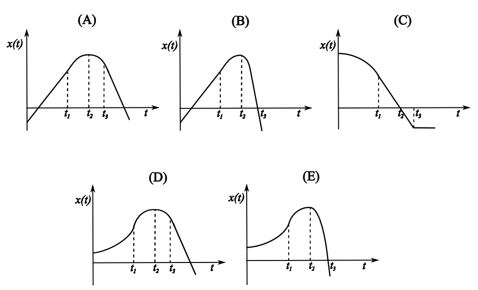
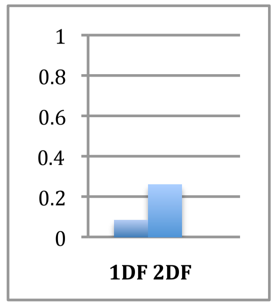
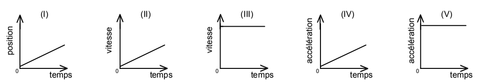
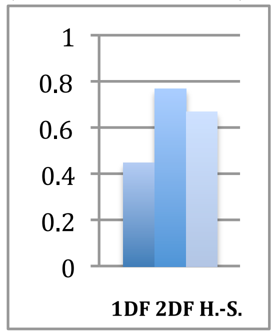
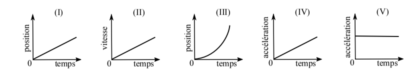
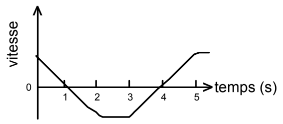
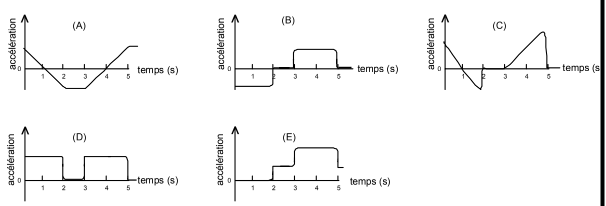
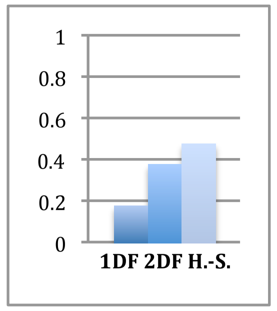
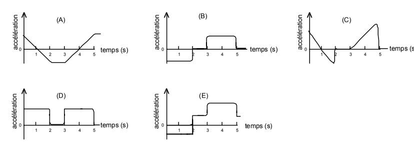
5) Dans un repère orthonormé du plan gradué en mètres (m), un point P est caractérisé par sa position $\vec{r} = (-3\text{m}; +4\text{m})$. Quel est l'angle formé par cette position avec la direction positive de l'axe *x*? (A)126,87°; (B)53,13°; (C)143,13°; (D)135°; (E)-53,13°	Adapted from 17 of TUV	Direction of a position vector 2D *Add a physical value to mathematical quantities*	A: 13* **B: 36** C: 7 D: 10 E: 6 0: 24	**A: 28*** B: 7 (not take into account - sign) C: 5 D: 11 E: 10 0: 0	Test A P = 0,14 D = 0,25 r_{it} = 0,31	Test A P = 0,45 D = 0,33 r_{it} = 0,33	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,54 D = 0,59 r_{it} = 0,43 	0,72344 (Test A) 0,74144	Activity 1 MDETs Not directly present in the kinematics or dynamics curriculum. No	-			-
6) La figure ci-contre représente les vitesses de deux corps à un instant donné, le premier au point P et le deuxième au point Q. Parmi les options ci-dessous, choisissez celle qui représente la vitesse avec laquelle le corps en P voit se déplacer le corps en Q 	Adapted from 13 of TUV	Difference between velocity vectors/relative velocity 2D *Add a physical value to math. quantities+ separated point of application*	A: 18 B: 11* **C: 28** D: 22 E: 0 0: 17	A: 13 **B: 17*** C: 14 (confuse A-B/A+B) D: 11 (diff of the magnitudes) E: 3 0: 3	Test A P = 0,11 D = 0,036 r_{it} = 0,033	Test A P = 0,27 D = 0,47 r_{it} = 0,39	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,56 D = 0,71 r_{it} = 0,56 	0,732693 (Test A) 0,74144	No MDETs activity directly connected (see table A.1). Relative velocity => not covered by all the teachers Low P No	-			-
7) La vitesse instantanée de la balle au point P, $\vec{v}_P$, peut se représenter  (A) par une flèche qui part du point P et se termine nécessairement au point R. (B) par une flèche qui part du point P et se termine nécessairement au point Q. (C) par une flèche tangente à la trajectoire au point P. (D) par une flèche dirigée du point P au point R, mais qui ne se termine pas nécessairement au point R. (E) par aucune flèche, car la vitesse instantanée est une grandeur scalaire	Created from situation of 5 & 6 of FCI Goes with items 8 and 9	Instant velocity vector 2D *Not in the known previous tests*	A: 8 B: 3 C: 6* **D: 50** E: 24 0: 5	A: 3 (conf. inst. v and displacement) B: 3 **C: 27*** D: 10 (confuse inst. and av. v) E: 17 (conf velocity and speed) 0: 1	Test A P = 0,063 D = 0,17 r_{it} = 0,31	Test A P = 0,44 D = 0,67 r_{it} = 0,50	- 	0,73579 (Test A) 0,74144	Activity 1 MDETs Strong D Yes Modification: change the drawing: 	-	Test A P = 0,44 D = 0,62 r_{it} = 0,49	0,6609 (Test A) 0,6784	Post

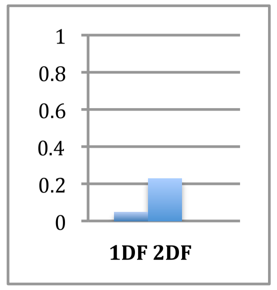
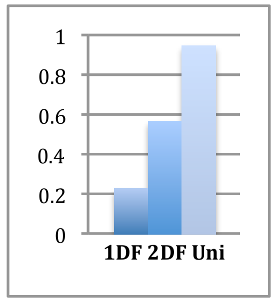
8) La vitesse moyenne de la balle du point P au point R , $\vec{v}_{mPR}$, peut se représenter (A) par une flèche tangente à la trajectoire au point Q. (B) par une flèche tangente à la trajectoire au point P. (C) par une flèche qui part du point P et se termine nécessairement au point R. (D) par une flèche qui part du point R et se termine nécessairement au point P. (E) par une flèche dirigée du point P au point R, mais qui ne se termine pas nécessairement au point R. (F) par aucune flèche, car il s'agit d'une quantité scalaire.	Created from situation of 5 & 6 of FCI Goes with items 7 and 9	Average velocity vector 2D *Not in the known std tests*	A: 10 B: 12 **<u>C: 25</u>** D: 5 E: 13* <u>F: 18</u> <u>0: 13</u>	A: 5 (conf. inst. and av. vel.) B: 3 (conf. inst. and average v) C: 16 (confuse average v and displ.) D: 2 **E: 22*** F: 10 (conf. veloc. and speed) 0: 3	Test A P = 0,14 D = 0,20 r_{it} = 0,17	Test A P = 0,35 D = 0,53 r_{it} = 0,39	- 	0,74480 (Test A) 0,74144	Activity 1 MDETs Understanding the average vector velocity is an important and difficult concept, never tested in the previous literature tests. Yes: <u>Separated analysis</u> <u>Modification</u>: point (D) dropped ("par une flèche qui part du point R et se termine nécessairement au point P"), to have 5 choices, as in the other items.	-			Post
9) Dans son mouvement du point P au point Q, l'accélération moyenne de la balle $\vec{a}_{mPQ}$ peut se représenter (A) par une flèche tangente à la trajectoire au point P. (B) par une flèche tangente à la trajectoire au point Q. (C) par une flèche dirigée du point P au point Q. (D) par une flèche perpendicul. au segment PQ. (E) par aucune flèche : l'accélération vaut zéro parce que l'intensité de sa vitesse est const.	Created from situation of 5 & 6 of FCI Goes with items 7 and 8	Average acceleration vector 2D - Difference between velocity vectors 2D *Not in the known std tests*	A: 4 <u>B: 12</u> <u>C: 20</u> D: 10* **<u>E: 37</u>** 0: 13	A: 1 B: 1 C: 1 (conf. av. a and av. v) D: 9* **<u>E: 48</u>** (no variation of speed = no acc.) 0: 1	Test A P = 0,10 D = 0,17 r_{it} = 0,30	Test A P = 0,15 D = 0,27 r_{it} = 0,31	- 	0,736608 (Test A) 0,741435	Activity 4 MDETs Strong misconception: "no variation of speed means no acceleration" Yes: <u>Separated analysis</u>	-			Post
10) On néglige tout frottement de la table et de l'air. Laquelle des 5 lignes en traitillé dans la figure ci-dessous représente le mieux la trajectoire que la balle suivra à sa sortie en R? 	Adapted form 6 of FCI (changing the possible "false" trajectories)	1st Newton law *Trajectory extending the circular path instead of trajectory 5 of item 6 of FCI (see corresp. misconception)*	A: 17 B: 54 **C: 66*** D: 9 E: 6 0: 13	A: 8 (inertia = keep on a circular motion) B: 29 **C: 69*** D: 3 E: 0 0: 2	Test comm. P = 0,40 D = 0,14 r_{it} = 0,28	Test comm. P = 0,62 D = 0,34 r_{it} = 0,22	[Traxler *et al.*, 2018] (Uni 1st year) P = 0,80 D = 0,34 	0,72066 (Test comm.) 0,71204	No MDETs activity directly connected (see table A.1). Decreasing alpha Small learning gain No	-			-

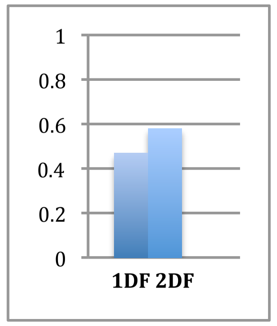
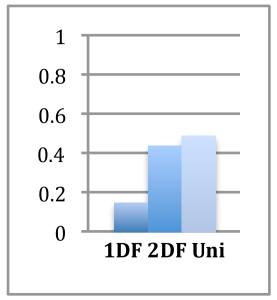
11) Un cycliste a effectué l'ascension d'un col à la vitesse scalaire moyenne de 30km/h, puis la descente, par le même chemin, à la vitesse scalaire moyenne de 60km/h. La vitesse scalaire moyenne totale du voyage a été (A) 45km/h. (B) moins que 45km/h. (C) plus que 45km/h. (D) nulle. (E) les informations fournies ne sont pas suffisantes pour répondre à la question.	Created	Average speed and the average of two speeds *Not found in the known std tests*	**A: 112** (77%) B: 14* C: 12 D: 4 E: 17 0: 5	**A: 57** (51%) (av. speed = math. av. of two speeds) B: 22* C: 3 D: 1 (zero) E: 27 (no enough inform.) 0: 0	Test comm. P = 0,085 D = 0,10 r_{it} = 0,21	Test comm. P = 0,20 D = 0,31 r_{it} = 0,30	[Reed & Saaveedra, 1986] Answer A: 84% 	0,7087 (Test comm.) 0,71204	Activity 2 MDETs Strong misconception: only item testing the second level of understanding of the average speed task [Reed & Saavedra, 1986] Yes	24 MCT	Test comm. P = 0,20 D = 0,30 r_{it} = 0,30	0,6763 (Test comm.) 0,6706	Pre + Post
12) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.  À propos de l'accélérations de ces deux blocs on peut dire que (A) l'accélération de A est plus grande que l'accélération de B. (B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro. (C) l'accélération de B est plus grande que l'accélération de A. (D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles. (E) les informations fournies ne sont pas suffisantes pour répondre à la question.	20 of FCI	Visualize acceleration from trajectory in linear motion (positions at equals durations)	A: 39 B: 9 **C: 82** D: 23* E: 7 0: 4	A: 12 (confuse x and a) B: 7 C: 23 (confuse v and a) **D: 64*** E: 3 0: 2	Test comm. P = 0,14 D = 0,19 r_{it} = 0,37	Test comm. P = 0,58 D = 0,75 r_{it} = 0,58	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,61 D = 0,55  P ≈ 0,42 in Scott *et al.* 2012 (Uni + H.S.)	0,68065 (Test common) 0,71204	Activities 3 and 5 MDETs Yes	60 MCT	Test comm. P = 0,58 D = 0,79 r_{it} = 0,62	0,6185 (Test comm.) 0,6706	Pre + Post
13) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de 0,20s. Les blocs se déplacent vers la droite.  Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse? (A) Non. (B) Oui, à l'instant 2. (C) Oui, à l'instant 5. (D) Oui, à l'instant 2 et 5. (E) Oui, à un certain temps dans l'intervalle entre les instants 3 et 4.	19 of FCI	Visualise velocity from trajectory in linear motion (positions at equals durations)	A: 13 B: 6 C: 10 D: 57 **E: 76*** 0: 2	A: 14 B: 0 C: 0 D: 22 (confuse position and v) **E: 74*** 0: 1	Test comm. P = 0,46 D = 0,22 r_{it} = 0,44	Test comm. P = 0,67 D = 0,70 r_{it} = 0,55	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,87 D = 0,33  P ≈ 0,48 in [Scott *et al.* 2012] (Uni + H.S.)	0,68426 (Test common) 0,71204	Activities 3 and 5 MDETs High D as pre-test "Easy item" Yes	59, 64 MCT	Test comm. P = 0,67 D = 0,70 r_{it} = 0,57	0,6302 (Test comm.) 0,6706	Pre + Post

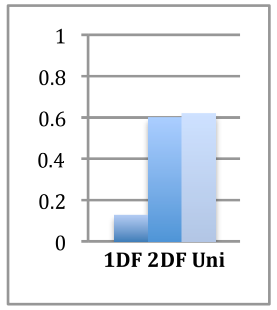
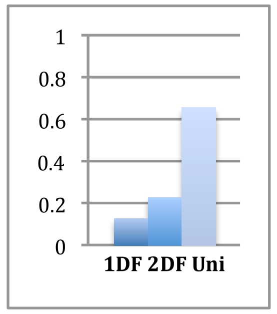
14) Les points de la figure ci-dessous représentent la position d'un objet à des intervalles de temps égaux. L'objet se déplace vers la droite sur une surface horizontale. Lequel de ces graphiques représente le mieux la vitesse de l'objet en fonction du temps ? 	1 of MBT Goes with item 15	Velocity diagram from trajectory in linear motion (positions at equals durations)	A: 12 **B: 33*** C: 3 D: 5 E: 4 0: 11	A: 18 **B: 30*** C: 0 D: 0 E: 2 0: 0	Test B P = 0,49 D = 0,66 r_{it} = 0,50	Test B P = 0,60 D = 0,50 r_{it} = 0,39	- 	0,75790 (Test B) 0,76526	Activities 3, 5 and 6 MDETs High D as pre-test Yes		Test B P = 0,60 D = 0,54 r_{it} = 0,48	0,7274 (Test B) 0,7419	Pre + Post
15) Lequel de ces graphiques représente le mieux l'accélération de l'objet en fonction du temps ? 	2 of MBT Goes with item 14	Acceleration diagram from 1D trajectory (positions at equals durations) or from previous velocity diagram	A: 8 B: 7 C: 17 **D: 20*** E: 1 0: 15	A: 5 B: 5 C: 6 **D: 25*** E: 9 0: 0	Test B P = 0,29 D = 0,70 r_{it} = 0,56	Test B P = 0,50 D = 0,41 r_{it} = 0,30	- 	0,76467 (Test B) 0,76526	Activities 3, 5 and 6 MDETs Yes	65 MCT	Test B P = 0,50 D = 0,63 r_{it} = 0,39	0,7381 (Test B) 0,7419	Post
16) Voici le diagramme horaire du mouvement d'un objet. Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?  (A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête. (B) Initialement l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête. (C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête. (D) Initialement, l'objet ne bouge pas. Par la suite il recule et il s'arrête. (E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.	8 of TUG	Description of a position-to-time diagram 1D *Arrows added in the graph*	A: 29 B: 40 **C: 46** D: 15* E: 32 0: 2	A: 7 (conf. time diag. and trajectory) B: 15 (conf. time diag. and trajectory) C: 29 (conf. time diag. and v(t)diag.) **D: 58*** E: 2 (conf. time diag. & trajectory) 0: 0	Test comm. P = 0,091 D = 0,14 r_{it} = 0,27	Test comm. P = 0,52 D = 0,48 r_{it} = 0,42	[Beichner, 1994] (H.S.) P = 0,37 r_{it} = 0,75 (Res:11,11,37,37,5,0) 	0,69970 (Test comm.) 0,71204	Activities 3 MDETs Yes	31 MCT	Test comm. P = 0,52 D = 0,59 r_{it} = 0,47	0,6549 (Test comm.) 0,6706	Pre + Post

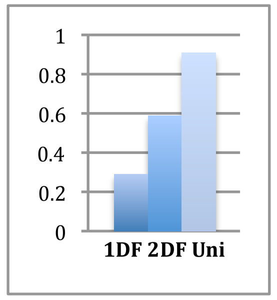
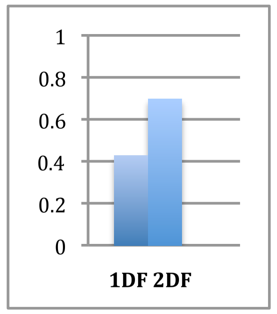
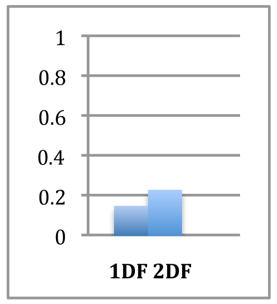
17) En se référant au diagramme horaire suivant, représentant le mouvement d'un objet, la vitesse à l'instant t = 2s est (A) 0,4m/s; (B) 2,0m/s; (C) 2,5m/s; (D)5,0m/s; (E)10,0m/s 	5 of TUG	Instant velocity as slope in the position to time diagram 1D	A: 0 B: 0 **C: 94*** D: 15 E: 1 0: 1	A: 0 B: 0 **C: 94*** D: 15 (conf. x and v in time diag.) E: 1 0: 1	Test comm. P = 0,49 D = 0,23 r_{it} = 0,45	Test comm. P = 0,85 D = 0,29 r_{it} = 0,31	[Beichner, 1994] (H.S.) P = 0,73 D = ? r_{it} = 0,78 (Res:3,2,73,18,4,0) 	0,70658 (Test comm..) 0,71204	No MDETs activity directly connected (see table A.1). High P as pre-test, low D as post-test Calculations => not a completely "concept" item Items 17 replaced by item 30 MCT "Voici le diagramme du mouvement d'une voiture. À quel couple d'inst. la vitesse de la voiture est la même ? 	Item 30 MCT			-Pre + Post
18) Un corps se déplace avec un mouvement rectiligne selon le graphique ci-dessous. Combien de mètres parcourt-il durant la durée comprise entre t = 4s et t = 8s ? (A) 0,75m; (B) 3,0m; (C) 4 ,0m; (D) 8,0m; (E) 12m 	20 of TUG	Determine displacement of a uniform linear motion using the velocity to time diagram 1D	A: 6 B: 27 C: 48 D: 7 **E: 66*** 0: 10	A: 4 B: 1 C: 5 D: 2 **E: 99*** 0: 0	Test comm. P = 0,40 D = 0,23 r_{it} = 0,49	Test comm. P = 0,89 D = 0,19 r_{it} = 0,26	[Beichner, 1994] (H.S.) P = 0,71 r_{it} = 0,82 (Res:11,6,10,2,72,1) 	0,70942 (Test comm.) 0,712037	No MDETs activity directly connected (see table A.1). High P in as pre-test, low D as post-test Calculations => not a completely "concept" item No				-
19) Le graphique ci-contre représente la vitesse d'un vélo en mouvement rectiligne pendant un certain intervalle de temps.  Le vélo a un mouvement rectiligne et uniforme (A) seulement pour $t < t_1$. (B) seulement pour $t_1 < t < t_3$. (C) seulement pour $t > t_3$. (D) pour $t < t_1$ et pour $t_1 < t < t_3$, avec un changement de vitesse à l'instant t_1. (E) jamais.	Created (Goes with item 20)	Recognize a uniform linear motion from the velocity-to-time diagram *Not tested in the known std tests*	A: 8 B: 14 **C: 49*** D: 31 E: 29 0: 33	A: 4 B: 6 **C: 64*** D: 29 (conf. v(t) and x(t) diagram) E: 15 0: 2	Test comm. P = 0,30 D = 0,24 r_{it} = 0,48	Test comm. P = 0,58 D = 0,38 r_{it} = 0,30	- 	0,71279 (Test common) 0,71204	Activities 5 and 6 MDETs Same (easy) concept tested in item 21 No				-

20) Parmi les options ci-dessous, choisissez celle qui pourrait représenter le diagramme horaire du mouvement du vélo 	Created (Goes with item 19)	Interpretation of a v(t) diagram (find the corresp. x(t) diag => parabola) *Not in the known std tests (but close to item 11 of TUG)*	A: 14 B: 16 **<u>C: 64</u>** D: 14* <u>E: 28</u> 0: 28	A: 14 B: 17 <u>C: 25</u> (when v is zero, a is zero too: conf. a and v) **D: 29*** <u>E: 23</u> (no ULM after t3) 0: 3	Test comm. P = 0,085 D = 0,095 r_{it} = 0,19	Test comm. P = 0,26 D = 0,45 r_{it} = 0,47	- 	0,693394 (Test common) 0,712037	Activities 5 and 6 MDETs Yes	29 MCT	Test comm. P = 0,26 D = 0,52 r_{it} = 0,46	0,6549 (Test comm.) 0,6520	Post
21) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.  Lequel ou lesquels représente(ent) un mouvement à vitesse constante ? (A) I, II et IV; (B) I et III; (C) II et V; (D) IV seulement; (E) V seulement	12 of TUG	Recognize *a(t)/v(t)/x(t)* diagrams representing a motion with constant velocity 1D *Arrows added in the graphs*	A: 27 **B: 73*** C: 14 D: 3 E: 30 0: 17	A: 5 **B: 86*** C: 10 D: 0 E: 9 0: 1	Test comm. P = 0,45 D = 0,18 r_{it} = 0,36	Test comm. P = 0,77 D = 0,48 r_{it} = 0,45	[Beichner, 1994] (H.S.) P = 0,67 r_{it} = 0,86 (Res:14,67,8,2,9,0) 	0,69519 (Test comm) 0,71204	Activity 3 MDETs Multiple options answers "Easy item" Yes <u>Modification</u> of the 3rd graph, to have one graph corresponding to each answer. (same nomber of graph for each answer)  (A) I; (B) II; (C) III; (D) IV; (E) V		Test comm. P = 0,77 D = 0,57 r_{it} = 0,51	0,6415 (Test comm.) 0,6706	Pre + Post
22) Le graphique ci-contre montre le diagramme de vitesse d'un corps en mouvement rectiligne, pendant une durée de 5 secondes.  Lequel de ces graphiques représente le mieux l'accélération en fonction du temps durant le même intervalle de temps ? 	14 of TUG	Interpretation of a velocity-to-time diagram (find the corresponding acceleration-to-time diagram, 1D) *Arrows added in the graphs*	**<u>A: 19</u>** B: 12* C: 17 D: 10 E: 2 0: 8	A: 14 (conf. a and v diag) **B: 19*** C: 14 D: 3 E: 0 0: 0	Test B P = 0,18 D = 0,28 r_{it} = 0,45	Test B P = 0,38 D = 0,82 r_{it} = 0,66	[Beichner, 1994] (H.S.) P = 0,48 r_{it} = 0,90 (Res:25,48,15,9,3,0) 	0,73811 (Test B) 0,76526	Activities 5 and 6 MDETs Yes <u>Modification</u>: Graph answer (E): start with a negative acceleration: 		Test B P = 0,38 D = 0,84 r_{it} = 0,69	0,6998 (Test B) 0,7419	Post

23) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut. L'accélération du caillou est maximale (A) dans l'instant juste après avoir été lancé. (B) dans l'instant juste avant d'être repris. (C) dans les deux instants juste après avoir été lancé et juste avant d'être repris. Dans ces deux instants l'accélération possède la même valeur. (D) au moment où sa hauteur est maximale. (E) il n'y a pas d'accélération maximale, elle est constante pendant toute la durée du vol.	Created	Gravity acceleration during a free fall with change in velocity's orientation 1D *Not in the known std tests, but close to item 13 of FCI, with a replaced by F*	A: 27 B: 48 **C: 60** D: 13 E: 8* 0: 8	**A: 28** (conf. velocity and acc.) B: 17 **C: 36** (conf. speed and acc.) D: 5 (conf. position and acc.) E: 25* 0: 0	Test comm. P = 0,049 D = 0,028 r_{it} = 0,056	Test comm. P = 0,23 D = 0,39 r_{it} = 0,37	-  P ≈ 0,28 in [Scott *et al.*, 2012] (Uni + H.S.)	0,70328 (Test comm.) 0,71204	Activities 4, 5 and 6 MDETs Strong misconception: acceleration *g* changes during the free fall: Yes Modification: Different formulation: " L'accélération du caillou (A) est maximale dans l'instant juste après avoir été lancé. (B) est maximale dans l'instant juste avant d'être repris. (C) est maximale dans les deux instants juste après avoir été lancé et juste avant d'être repris. (D) est maximale au moment où sa hauteur est maximale. (E) est constante pendant toute la durée du vol."	45, 46, 50, 51 MCT	Test comm. P = 0,23 D = 0,37 r_{it} = 0,44	0,6541 (Test comm.) 0,6706	Pre + Post
24) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air. Le temps pris par les balles pour atteindre le sol est (A) la moitié pour la balle plus lourde que pour la balle plus légère. (B) la moitié pour la balle plus légère que pour la balle plus lourde. (C) pareil pour les deux balles. (D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié. (E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.	1 of FCI	Kinematics of free falling different bodies – covered distance 1D R*emoved all the "about" (no friction)*	A: 28 B: 11 C: 37* **D: 63** E: 20 0: 5	A: 13 (fall time is inv. prop to *m*) B: 6 **C: 63*** D: 17 (heavier bodies fall faster / conf. *F* and *a*) E: 11 0: 1	Test comm. P = 0,23 D = 0,18 r_{it} = 0,36	Test comm. P = 0,57 D = 0,56 r_{it} = 0,43	[Barinol & Zavala, 2014] (Uni 1st year) P = 0,95 D = 0,13  P ≈ 0,88 in [Scott *et al.* 2012] (Uni + H.S.)	0,69832 (Test comm.) 0,71204	Activities 5 and 6 MDETs Strong misconception: in a free fall, a different mass gives a different kinematics Yes	-	Test comm. P = 0,57 D = 0,63 r_{it} = 0,54	0,6473 (Test comm.) 0,6706	Pre + Post

25) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air. Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est (A) la moitié que pour la balle lâchée depuis plus bas. (B) le même que pour la balle lâchée depuis plus bas. (C) le double que pour la balle lâchée depuis plus bas. (D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double. (E) plus grand que le double que pour la balle lâchée depuis plus bas.	Created from situation of 1 of FCI	Quadratic relationship between distance and time in free fall (uniformly accelerated linear motion) *Not in the known std tests*	A: 15 B: 19 C: 44 **D: 77*** E: 1 0: 8	A: 5 B: 14 C: 26 (x is prop to t in a free fall) **D: 64*** E: 2 0: 0	Test comm. P = 0,47 D = 0,18 r_{it} = 0,36	Test comm. P = 0,58 D = 0,46 r_{it} = 0,41	- 	0,70073 (Test comm.) 0,71204	Activities 5 and 6 MDETs Yes	-	Test comm. P = 0,58 D = 0,70 r_{it} = 0,54	0,6384 (Test comm.) 0,6706	Pre + Post
26) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'il est illustré dans la figure suivante. Tous les frottements sont négligeables. Dans cette situation, les forces appliquées sur l'ascenseur sont telles que (A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas. (B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas. (C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas. (D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas. (E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.	17 of FCI	1st Newton law and gravitation	**A: 63** B: 24* C: 12 **D: 36** E: 12 0: 17	A: 46 (a non vanishing net force is needed to keep a body with a constant velocity) **B: 49*** C: 1 D: 12 (misc. in A + air friction) E: 2 (no acceleration => no forces acting on a body) 0: 1	Test comm. P = 0,15 D = 0,090 r_{it} = 0,18	Test comm. P = 0,44 D = 0,60 r_{it} =0,45	[Traxler *et al.*, 2018] (Uni 1st year) P = 0,49 D = 0,62  P ≈ 0,42 in [Scott *et al.*, 2012] (Uni + H.S.)	0,69640 (Test comm.) 0,71204	Strong misconception Yes Modification: different formulation of last 2 answers (D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force ~~causée par~~ de l'air dirigée vers le bas. (E) il n'y a pas de forces agissant sur l'ascenseur, ~~car sa vitesse est constante.~~	-	Test comm. P = 0,44 D = 0,54 r_{it} =0,41	0,6678 (Test comm.) 0,6706	Pre + Post

27) Un gros camion entre en collision avec une petite voiture compacte. Pendant la collision (A) le camion exerce une force plus intense sur la voiture que la voiture sur le camion. (B) la voiture exerce une force plus intense sur le camion que le camion sur la voiture. (C) aucun des deux n'exerce de force sur l'autre. La voiture se fait frapper simplement parce qu'elle est devant le camion. (D) Le camion exerce une force sur la voiture mais la voiture n'exerce pas de force sur le camion. (E) Le camion exerce une force aussi intense sur la voiture que la voiture sur le camion.	4 of FCI	3rd Newton law – frontal collision	**<u>A: 44</u>** B: 3 C: 1 D: 8 E: 9* 0: 3	A: 19 (heavier bodies exert greater forces) B: 0 C: 0 D: 1 **E: 30*** 0: 0	Test B P = 0,13 D = 0,13 r_{it} = 0,29	Test B P = 0,60 D = 0,33 r_{it} = 0,22	[Traxler *et al*., 2018] (Uni 1st year) P = 0,62 D = 0,57  P ≈ 0,40 in [Scott *et al*. 2012] (Uni + H.S.)	0,76942 (Test B) 0,76526	Activity 6 MDETs Strong misconception Yes	-	Test B P = 0,60 D = 0,35 r_{it} = 0,21	0,7567 (Test B) 0,7419	Pre + Post
28) Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, Pendant que la voiture, poussant toujours le camion, augmente sa vitesse jusqu'à sa vitesse de croisière, (C) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture. (D) la force avec laquelle la voiture pousse le camion est moins intense que … (E) la force avec laquelle la voiture pousse le camion est plus intense que … (F) le moteur de la voiture est en marche, alors la voiture exerce une force sur le camion, par contre, puisque le moteur du camion est à l'arrêt, le camion n'exerce pas de force. (G) ni la voiture ni le camion n'exercent de forces…	15 of FCI Goes with item 29	3rd Newton law – accelerated system	A: 12* B: 12 **<u>C: 43</u>** D: 23 E: 1 0: 5	A: 14* B: 5 (heavier bodies exert greater f.) **<u>C: 39</u>** (active agents exert greater f.) D: 2 (only active agents exert f.) E: 0; 0: 1	Test A P = 0,13 D = 0,29 r_{it} = 0,36	Test A P = 0,23 D = 0,33 r_{it} = 0,32	[Traxler *et al*., 2018] (Uni 1st year) P = 0,66 D = 0,54  P ≈ 0,21 in [Scott *et al*. 2012] (Uni + H.S.)	0,73654 (Test A) 0,74144	Activity 6 MDETs Yes <u>Modification:</u> Different formulation: (D) ~~le moteur de la voiture est en marche, alors~~ la voiture exerce une force sur le camion, par contre~~,~~ ~~puisque le moteur du camion est à l'arrêt,~~ le camion n'exerce pas de force sur la voiture.	-	Test A P = 0,23 D = 0,33 r_{it} = 0,39	0,6703 (Test A) 0,6784	Pre + Post

29)Une fois que le système voiture + camion atteint la vitesse de croisière constante désirée: (A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture. (B) la force avec laquelle la voiture pousse le camion est moins intense que … (C) la force avec laquelle la voiture pousse le camion est plus intense que … (D) le moteur de la voiture est en marche, alors la voiture exerce une force sur le camion, par contre, puisque le moteur du camion est à l'arrêt, le camion n'exerce pas de (E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.	16 of FCI Goes with item 28	3rd Newton law – equilibrium system	A: 47* B: 14 **C: 52** D: 25 E: 7 0: 19	**A: 66*** B: 6 C: 34 (heavier bodies exert greater f.) D: 3 (only active agents exert f.) E: 1 (no a => no f.) 0: 1	Test comm. P = 0,29 D = 0,13 r_{it} = 0,26	Test comm. P = 0,59 D = 0,49 r_{it} = 0,40	[Traxler *et al*., 2018] (Uni 1st year) P = 0,91 D = 0,28  P ≈ 0,79 in [Scott *et al*. 2012] (Uni + H.S.)	0,70188 (Test comm.) 0,712037	Activity 6 MDETs 1) Neglecting friction, a pupil could answer (E), then false, but the 3rd Newton's law being understood. 2) 1st and 3rd Newton's laws can be confused in this item: a pupil could answer A, then correctly, but not have understood the 3rd Newton's law. (SSG12) No	-			
30) Au milieu d'une patinoire, deux patineurs, Ana et Bob, sont debout face à face. Ana, qui pèse 60 kg, pousse soudainement Bob, qui pèse 80 kg. Pendant la poussée (A) Bob accélère mais Ana reste immobile. (B) Ana accélère mais Bob reste immobile. (C) Ana et Bob accélèrent en sens opposés mais avec des accélérations de même intensité. (D) Ana et Bob accélèrent en sens opposés mais Ana accélère plus que Bob. (E) Ana et Bob accélèrent en sens opposés mais Bob accélère plus qu'Ana.	Created	2nd and 3rd Newton laws	A: 16 B: 14 C: 10 **D: 71*** E: 45 0: 8	A: 10 B: 2 C: 8 **D: 78*** E: 12 0: 1	Test comm. P = 0,43 D = 0,16 r_{it} = 0,31	Test comm. P = 0,70 D = 0,44 r_{it} = 0,34	- 	0,70634 (Test comm.) 0,71204	Activity 6 MDETs Item testing at the same time the 2nd and 3rd Newton's law, both laws can be not understood and the correct answer given (-)*(-) = (+) (Better to give this questions with numerical calculations) No	-			
31) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement. Dans ces conditions, (A) les deux billes atteignent la même vitesse. (B) la bille plus lourde atteint une vitesse exactement trois fois plus grande que …. (C) la bille plus légère atteint une vitesse exactement trois plus grande que …. (D) la bille plus lourde atteint une vitesse plus grande que bille plus légère, mais pas exactement trois fois plus grande. (E) la bille plus légère atteint une vitesse plus grande que la bille plus lourde, mais pas exactement trois fois plus grande.	Created	2nd Newton law – acceleration is inversely proportional to the mass with one dimension kinematics. *Not in the known std tests*	A: 12 B: 13 C: 25* D: 40 **E: 66** 0: 8	A: 20 (same force = same acceleration) B: 10 **C: 25*** D: 10 E: 43 0: 3 B+D: 20 (heavier bodies go faster)	Test comm. P = 0,15 D = 0,11 r_{it} = 0,21	Test comm. P = 0,23 D = 0,47 r_{it} = 0,45	- 	0,69505 (Test comm.) 0,71204	Activity 6 MDETs Only item testing the Newton's 2nd law Yes	-	Test comm. P = 0,23 D = 0,39 r_{it} = 0,44	0,6541 (Test comm.) 0,6706	Pre + Post

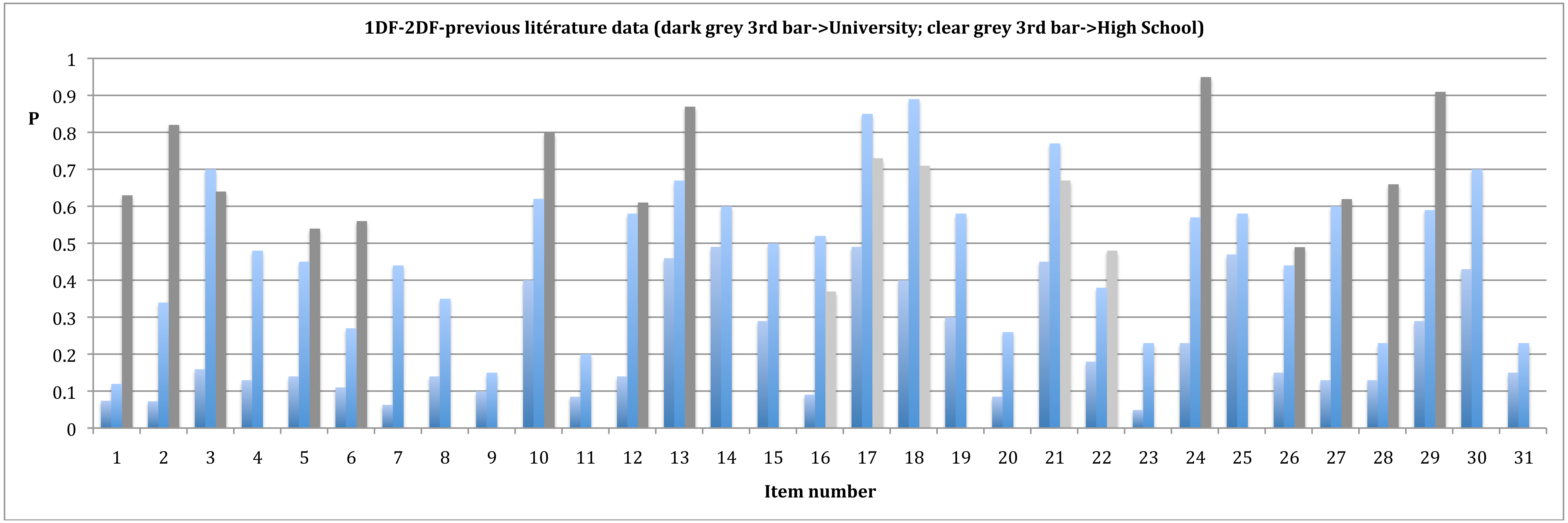


Figure A.1: Histograms of the average difficulty P for each item of the validation of the concept test: the first bar represent the average P for 1DF Geneva high-school pupils, the second bar for 1DF Geneva high-school pupils, and the 3rd bar, when possible, represent the average P for students in a previous study, coming from Barinol & Zavala (2014, Uni - 1st year), Beichner, R. (1994), Scott *et al*. (2012) and Traxler *et al*. (2018 Uni - 1st year).

Table A.4: Item analysis of the conceptual pre-test of the pilot study. N = 105; N_{TG} = 61; N_{CG} = 44.

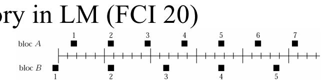
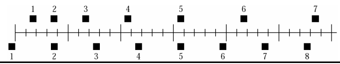
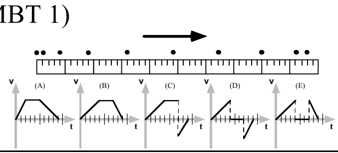
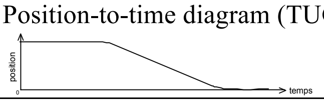
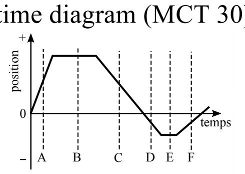
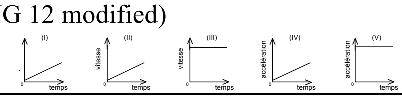
Item keywords (source)	**P(SD)**	**D**	**r_{it}(CI)**	**α - α***
LPR1 : Visualize acceleration from trajectory in LM (FCI 20) 	0,16 (0,37)	0,44	0,54(0,28)	+0,049
LPR2: Visualize velocity from trajectory in LM (FCI 19) 	0,48(0,50)	0,61	0,48(0,30)	+0,032
LPR3: Average speed and the average of two speeds *	0,17(0,38)	0,31	0,42(0,32)	+0,025
LPR4: Velocity diagram from trajectory in LM (MBT 1) 	0,50(0,50)	0,51	0,38(0,33)	+0,007
LPR5: Position-to-time diagram (TUG 8) 	0,11(0,32)	0,31	0,41(0,32)	+0,025
LPR6: Instant velocity as slope in the position to time diagram (MCT 30) 	0,25(0,43)	0,39	0,47(0,30)	+0,034
LPR7: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified) 	0,17(0,38)	0,49	0,59(0,25)	+0,061
LPR8: *g* during a free fall with change in velocity's orientation *	0,09(0,28)	0,17	0,37(0,33)	+0,020
LPR9: Kinematics of free falling different bodies – covered distance (FCI 1 – removed all the « about », no friction at all)	0,30(0,46)	0,32	0,33(0,34)	+0,001
LPR10: Quadratic relationship between distance and time in free fall: UALM (created from FCI 1)	0,57(0,50)	0,46	0,36(0,33)	+0,003
LPR11: 1st Newton's law and gravitation – lift at constant velocity (FCI 17, answer E modified)	0,23(0,42)	0,24	0,18(0,37)	-0,024
LPR12: 2nd Newton's law – acceleration is inversely proportional to the mass* (created – acceleration of two different masses with the same net force)	0,13(0,34)	0,12	0,25(0,36)	-0,001
LPR13: 3rd Newton's law – frontal collision (FCI 14)	0,47(0,50)	0,63	0,47(0,30)	+0,030
LPR14: 3rd Newton's law – accelerated system in contact (FCI 15, answer D modified)	0,24(0,43)	0,40	0,32(0,35)	+0,002

Table A.5: Item analysis of the conceptual post-test of the pilot study. N = 103; N_{TG} = 59; N_{CG} = 44. * = created items.

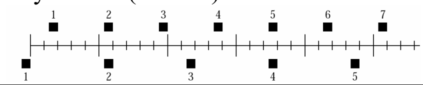
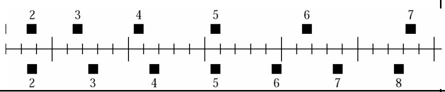
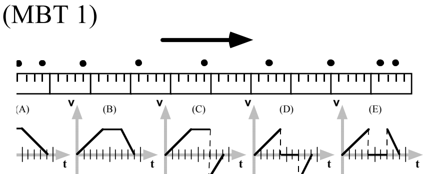
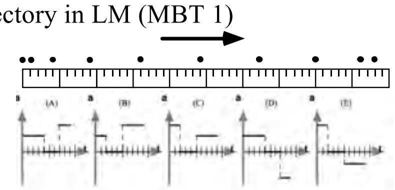
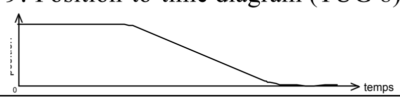
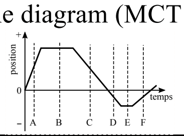
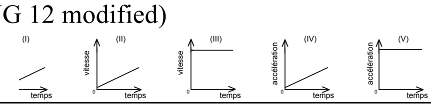
Item keywords (source)	P(SD)	D	r_{it}(CI)	α - α*
LPO1 : Visualize acceleration from trajectory in LM (FCI 20) 	0,61 (0,49)	0,64	0,49(0,30)	+0,024
LPO2: Visualize velocity from trajectory in LM (FCI 19) 	0,68(0,47)	0,58	0,43(0,32)	+0,017
LPO3: Average speed and the average of two speeds*	0,22(0,41)	0,47	0,44(0,32)	+0,018
LPO4: Instant velocity (created from situation of 5 and 6 of FCI)	0,79(0,41)	0,39	0,37(0,34)	+0,011
LPO5: Average velocity (created from situation of 5 and 6 of FCI)	0,62(0,49)	0,40	0,32(0,35)	+0,003
LPO6: Average acceleration (created from situation of 5 and 6 of FCI)	0,06(0,24)	0,16	0,26(0,36)	+0,005
LPO7: Velocity diagram from trajectory in LM (MBT 1) 	0,68(0,47)	0,63	0,47(0,31)	+0,021
LPO8: Acceleration diagram from trajectory in LM (MBT 1) 	0,56(0,50)	0,67	0,49(0,30)	+0,024
LPO9: Position-to-time diagram (TUG 8) 	0,45(0,50)	0,64	0,52(0,29)	+0,027
LPO10: Instant velocity as slope in the position to time diagram (MCT 30) 	0,49(0,50)	0,67	0,51(0,29)	+0,026
LPO11: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified) 	0,63(0,49)	0,40	0,32(0,35)	+0,003

Table A.5 continued

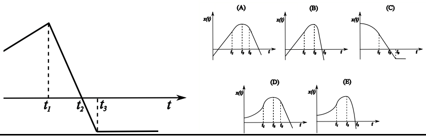
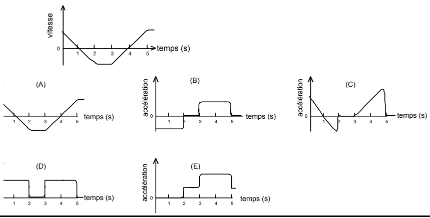
LPO12: Time diagram from velocity diagram* 	0,30(0,46)	0,37	0,36(0,34)	+0,009
LPO13: Acceleration diagram from velocity diagram (TUG 14) 	0,60(0,49)	0,78	0,59(0,26)	+0,036
LPO14: *g* during a free fall with change in velocity's orientation*	0,08(0,27)	0,18	0,26(0,36)	+0,005
LPO15: Kinematics of free falling different bodies – covered distance (FCI 1 – removed all the « about », no friction at all)	0,65(0,48)	**-0,01**	**0,01**(0,39)	**-0,028**
LPO16: Quadratic relationship between distance and time in free fall : UALM (created from FCI 1)	0,59(0,49)	0,52	0,41(0,32)	+0,014
LPO17: 1st Newton's law and gravitation – lift at constant velocity (FCI 17, answer E modified)	0,34(0,48)	0,46	0,40(0,33)	+0,012
LPO18: 2nd Newton's law – acceleration is inversely proportional to the mass* (created – acceleration of two different masses with the same net force)	0,21(0,41)	0,29	0,30(0,35)	+0,005
LPO19: 3rd Newton's law – frontal collision (FCI 14)	0,72(0,45)	0,33	0,29(0,36)	+0,002
LPO20: 3rd Newton's law – accelerated system in contact (FCI 15, answer D modified)	0,37(0,49)	0,33	0,27(0,36)	-0,002

Table A.6: Item analysis of the spatial abilities test of the pilot study: a QCM with 10 + 10 items, 1 right answer on 5.

Item	P	D	r_{it}(CI)	α - α*
SA1	0,93(0,25)	0,20	0,37(0,33)	+0,003
SA2	0,78(0,42)	0,51	0,43(0,31)	+0,005
SA3	0,74(0,44)	0,37	0,37(0,33)	-0,001
SA4	0,73(0,44)	0,56	0,47(0,30)	+0,007
SA5	0,75(0,43)	0,66	0,58(0,26)	+0,015
SA6	0,88(0,33)	0,39	0,53(0,28)	+0,011
SA7	0,39(0,49)	0,84	0,61(0,24)	+0,017
SA8	0,63(0,49)	0,58	0,49(0,29)	+0,007
SA9	0,18(0,39)	0,41	0,36(0,33)	+0,001
SA10	0,44(0,50)	0,66	0,49(0,29)	+0,007
SA11	**0,97(0,17)**	0,08	0,21(0,37)	-0,002
SA12	0,93(0,25)	0,23	0,38(0,33)	+0,003
SA13	**0,95(0,21)**	0,15	0,32(0,34)	+0,001
SA14	0,90(0,29)	0,38	0,49(0,30)	+0,008
SA15	0,51(0,50)	0,58	0,44(0,31)	+0,002
SA16	0,84(0,37)	0,54	0,60(0,25)	+0,016
SA17	0,74(0,44)	0,79	0,66(0,22)	+0,021
SA18	0,15(0,36)	0,38	0,41(0,32)	+0,004
SA19	0,71(0,45)	0,47	0,39(0,33)	+0.000
SA20	0,20(0,40)	0,46	0,43(0,31)	+0,005

Table A.7: Item analysis of the affective outcomes in the pre-test of the main study. Barred items were present in the pilot study and were dropped for the main study. The modifications with respect to the pilot study are reported (up to the explanations given in the section 4.6.3). N = 116; N_{TG} = 56; N_{CG} = 60 ; 6-level items 1= completely disagree, 6 = completely agree; * = created items. $^{-}$ = scales of "negative" items are inverted (value = 7 - rating).

Item	**M(SD)**	**r_{it}(CI)**	**α - α***	**α**
SC1: J'ai pu résoudre les problèmes	4,00 (1,13)	0,71(0,18)	+0,007	0,85 (0,09)
SC2: Mes camarades ont trouvé que j'étais bon(ne)	3,44(1,23)	0,80(0,14)	+0,031	
SC3: J'ai bien compris les sujets traités au cours	3,69(1,18)	0,82(0,12)	+0,041	
~~SC4: Mes résultats en physique ont été satisfaisants pour moi~~	-	-	-	
~~SC5: Je m'attends à ce que mes résultats en physique soient bons~~	-	-	-	
SC6^{-} : J'ai eu des difficultés à comprendre les sujets traités	3,16(1,32)	0,82(0,12)	+0,037	
SC7^{-} : Je suis nul(le) en physique*	3,52(1,46)	0,83(0,11)	+0,037	
IN1: Suis plus investi pour ce cours que pour les autres matières	2,96(1,42)	0,60(0,24)	-0,025	0,72 (0,16)
IN2: J'ai bien aimé résoudre des problèmes de physique	3,35(1,13)	0,80(0,13)	+0,121	
IN3: J'ai bien aimé le cours de physique	3,65(1,26)	0,73(0,18)	+0,071	
~~IN4: J'ai fait des recherches dans des livres, les journaux, etc.~~	-	-	-	
~~IN5: En plus des devoirs, j'ai consacré du temps libre …~~	-	-	-	
IN6^{-} : J'ai trouvé ennuyeux de résoudre des problèmes*	2,50(1,22)	0,61(0,23)	+0,010	
IN7^{-} : Je me suis ennuyé dans les heures de physique*	3,32(1,20)	0,72(0,18)	+0,071	
CS1: Je voudrais en savoir davantage sur les sujets traités au …	3,63(1,15)	0,79(0,15)	+0,032	0,86 (0,08)
CS2: Je voudrais ~~mieux comprendre~~ **approfondir** les sujets trait.	3,49(1,22)	0,81(0,14)	+0,044	
CS3: Je trouve fascinants les sujets traités au cours	3,26(1,21)	0,83(0,12)	+0,021	
CS4: Le cours a éveillé ma curiosité à propos des sujets traités	3,44(1,23)	0,78(0,15)	+0,022	
CS5: J'aime passer du temps à réfléchir sur les sujets traités	2,74(1,15)	0,77(0,16)	+0,041	
RR1: Les probl. sont utiles pour les situat. en dehors de l'école	3,03(1,31)	0,84(0,11)	+0,041	0,87 (0,08)
RR2: Les sujets sont utiles pour des sit. de la vie quotidienne	3,06(1,18)	0,78(0,16)	+0,020	
~~RR3: Le cours a traité des situations de la vie quotidienne~~	-	-	-	
RR4: Les sujets sont utiles pour des sit. en dehors de l'école	3,33(1,36)	0,83(0,12)	+0,037	
RR5: Il m'arrive de relier les contenus à des sit. de la vie quot.*	3,36(1,42)	0,78(0,15)	+0,015	
RR6^{-} : Je ne vois pas de liens entre les sujets et la vie quot.*	3,86(1,37)	0,81(0,14)	+0,026	

Table A.8: Item analysis of the affective dependent variables in the post-test of the main study. N = 111; N_{TG} = 55; N_{CG} = 56; 6-level items 1= completely disagree, 6 = completely agree; * = created items. Scales of “negative” items are inverted (value = 7 - rating). Barred items were present in the pilot study and were dropped for the main study. The modifications with respect to the pilot study are reported (up to the explanations given in the section 4.6.3).

Item	**M(SD)**	**r_{it}(CI)**	**α - α***	**α**
SC1: J’ai pu résoudre les problèmes	4,11(1,12)	0,75(0,17)	+0,002	0,89 (0,06)
SC2: Mes camarades ont trouvé que j’étais bon(ne)	3,26(1,40)	0,82(0,13)	+0,017	
SC3: J’ai bien compris les sujets traités au cours	3,86(1,29)	0,89(0,08)	+0,042	
~~SC4: Mes résultats en physique ont été satisfaisants pour moi~~	-	-	-	
~~SC5: Je m’attends à ce que mes résultats en physique soient bons~~	-	-	-	
SC6$^-$: J’ai eu des difficultés à comprendre les sujets traités	3,18(1,43)	0,87(0,09)	+0,034	
SC7$^-$: Je suis nul(le) en physique*	3,59(1,61)	0,86(0,10)	+0,024	
IN1: Suis plus investi pour ce cours que pour les autres matières	3,32(1,39)	0,56(0,26)	-0,033	0,71 (0,17)
IN2: J’ai bien aimé résoudre des problèmes de physique	3,45(1,23)	0,76(0,16)	+0,101	
IN3: J’ai bien aimé le cours de physique	3,93(1,16)	0,72(0,18)	+0,078	
~~IN4: J’ai fait des recherches dans des livres, les journaux, etc.~~	-	-	-	
IN5: En plus des devoirs, j’ai consacré du temps libre …	2,51(1,37)	0,66(0,22)	+0,023	
IN6$^-$: J’ai trouvé ennuyeux de résoudre des problèmes*	3,54(1,20)	0,73(0,18)	+0,084	
~~IN7$^-$: Je me suis ennuyé dans les heures de physique*~~	-	-	-	
CS1: Je voudrais en savoir davantage sur les sujets traités	3,41(1,32)	0,83(0,12)	+0,083	0,89 (0,07)
CS2: Je voudrais ~~mieux comprendre~~ **approfondir** les sujets trait.	3,23(1,42)	0,86(0,10)	+0,086	
CS3: Je trouve fascinants les sujets traités au cours	3,25(1,22)	0,81(0,13)	+0,081	
CS4: Le cours a éveillé ma curiosité à propos des sujets traités	3,43(1,31)	0,84(0,11)	+0,084	
CS5: J’aime passer du temps à réfléchir sur les sujets traités	2,95(1,29)	0,84(0,12)	+0,084	
RR1: Les probl. sont utiles pour les situat. en dehors de l’école	3,45(1,41)	0,87(0,10)	+0,028	0,90 (0,06)
RR2: Les sujets sont utiles pour des sit. de la vie quotidienne	3,39(1,24)	0,86(0,10)	+0,028	
~~RR3: Le cours a traité des situations de la vie quotidienne~~	-	-	-	
RR4: Les sujets sont utiles pour des sit. en dehors de l’école	3,63(1,29)	0,90(0,08)	+0,039	
RR5: Il m’arrive de relier les contenus à des sit. de la vie quot.*	3,51(1,36)	0,82(0,13)	+0,013	
RR6$^-$: Je ne vois pas de liens entre les sujets et la vie quot.*	4,37(1,39)	0,79(0,14)	+0,003	

Table A.9: Item analysis for the eight items of the factor analysis' sub-dimension "one-dimensional kinematics" (the only one containing more than three items) of the conceptual pre-test of the main study. QCM with 1 right answer on 5, k = 8 items and dichotomous scale level; N = 116 : N_{TG} = 56; N_{CG} = 60.

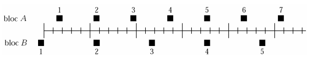
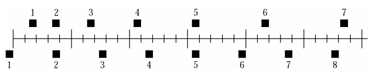
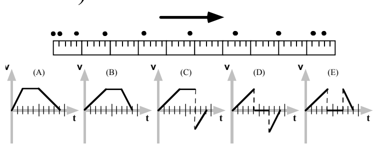
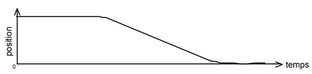
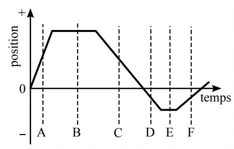
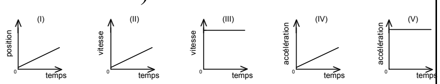
Item keywords (source)	P(SD)	D	r_{it}(CI)	α - α*
LPR1 : Visualize acceleration from trajectory in LM (FCI 20) 	0,19 (0,39)	0,59	0,58(0,25)	+0,055
LPR2: Visualize velocity from trajectory in LM (FCI 19) 	0,43(0,50)	0,81	0,62(0,23)	+0,062
LPR3: Average speed and the average of two speeds (inspired by Ree85 and RS86)	0,16(0,36)	0,49	0,54(0,26)	+0,044
LPR4: Velocity diagram from trajectory in LM (MBT 1) 	0,39(0,49)	0,52	0,35(0,32)	-0,038
LPR5: Position-to-time diagram (TUG 8) 	0,17(0,38)	0,41	0,38(0,31)	0,000
LPR6: Instant velocity as slope in the position to time diagram (MCT 30) 	0,28(0,45)	0,76	0,61(0,23)	+0,063
LPR7: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified) 	0,19(0,38)	0,59	0,58(0,25)	+0,055
LPR8: Quadratic relationship between distance and time in free fall: UALM (created from FCI 1)	0,50(0,28)	0,78	0,55(0,26)	+0,028

Table A.10: Item analysis for the conceptual post-test of the main study. Values in the full test (19 items, first line) and in the restricted test (16 items, second line), i.e. dropping the items with low r_{it} , decreasing α or too low P. QCM with 1 right answer on 5; N = 111: N_{TG} = 55; N_{CG} = 56. Modified or new items with respect to the pilot study test are indicated with an *.

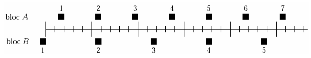
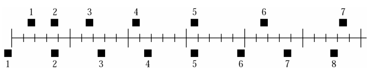
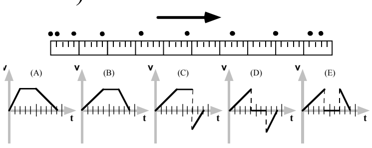
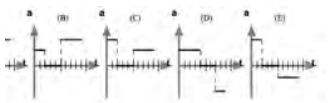
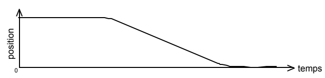
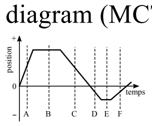
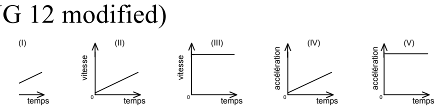
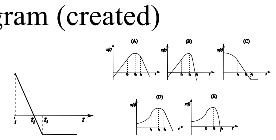
Item keywords (source)	P(SD)	D	r_{it}(CI)	α - α*
LPO1: Visualize acceleration from trajectory in LM (FCI 20) 	0,50 (0,50)	0,77 -------------------- 0,70	0,53(0,27) -------------------- 0,49(0,28)	+0,044 ---------------- +0,047
LPO2: Visualize velocity from trajectory in LM (FCI 19) 	0,66(0,48)	0,64 -------------------- 0,62	0,49(0,28) -------------------- 0,49(0,28)	+0,038 ---------------- +0,047
LPO3: Average speed and the average of two speeds.	0,16(0,37)	0,26 -------------------- 0,27	0,31(0,34) -------------------- 0,28(0,34)	+0,012 ---------------- +0,021
LPO4: Velocity diagram from trajectory in LM (MBT 1) 	0,62(0,49)	0,30 -------------------- 0,36	0,28(0,34) -------------------- 0,28(0,34)	+0,002 ---------------- +0,015
LPO5: Acceleration diagram from trajectory in LM (MBT 1), following of LPO4. 	0,43(0,50)	0,58 -------------------- 0,62	0,45(0,30) -------------------- 0,49(0,28)	+0,030 ---------------- +0,047
LPO6: Position-to-time diagram (TUG 8) 	0,28(0,45)	0,46 -------------------- 0,48	0,35(0,33) -------------------- 0,41(0,31)	+0,014 ---------------- +0,035
LPO7: Instant velocity as slope in the position to time diagram (MCT 30) 	0,48(0,50)	0,51 -------------------- 0,56	0,40(0,31) -------------------- 0,40(0,31)	+0,020 ---------------- +0,032
LPO8: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified) 	0,53(0,50)	0,68 -------------------- 0,67	0,49(0,28) -------------------- 0,48(0,28)	+0,038 ---------------- +0,046
LPO9: Time diagram from velocity diagram (created) 	0,26(0,44)	0,42 -------------------- 0,40	0,34(0,33) -------------------- 0,34(0,33)	+0,013 ---------------- +0,025

Table A.10 continued

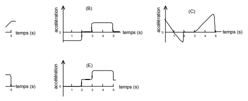
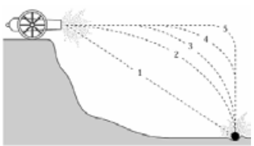
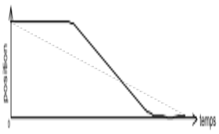
LPO10: Acceleration diagram from velocity diagram (TUG 14) 	0,58(0,50)	0,68 -------------------- 0,65	0,54(0,27) -------------------- 0,53(0,27)	+0,047 ---------------- +0,054
LPO11: Kinematics of free falling different bodies – covered distance (FCI 1 – removed all the « about », no friction at all)	0,76(0,43)	0,48 -------------------- 0,44	0,41(0,31) -------------------- 0,40(0,31)	+0,024 ---------------- +0,034
LPO12: Quadratic relationship between distance and time in free fall: UALM (created from FCI 1)	0,54(0,50)	0,40 -------------------- 0,40	0,32(0,33) -------------------- 0,32(0,33)	+0,006 ---------------- +0,019
LPO13: *g* during a free fall with change in velocity's orientation (throwing a stone upward)	0,20(0,40)	0,30 -------------------- 0,35	0,30(0,34) -------------------- 0,34(0,33)	+0,010 ---------------- +0,027
LPO14: (FCI11)* 	0,47(0,50)	0,31 -------------------- 0,30	0,30(0,34) -------------------- 0,29(0,34)	+0,004 ---------------- +0,014
LPO15: (FCI 14)* 	0,23(0,42)	0,30 -------------------- 0,31	0,24(0,35) -------------------- 0,29(0,34)	+0,001 ---------------- +0,021
LPO16: 1st Newton's law and gravitation – lift at constant velocity (FCI 17, answer E modified)	0,27(0,45)	0,26 Removed	**0,21(0,36)** **-**	**-0,005** **-**
LPO17: 2nd Newton's law – acceleration is inversely proportional to the mass (created – acceleration of two different masses with the same net force)*	0,44(0,50)	**-0,01** Removed	**0,05(0,37)** **-**	**-0,035** **-**
LPO18: 3rd Newton's law – frontal collision (FCI 14)	0,65(0,48)	0,51 -------------------- 0,51	0,42(0,31) -------------------- 0,42(0,30)	+0,025 ---------------- +0,037
LPO19: 3rd Newton's law – accelerated system in contact (FCI 15, answer D modified)	0,18(0,39)	**-0,02** Removed	**0,06(0,37)** **-**	**-0,019** **-**

Table A11: Item analysis for the restricted conceptual post-test of the main study, considering only the 12 items belonging to the first factor of the FA. N = 111: N_{TG} = 55; N_{CG} = 56. Modified or new items with respect to the pilot study test are indicated with a *.

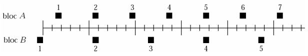
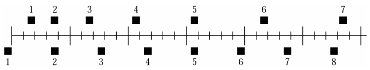
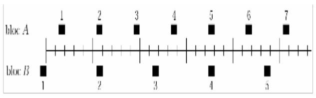
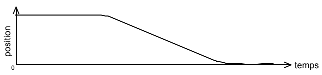
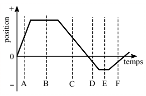
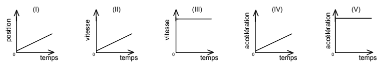
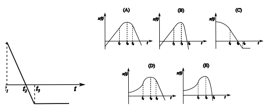
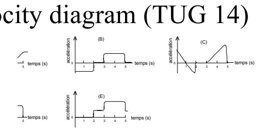
Item keywords (source)	P(SD)	D	r_{it}(CI)	α - α*
LPO1: Visualize acceleration from trajectory in LM (FCI 20) 	0,50 (0,50)	0,70	0,54(0,27)	+0,053
LPO2: Visualize velocity from trajectory in LM (FCI 19) 	0,66(0,48)	0,65	0,55(0,26)	+0,055
LPO5: Acceleration diagram from trajectory in LM (MBT 1), following of LPO4. 	0,43(0,50)	0,65	0,46(0,29)	+0,035
LPO6: Position-to-time diagram (TUG 8) 	0,28(0,45)	0,47	0,44(0,30)	+0,035
LPO7: Instant velocity as slope in the position to time diagram (MCT 30) 	0,48(0,50)	0,56	0,43(0,30)	+0,029
LPO8: Recognize *a(t)*/*v(t)*/*x(t)* diagrams representing a motion with constant velocity (TUG 12 modified) 	0,53(0,50)	0,68	0,51(0,27)	+0,045
LPO9: Time diagram from velocity diagram (created) 	0,26(0,44)	0,42	0,38(0,32)	+0,024
LPO10: Acceleration diagram from velocity diagram (TUG 14) 	0,58(0,50)	0,75	0,57(0,25)	+0,060
LPO11: Kinematics of free falling different bodies – covered distance (FCI 1 – removed all the « about », no friction at all)	0,76(0,43)	0,46	0,40(0,31)	+0,028
LPO12: Quadratic relationship between distance and time in free fall: UALM (created from FCI 1)	0,54(0,50)	0,44	0,35(0,32)	+0,013

Table A.11 continued

LPO13: *g* during a free fall with change in velocity's orientation (throwing a stone upward)	0,20(0,40)	0,37	0,35(0,33)	+0,022
LPO18: 3rd Newton's law – frontal collision (FCI 14)	0,65(0,48)	0,52	0,40(0,31)	+0,025

Table A.12: Item analysis of the affective control variables of the main study. N = 111 (pre) or 111 (post) except for the subscale CLS (N_{TG} = 55); 6-level items 1= completely disagree, 6 = completely agree; * = created items. Barred items were present in the pilot study and were dropped for the main study. The modifications with respect to the pilot study are indicated (see the explanations given in section 4.6.3). $^{-}$ = scales of "negative" items are inverted (value = 7 - rating). We remind that acronyms are: CT = curiosity trait; CLE and CAE = cognitive load/activation during the experiment; INV = involvement; SCS = self-concept regarding Smartphone's apps; AT = personal assessment of the teacher; CLS = cognitive load due to the Smartphone's apps.

Item	M (SD)	r_{it}(CI)	α - α*	α
CT1: Je trouve fascinant d'apprendre des nouvelles choses	5,01(0,90)	0,76(0,16)	+0,062	0,77 (0,13)
CT2: J'aime apprendre des choses que je ne connais pas	5,22(0,82)	0,76(0,16)	+0,061	
CT3: Ls. j'apprends qqe ch. de nouveau, je veux en savoir plus	4,35(0,93)	0,66(0,21)	+0,017	
CT4: J'aime faire des rech. sur les ch. que je ne comprends pas	4,74(1,01)	0,71(0,18)	+0,031	
~~CT5: J'aime essayer de résoudre des problèmes qui m'intriguent~~				
CT6: Je veux toujours examiner les choses en profondeur	3,79(1,17)	0,76(0,16)	+0,030	
CLE1: Me concentrer sur les act., sans me battre avec le matériel	4,51(1,29)	0,66(0,21)	+0,054	0,66 (0,20)
CLE2: J'ai pu démarrer les activités rapidement.	4,03(1,09)	0,66(0,21)	+0,071	
~~CLE3: J'ai eu des informations suff. pour les expériences~~				
CLE4: Les activités expérimentales étaient simples à effectuer	3,70(1,36)	0,66(0,21)	+0,045	
CLE5^{-}: Peine à comprendre les notions des expériences	3,40(1,44)	0,75(0,17)	+0,106	
CLE6^{-}: Problèmes à utiliser les instruments de mesure	4,68(1,09)	0,51(0,28)	-0,003	
CAE1: J'étais concentré lors des expériences	4,59(1,16)	0,75(0,16)	+0,173	0,59 (0,24)
CAE2: Je me suis engagé(e) activement lors des expériences	4,41(1,15)	0,69(0,20)	+0,120	
CAE3: J'ai eu un regard critique sur les idées testées	3,84(1,10)	0,57(0,26)	+0,035	
CAE4: Différencier les choses importantes de celles moins imp.	3,96(1,24)	0,51(0,28)	-0,023	
CAE5: Relier aux connaissances antérieures	3,98(1,31)	0,57(0,25)	-0,003	
INV1: J'ai participé activement	3,82(1,19)	0,75(0,17)	+0,072	0,75 (0,15)
INV2: J'ai posé souvent des questions	3,64(1,38)	0,72(0,18)	+0,051	
INV3: J'ai expliqué mes idées sur les sujets à mes camarades	3,19(1,36)	0,66(0,21)	+0,020	
INV4: Discuté avec les camarades sur la résolution des prob.	3,99(1,44)	0,69(0,20)	+0,032	
INV5: ~~On m'a demandé d'expliquer comm. j'ai résolu des prob~~ **J'ai débattu sur les sujets traités en classe.**	3,34(1,38)	0,72(0,18)	+0,049	
SCS1. Je suis à l'aise avec l'utilisation des apps	4,79(1,38)	0,78(0,15)	+0,120	0,69 (0,18)
SCS2: Les apps m'aident à comprendre des choses	4,20(1,21)	0,73(0,19)	+0,089	
SCS3^{-}: Les apps ne me semblent pas utiles pour apprendre	4,19(1,23)	0,74(0,18)	+0,095	
~~SCS4^{-}: Parf. les apps font des choses que je ne comprends pas~~				
SCS5^{-}: Si j'ai des problèmes avec les apps je me sens démuni	4,55(1,28)	0,43(0,31)	-0,060	
SCS6: J'utilise des apps pour effectuer des mesures (nb. de pas)*	4,63(1,53)	0,68(0,21)	+0,034	

Table A.12 continued

AT1: L'e. pris du temps pour nous aider si nous avions des prob.	4,86(1,23)	0,85(0,10)	+0,067	0,83 (0,10)
AT2: Les explications de l'e. nous ont aidés à mieux comprendre	4,46(1,12)	0,81(0,13)	+0,049	
AT3: ~~L'e. donnait l'impression d'être passionné par la physique~~ **L'e. semblait être particulièrment engagé**	5,29(0,90)	0,84(0,11)	+0,063	
AT4: L'enseignant nous encourageait	4,66(1,13)	0,75(0,17)	+0,021	
AT5: L'e. s'est déplacé dans la classe pour rép. aux questions	5,24(0,89)	0,59(0,25)	-0,015	
CLS1: Me concentrer sur les act. sans me battre avec les apps.	4,26(1,43)	0,75(0,24)	0,000	0,88 (0,10)
~~CLS2: Reçu des informations suff. pour utiliser les appls.~~				
CLS3^{-}: Les applications étaient difficiles à utiliser	4,45(1,42)	0,92(0,09)	+0,063	
CLS4^{-}: Difficile de comprendre les instructions pour les apps.	4,52(1,40)	0,84(0,16)	+0,035	
CLS5^{-}: Eu des probs en effectuant les mesures avec les tabs.	3,78(1,45)	0,86(0,15)	+0,040	
CLS6: Pratique d'utiliser des tablettes pour les activités de phy.	4,76(1,30)	0,73(0,26)	0,000	
~~CLS7: L'util. des tabs. m'a aidé à mieux comprendre les sujets~~	-	-	-	

Table A.13: Item analysis of the spatial abilities test: a QCM with 20 items, 1 right answer on 5.

Item	P	D	r_{it}(CI)	α - α*
SA1	0,95(0,22)	0,19	0,20(0,35)	-0,003
SA2	0,65(0,48)	0,64	0,41(0,31)	+0,003
SA3	0,70(0,46)	0,48	0,37(0,32)	0,000
SA4	0,60(0,49)	0,78	0,51(0,27)	+0,011
SA5	0,59(0,49)	0,91	0,68(0,20)	+0,026
SA6	0,83(0,37)	0,45	0,51(0,27)	+0,011
SA7	0,27(0,45)	0,65	0,48(0,28)	+0,009
SA8	0,57(0,50)	0,75	0,52(0,27)	+0,011
SA9	0,10(0,30)	0,25	0,25(0,34)	-0,002
SA10	0,32(0,47)	0,54	0,41(0,31)	+0,003
SA11	0,98(0,13)	0,07	0,25(0,34)	-0,001
SA12	0,84(0,36)	0,46	0,50(0,28)	+0,011
SA13	0,92(0,27)	0,22	0,37(0,32)	+0,003
SA14	0,78(0,41)	0,60	0,54(0,26)	+0,013
SA15	0,38(0,49)	0,42	0,37(0,32)	-0,001
SA16	0,80(0,40)	0,58	0,51(0,27)	+0,012
SA17	0,68(0,47)	0,68	0,56(0,25)	+0,015
SA18	0,17(0,38)	0,32	0,31(0,33)	-0,001
SA19	0,53(0,50)	0,63	0,46(0,29)	+0.006
SA20	0,14(0,35)	0,36	0,43(0,30)	+0,007

Table A.14: Standard p-values and adjusted p-values for LPO1, LPO2, …, LPO19 (main study).

DV (outcome)	IV (predictor)	p-value	Effect	Adjusted p-value	Surviving effect
LPO1	Treatment	0.92	-	> 0.05	-
LPO2	Treatment	0.95	-	> 0.05	-
LPO3	Treatment	0.58	-	> 0.05	-
LPO4	Treatment	0.75	-	> 0.05	-
LPO5	Treatment	0.0054	✔	> 0.05	-
LPO6	Treatment	0.57	-	> 0.05	-
LPO7	Treatment	0.51	-	> 0.05	-
LPO8	Treatment	0.40	-	> 0.05	-
LPO9	Treatment	0.26	-	> 0.05	-
LPO10	Treatment	0.91	-	> 0.05	-
LPO11	Treatment	0.87	-	> 0.05	-
LPO12	Treatment	0.63	-	> 0.05	-
LPO13	Treatment	0.37	-	> 0.05	-
LPO14	Treatment	0.64	-	> 0.05	-
LPO15	Treatment	0.86	-	> 0.05	-
LPO16	Treatment	0.63	-	> 0.05	-
LPO17	Treatment	**0.016**	✔	> 0.05	-
LPR18	Treatment	0.51	-	> 0.05	-
LPO19	Treatment	0.66	-	> 0.05	-

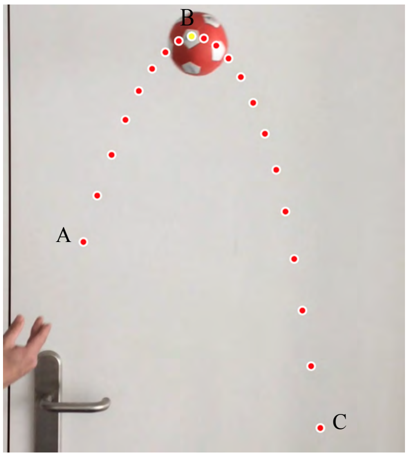
Nom et prénom : Groupe : Date :

Rappel des consignes (à lire intégralement, ainsi que le protocole, avant de commencer):

Veuillez réaliser l'activité (seul ou en binôme) et le rapport manuscrit (un par élève, même si les deux élèves d'un binôme rendent des rapports identiques). Respectez les règles habituelles quant à la présentation et à l'orthographe, notamment : en-tête rempli, pas de crayon (sauf pour les dessins) ni d'effaceur (erreurs éventuelles à biffer proprement), soin de la langue française, protocole à rendre avec le rapport, précision dans les dessins et les résultats (nombre adéquat de chiffres significatifs).

LANCER DE BALLE (position et vitesse)

Utiliser l'application « Video Physics » pour filmer le mouvement d'un objet (une balle de tennis, par exemple) lancé en l'air, de sorte que sa trajectoire soit du même type que celle montrée dans l'image ci-dessous.



Avec la même application, tracer les points du mouvement. Ensuite **fixer une échelle** et un repère (origine et axes). Cette application vous donnera automatiquement (1) le graphique de la trajectoire du mouvement dans le repère choisi, (2) les deux graphiques de $x(t)$ et de $v_x(t)$ et (3) les deux graphiques de $y(t)$ et de $v_y(t)$.
Cliquer sur « ouvrir le fichier données dans… » (en haut à droite) et choisir l'application « Graphical » pour accéder à la liste des données du mouvement enregistrées : le temps (t), les coordonnées de la position à cet instant (x et y) ainsi que les composantes de la vitesse instantanée au même instant (v_x et v_y).
Choisir le point A au début du mouvement, quand la balle a *déjà quitté les mains* du laceur, le point B au sommet de la trajectoire, et le point C à la fin du mouvement, mais *avant qu'elle ne tombe* (ou soit reprise).

Exercice 1 – Vecteurs position et déplacement (chapitre 1)

À l'aide des données de Graphical, remplir les premières trois colonnes du tableau à la fin de l'énoncé (les colonnes des t, x et y au passage dans les points indiqués) et répondre aux points suivants. *Prendre les données arrondies à trois chiffres après la virgule.*

a) Sur une feuille A4, imprimer le graphique de l'image avec le repère, la trajectoire de la balle et indiquer les points A, B et C. *La taille du graphique doit occuper la plus grande place possible sur la feuille.*

b) Sur le même graphique tracer les trois vecteurs positions de la balle lorsqu'elle est au point A, au point B, puis au point C. Les indiquer respectivement $\vec{r}_A$, $\vec{r}_B$ et $\vec{r}_C$.

c) Exprimer $\vec{r}_A$, $\vec{r}_B$ et $\vec{r}_C$ en utilisant leurs coordonnées : $\vec{r} = (x\,;y)$, sans oublier les unités. Puis, pour chacune, calculer sa norme.

d) Calculer l'angle formé par $\vec{r}_A$ avec l'axe x (donnant sa direction).

e) Dessiner et nommer sur le même graphique le déplacement de la balle entre A et C, $\Delta\vec{r}_{AC}$, puis calculer sa norme.

f) En utilisant l'échelle du graphique, donner une estimation de la distance parcourue entre A et C (Δs_{AC}), puis la comparer avec la norme du déplacement entre A et C, $\| \Delta\vec{r}_{AC} \|$.

Exercice 2 – Vecteur vitesse et vitesse scalaire (chapitre 2)

À l'aide des réponses données de l'exercice 1, répondre aux points suivants.

a) Calculer l'intensité du *vecteur vitesse moyenne* du corps entre t_A et t_C, $\|\vec{v}_{mAC}\|$;

b) Représenter ce vecteur sur le graphique de l'exercice 1, avec l'échelle de vitesse 1cm <-> 1m/s.

c) Calculer la *vitesse scalaire moyenne* du pendule entre t_A et t_C, v_{AC} .

d) Si on compare l'intensité de la vitesse moyenne avec la vitesse scalaire moyenne entre A et C, laquelle est la plus grande ? Expliquer pourquoi *sans effectuer de calcul*.

Exercice 3 – Vecteur vitesse instantanée (chapitre 2)

À l'aide des données de Graphical, remplir les dernières deux colonnes du tableau à la fin de l'énoncé (composantes de la vitesse instantanée, v_x et v_y, au passage dans les points indiqués) et répondre aux points suivants.

a) Exprimer les vecteurs vitesses instantanées lors des passages aux points A, B et C, (resp. $\vec{v}_A = \vec{v}(t_A)$, $\vec{v}_B = \vec{v}(t_B)$ et $\vec{v}_C = \vec{v}(t_C)$) en utilisant leurs composantes respectives : $\vec{v} = (v_x ; v_y)$, sans oublier les unités.

b) Déterminer les intensités des vitesses instantanées, $\|\vec{v}\|$, lors des passages aux points A, B et C.

c) Représenter chacune de ces deux vitesses instantanées sur le graphique avec la même échelle utilisée ci-dessus.

Tableau des données du mouvement

Point	t [s]	x [m]	y [m]	v_x [m/s]	v_y [m/s]
A	$t_A =$	$x_A =$	$y_A =$	$v_{xA} =$	$v_{yA} =$
B	$t_B =$	$x_B =$	$y_B =$	$v_{xB} =$	$v_{yB} =$
C	$t_C =$	$x_C =$	$y_C =$	$v_{xC} =$	$v_{yC} =$

LANCER DE BALLE (position et vitesse) - Exemple de corrigé

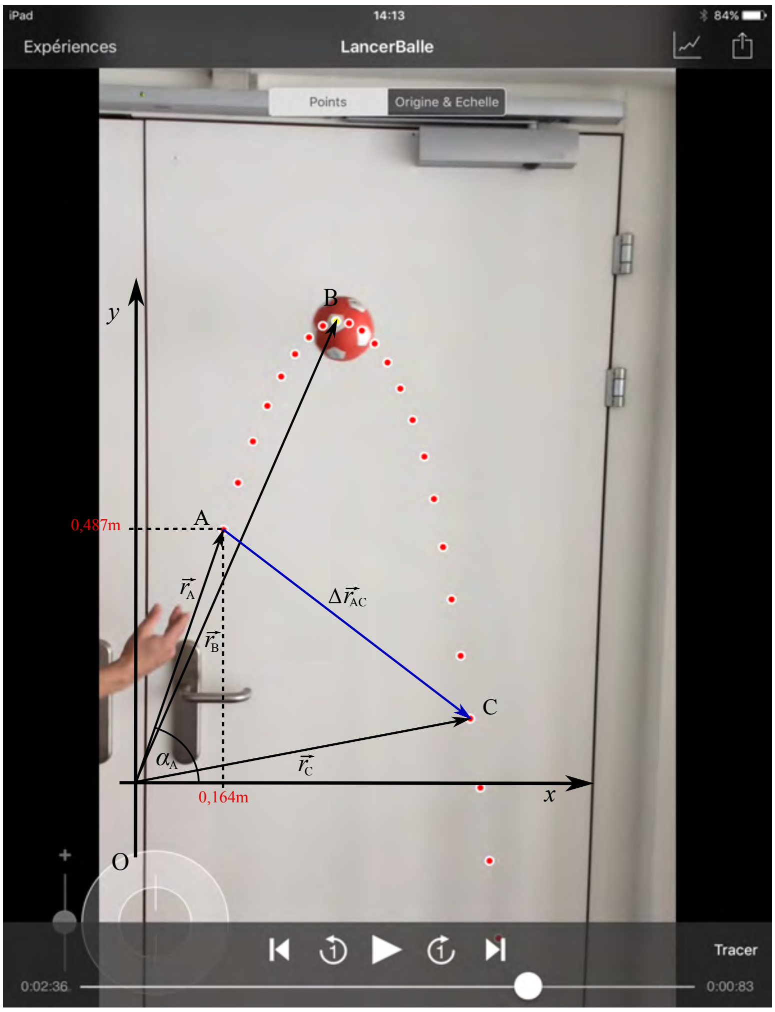
Tableau des données du mouvement

Point	***t* [s]**	***x* [m]**	***y* [m]**	**v_x [m/s]**	**v_y [m/s]**
A	t_A = 2,102	x_A = 0,1641	y_A = 0,4867	v_{xA} = 0,821	v_{yA} = 2,612
B	t_B = 2,368	x_B = 0,3791	y_B = 0,8875	v_{xB} = 0,748	v_{yB} = 0,086
C	t_C = 2,768	x_C = 0,6266	y_C = 0,1196	v_{xC} = 0,522	v_{yC} = -3,795

Exercice 1 – Vecteurs position et déplacement (chapitre 1)

a) Sur une feuille quadrillée A4, imprimer le graphique de l'image avec le repère, la trajectoire de la balle et indiquer les points A, B et C. La taille du graphique doit occuper la plus grande place possible sur la feuille.

b) Sur le même graphique tracer les trois vecteurs positions de la balle lorsqu'elle est au point A, au point B, puis au point C. Les indiquer respectivement $\vec{r}_A$, $\vec{r}_B$ *et* $\vec{r}_C$.



c) Exprimer $\vec{r}_A$, $\vec{r}_B$ *et* $\vec{r}_C$ *en utilisant leurs coordonnées :* $\vec{r} = (x;y)$, *sans oublier les unités. Puis, pour chacune, calculer sa norme.*

$\vec{r}_A = (x_A;y_A) = (0{,}164\text{m}; 0{,}487\text{m})$; $\|\vec{r}_A\| = \sqrt{0{,}164^2 + 0{,}487^2} = 0{,}514\text{m}$;

$\vec{r}_B = (x_B;y_B) = (0{,}379\text{m}; 0{,}888\text{m})$; $\|\vec{r}_B\| = \sqrt{0{,}379^2 + 0{,}888^2} = 0{,}965\text{m}$;

$\vec{r}_C = (x_C;y_C) = (0{,}627\text{m}; 0{,}120\text{m})$; $\|\vec{r}_C\| = \sqrt{0{,}627^2 + 0{,}120^2} = 0{,}638\text{m}$;

d) Calculer l'angle formé par $\vec{r}_A$ *avec l'axe x (donnant sa direction).*

$$\alpha_A = \tan^{-1}\left(\frac{0{,}487}{0{,}164}\right) = 71{,}4°;$$

e) *<u>Dessiner</u> et <u>nommer</u> sur le même graphique le déplacement de la balle entre A et C,* $\Delta\vec{r}_{AC}$, *puis calculer sa norme.*

Vecteur bleu sur le graphique.

$$\Delta\vec{r}_{AC} = (x_C - x_A; y_C - y_A) = (0{,}627 - 0{,}164; 0{,}120 - 0{,}487) = (0{,}463\text{m}; -0{,}367\text{m});$$

La variation de y st négative, car le point C est 0,367m plus bas que le point A.

$$\|\Delta\vec{r}_{AC}\| = \sqrt{0{,}463^2 + (-0{,}367)^2} = 0{,}591\text{m};$$

f) En utilisant l'échelle du graphique, donner une estimation de la distance parcourue entre A et C (Δs_{AC}*), puis la comparer avec la norme du déplacement entre A et C,* $\|\Delta\vec{r}_{AC}\|$.

Dans notre graphique 8,2 cm correspondent à 0,487 m dans la réalité.

0,487m <-> 6,5cm (= y_A)
ou
0,075m <-> 1,0cm

L'échelle du graphique est donc de 0,075m/cm.
L'estimation de la distance parcourue par la balle entre A et C peut s'obtenir en effectuant la somme des déplacements (pratiquement rectilignes) entre un point et le suivant. Avec une règle, on trouve sur le graphique
$\Delta s_{AC} \approx 17{,}8\text{cm} \cdot 0{,}075\text{m/cm} \approx 1{,}3\text{m}$.
Attention : on perd en précision, en réalité ce résultat a seulement 2 chiffres significatifs : Δs_{AC} est compris entre 1,2m et 1,4m.

Exercice 2 – Vecteur vitesse et vitesse scalaire (chapitre 2)

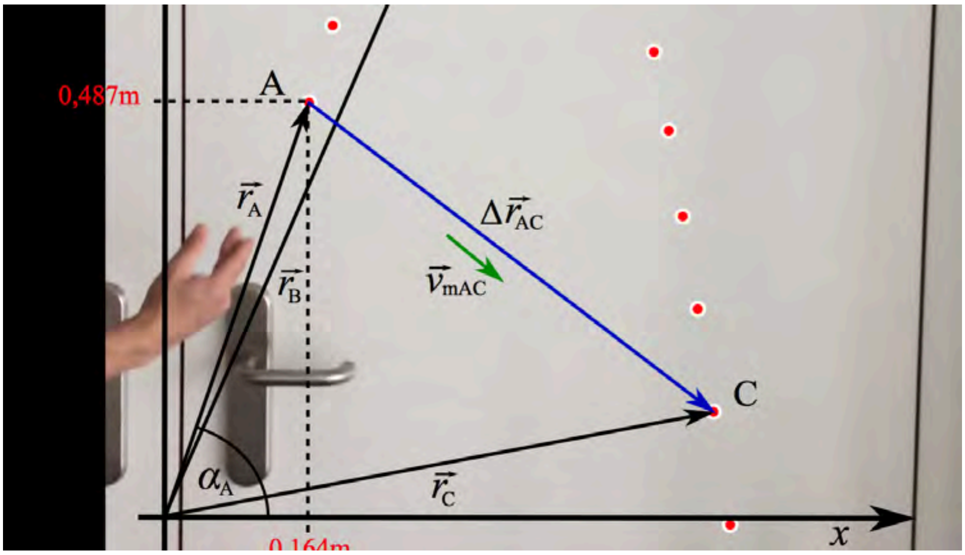
a) Calculer l'intensité du vecteur vitesse moyenne du corps entre t_A et t_C, $\left\|\vec{v}_{AC}\right\|$;

$\left\|\Delta\vec{r}_{AC}\right\| = 0{,}591\text{m}$; $\Delta t_{AC} = t_C - t_A = 2{,}768 - 2{,}102 = 0{,}666\text{s}$.

$$\left\|\vec{v}_{mAC}\right\| = \frac{\left\|\Delta\vec{r}_{AC}\right\|}{\Delta t_{AC}} = \frac{0{,}591\text{m}}{0{,}666\text{s}} = 0{,}887\text{m/s}.$$

b) Représenter ce vecteur sur le graphique de l'exercice 1, avec l'échelle de vitesse 1cm <-> 1m/s.

0,9cm avec la même direction et le même sens que le vecteur déplacement $\Delta\vec{r}_{AC}$, en vert sur le graphique.



c) Calculer la vitesse scalaire moyenne du pendule entre t_A et t_C, v_{AC} .

$v_{mAC} = \Delta s_{AC} / \Delta t_{AC} = 1{,}3\text{m} : 0{,}666\text{s} \approx 2{,}0\text{m/s}$.

d) Si on compare l'intensité de la vitesse moyenne avec la vitesse scalaire moyenne entre A et C, laquelle est la plus grande ? Expliquer pourquoi sans effectuer de calcul.

$$\left\|\vec{v}_m\right\| = \frac{\left\|\Delta\vec{r}\right\|}{\Delta t} < \frac{\Delta s}{\Delta t} = v_m.$$

Parce que la norme du déplacement (utilisée pour trouver l'intensité de la vitesse moyenne) est la mesure de la distance « à vol d'oiseau » entre le point de départ et le point d'arrivée. Alors que la distance parcourue Δs (pour trouver la vitesse scalaire moyenne) est la longueur de la trajectoire, plus longue.

N. B. In English : **vecteur** vitesse = velocity = $\Delta\vec{r} / \Delta t$;
vitesse **scalaire** = speed = $\Delta s / \Delta t$.

Exercice 3 – Vecteur vitesse instantanée (chapitre 2)

Tableau des données du mouvement

Point	***t* [s]**	***x* [m]**	***y* [m]**	**v_x [m/s]**	**v_y [m/s]**
A	t_A = 2,102	x_A = 0,1641	y_A = 0,4867	v_{xA} = 0,821	v_{yA} = 2,612
B	t_B = 2,368	x_B = 0,3791	y_B = 0,8875	v_{xB} = 0,748	v_{yB} = 0,086
C	t_C = 2,768	x_C = 0,6266	y_C = 0,1196	v_{xC} = 0,522	v_{yC} = -3,795

a) Exprimer les vecteurs vitesses instantanées lors des passages aux points A, B et C, (resp. $\vec{v}_A = \vec{v}(t_A)$, $\vec{v}_B = \vec{v}(t_B)$ et $\vec{v}_C = \vec{v}(t_C)$) en utilisant leurs composantes respectives : $\vec{v} = (v_x ; v_y)$, sans oublier les unités.

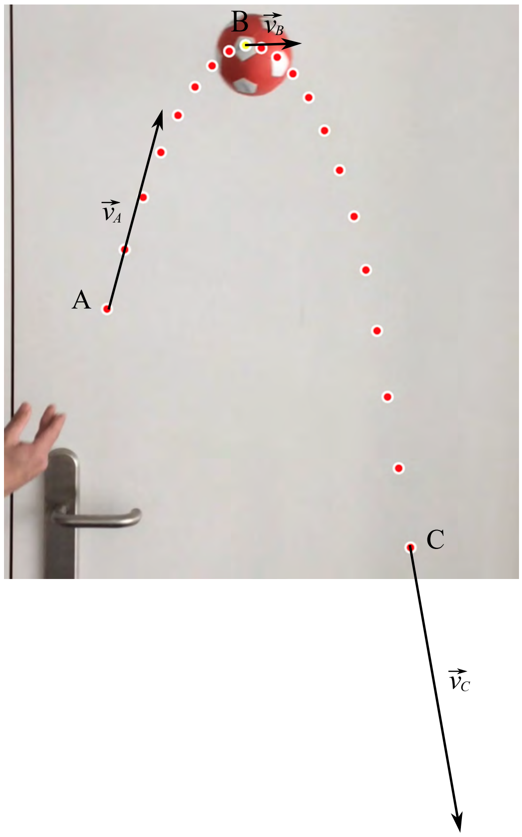
$\vec{v}_A = (0{,}821\text{m/s} \; ; \; 2{,}612\text{m/s})$
$\vec{v}_B = (0{,}748\text{m/s} \; ; \; 0{,}086\text{m/s})$
$\vec{v}_C = (0{,}522\text{m/s} \; ; \; -3{,}795\text{m/s})$

b) Déterminer les intensités des vitesses instantanées, $\|\vec{v}\|$, lors des passages aux points A, B et C.

$\|\vec{v}_A\| = \sqrt{0{,}821^2 + 2{,}612^2} = 2{,}74\text{m/s}$
$\|\vec{v}_B\| = \sqrt{0{,}748^2 + 0{,}086^2} = 0{,}753\text{m/s}$
$\|\vec{v}_B\| = \sqrt{0{,}522^2 + (-3{,}795)^2} = 3{,}83\text{m/s}$

c) Représenter chacune de ces deux vitesses instantanées sur le graphique avec la même échelle utilisée ci-dessus.

Echelle : 1cm <-> 1m/s
=> $\|\vec{v}_A\|$ -> 2,7cm ;
$\|\vec{v}_B\|$-> 0,8cm ;
$\|\vec{v}_C\|$-> 3,8cm.



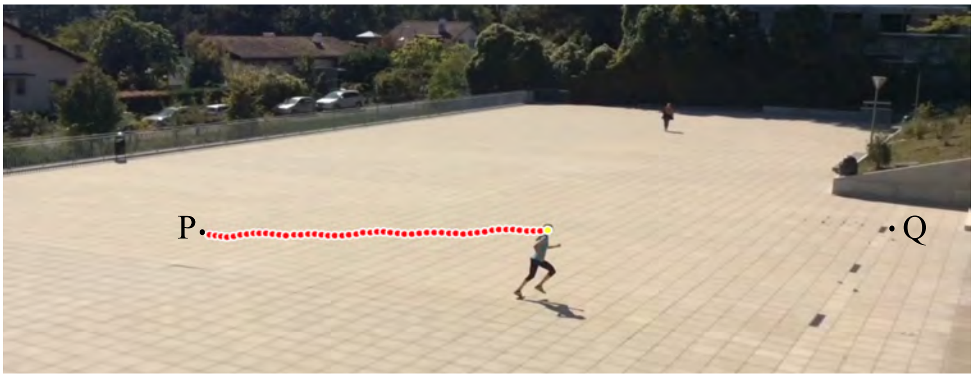
	Time (s)	X (m)	Y (m)	Vx (m/s)	Vy (m/s)
A →	2.101667	0.164113	0.486723	0.821477	2.61152
	2.135	0.191017	0.57753	0.834162	2.440874
	2.168333	0.219861	0.657233	0.836641	2.179557
	2.201667	0.247614	0.724845	0.818791	1.857887
	2.235	0.274281	0.781373	0.803716	1.50007
	2.268333	0.300858	0.824796	0.796213	1.14388
	2.301667	0.327359	0.857128	0.788792	0.799453
	2.335	0.353782	0.87837	0.772083	0.448369
	2.368333	0.379114	0.887521	0.747731	0.085574
	2.401667	0.403348	0.883573	0.731034	-0.26383
	2.435	0.427511	0.869543	0.724488	-0.603222
	2.468333	0.451591	0.843415	0.720457	-0.943472
	2.501667	0.475601	0.807204	0.713812	-1.297147
	2.535	0.499514	0.75688	0.693742	-1.648208
	2.568333	0.522349	0.69648	0.654512	-1.975611
	2.601667	0.544099	0.624998	0.58762	-2.293582
	2.635	0.561747	0.543461	0.516591	-2.602281
	2.668333	0.577302	0.450849	0.482663	-2.891913
	2.701667	0.592801	0.350171	0.485782	-3.170038
	2.735	0.609246	0.240412	0.50554	-3.472118
C →	2.768333	0.626622	0.119557	0.521792	-3.795179
	2.801667	0.644922	-0.013404	0.513653	-4.073268
	2.835	0.661148	-0.154794	0.497063	-4.27334
	2.868333	0.677319	-0.304124	0.489049	-4.399681

L'ALLER-RETOUR

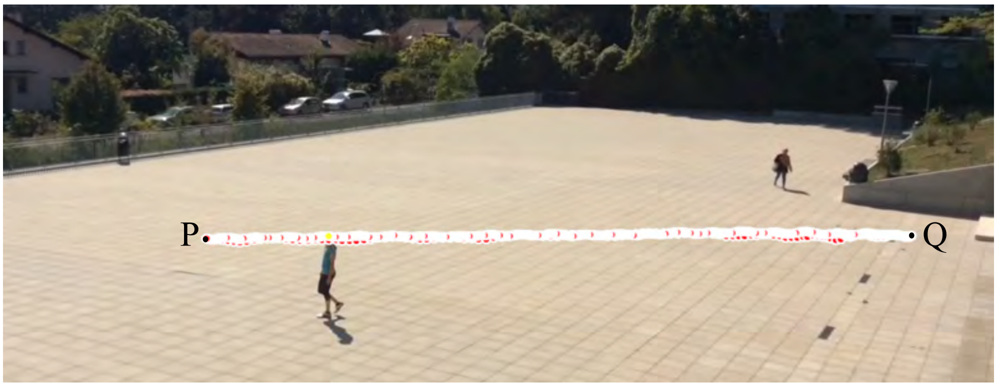
Vitesse scalaire moyenne (chapitre 2)

Alice fait un aller-retour dans la cour du collège : en partant du point P elle « sprinte » jusqu'au point Q en mouvement rectiligne, puis elle revient au point P en marchant.
Un programme d'analyse vidéo permet le suivi du mouvement, en mesurant la position d'un corps trois fois par seconde (points dans les images ci-dessous).

Aller

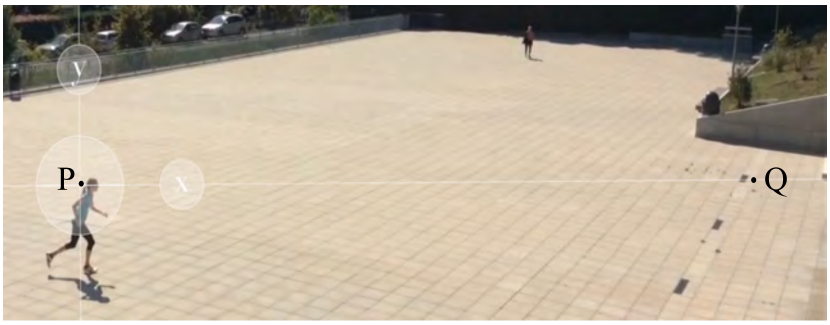


Retour



On fixe le repère de sorte que la trajectoire soit le long de l'axe x : on pourra ainsi étudier le mouvement en considérant uniquement cette coordonnée (position, déplacement et vitesse):

Repère



Dans ce repère nous écrivons la position : $\vec{r} = (x; 0) = x$;
le module de la position : $\|\vec{r}\| = \sqrt{x^2 + 0^2} = |x|$; la vitesse vectorielle : $\vec{v} = (v_x; 0) = v_x$;
le module ou l'intensité de la vitesse vectorielle : $\|\vec{v}\| = \sqrt{v_x^2 + 0^2} = |v_x|$

Rappel : Vitesse vectorielle moyenne $\vec{v} = \frac{\Delta \vec{r}}{\Delta t} \Rightarrow v_x = \frac{\Delta x}{\Delta t}$;

Vitesse scalaire moyenne $v = \frac{\Delta s}{\Delta t}$

On démarre le chronomètre (la vidéo) quelques secondes avant qu'Alice soit au point P (l'origine). Ensuite on mesure sa position ainsi que les temps correspondants pour chaque point de la trajectoire. Le du tableau suivant donne les mesures aux points P et Q.

Point	***t* [s]**	***x* [m]**
P (départ)	$t_0 = 3,8$	$x_0 = 0,0$
Q	$t_1 = 7,9$	$x_1 = 12,3$
P (arrivée)	$t_2 = 20,8$	$x_2 = 0,0$

i. Vitesse vectorielle moyenne

a) Déterminer la *vitesse vectorielle* moyenne
- à l'aller v_{x01} ;
- au retour v_{x12} ;
- pour tout le trajet v_{x02}.

Attention au signe.

b) Représenter les vitesses vectorielles calculées au point (a) sur l'image avec le repère. *Utiliser l'échelle : 1 cm <-> 0,5 m/s.*

ii. Vitesse scalaire moyenne

c) Déterminer la *vitesse scalaire* moyenne
- à l'aller v_{01} ;
- au retour v_{12} ;
- pour tout le trajet v_{02}.

d) Est la vitesse scalaire moyenne du trajet total est égale à la moyenne mathématique des vitesses scalaires à l'aller et au retour ? Pourquoi ?

e) Quelle devrait être la vitesse scalaire moyenne à l'aller pour que la vitesse scalaire moyenne de tout le trajet (aller-retour) soit
- 1,8 m/s ?
- 2,0 m/s ?

Attention : donner les réponses avec un nombre pertinent de chiffres significatifs.

L'ALLER-RETOUR – Exemple de corrigé

Vitesse scalaire moyenne et moyenne des vitesses scalaires (chapitre 2)

Point	***t* [s]**	***x* [m]**
P (départ)	$t_0 = 3{,}8$	$x_0 = 0{,}0$
Q	$t_1 = 7{,}9$	$x_1 = 12{,}3$
P (arrivée)	$t_2 = 20{,}8$	$x_2 = 0{,}0$

a) + b)

$$v_{x01} = \frac{x_1 - x_0}{t_1 - t_0} = \frac{\Delta x_{01}}{\Delta t_{01}} = \frac{12{,}3 - 0{,}0}{7{,}9 - 3{,}8} = 3{,}0 \text{ m/s}$$

=> 6,0cm, horizontale et dirigée de P à Q (car positive).

$$v_{x12} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x_{12}}{\Delta t_{12}} = \frac{0{,}0 - 12{,}3}{20{,}8 - 7{,}9} = -0{,}95 \text{ m/s}$$

=> 1,9cm, horizontale et dirigée de Q à P (car négative).

$$v_{x02} = \frac{x_2 - x_0}{t_2 - t_0} = \frac{0{,}0 - 0{,}0}{20{,}8 - 3{,}8} = 0{,}0 \text{ m/s}$$

c)

$$v_{01} = \frac{\Delta s_{01}}{\Delta t_{01}} = \frac{|\Delta x_{01}|}{\Delta t_{01}} = \frac{12{,}3 \text{ m}}{7{,}9 \text{ s} - 3{,}8 \text{ s}} = 3{,}0 \text{ m/s}$$

$$v_{12} = \frac{\Delta s_{12}}{\Delta t_{12}} = \frac{|\Delta x_{12}|}{\Delta t_{12}} = \frac{12{,}3 \text{ m}}{20{,}8 \text{ s} - 7{,}9 \text{ s}} = 0{,}95 \text{ m/s}$$

$$v_{02} = \frac{\Delta s_{02}}{\Delta t_{02}} = \frac{|\Delta x_{01}| + |\Delta x_{12}|}{\Delta t_{02}} = \frac{24{,}6 \text{ m}}{20{,}8 \text{ s} - 3{,}8 \text{ s}} = 1{,}4 \text{ m/s}$$

d)

$$\frac{v_{01} + v_{12}}{2} = \frac{3{,}0 \text{ m/s} + 0{,}95 \text{ m/s}}{2} = 2{,}0 \text{ m/s} \neq v_{02}$$

La vitesse scalaire moyenne de tout le trajet n'est pas égale à la moyenne mathématique des vitesses scalaires à l'aller et au retour, car, dans ce cas, on passe plus de temps pour le retour que pour l'aller. Il faudrait faire une moyenne pondérée, avec comme poids la durée de chaque trajet à vitesse scalaire constante.

$$v_{02} = \frac{v_{01} \cdot \Delta t_{01} + v_{m01} \cdot \Delta t_{12}}{\Delta t_{01} + \Delta t_{12}} = \frac{3{,}0 \text{ m/s} \cdot 4{,}1 \text{ s} + 0{,}95 \text{ m/s} \cdot 12{,}9 \text{ s}}{4{,}1 \text{ s} + 12{,}9 \text{ s}} = 1{,}4 \text{ m/s}.$$

e) Nous appelons $\Delta s_{01} = \Delta s_{12} = d$. On sait que $\Delta t_{12} = 12{,}9\text{s}$.

- On impose

$$v_{02} = \frac{\Delta s_{02}}{\Delta t_{02}} = \frac{\Delta s_{01} + \Delta s_{12}}{\Delta t_{01} + \Delta t_{12}} = \frac{2d}{\Delta t_{01} + \Delta t_{12}} = 1{,}8 \text{ m/s}$$

$$\Rightarrow \quad \Delta t_{01} + \Delta t_{12} = \frac{2d}{1{,}8 \text{ m/s}} = \frac{24{,}6 \text{ m}}{1{,}8 \text{ m/s}} = 13{,}7 \text{ s}$$

$$\Rightarrow \quad \Delta t_{01} = 13{,}7\text{s} - 12{,}9\text{s} = 0{,}77\text{s}$$

$$\Rightarrow \quad v_{01} = \frac{d}{\Delta t_{01}} = \frac{12{,}3 \text{ m}}{0{,}77 \text{ s}} = 16 \text{ m/s} \quad (\approx 60 \text{ km/h!})$$

- On impose

$$v_{02} = \frac{2d}{\Delta t_{01} + \Delta t_{12}} = 2{,}0 \text{ m/s} \quad \Rightarrow \quad \Delta t_{01} + \Delta t_{12} = \frac{2d}{2{,}0 \text{ m/s}} = \frac{24{,}6 \text{ m}}{2{,}0 \text{ m/s}} = 12{,}3 \text{ s}$$

12,3 s est moins que la durée de l’aller seulement, donc il ne sera pas possible d’aller assez vite pour avoir une vitesse moyenne de 2,0 m/s.

Nom et prénom : Activité réalisée avec : Date :

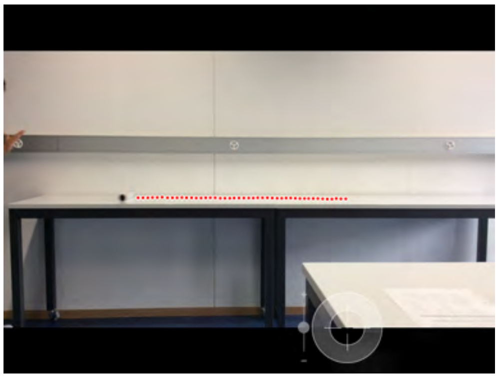
Rappel des consignes (à lire intégralement, ainsi que le protocole, avant de commencer)

Veuillez réaliser l'activité et le rapport manuscrit (un par élève, même si les deux élèves d'un binôme rendent des rapports identiques). Respectez les règles habituelles quant à la présentation et à l'orthographe, notamment : en-tête rempli, pas de crayon (sauf pour les dessins) ni d'effaceur (erreurs éventuelles à biffer proprement), soin de la langue française, protocole/graphique(s)/données à rendre avec le rapport, précision dans les dessins et les résultats (nombre pertinent de chiffres significatifs).

LE MRU

Le but de cette activité est d'étudier le mouvement rectiligne uniforme d'un corps (par exemple un chariot sur un rail ou un rouleau sur un plan horizontal), où l'on peut négliger les frottements.

I. Prise des mesures avec l'iPad



a) Mettre en marche le iPad (*mot de passe: 0987*).

b) Appeler le programme « Video Physics » (Icône: ).

c) Débuter une nouvelle Expérience (+) et sélectionner « *Faire un film* ».

d) Durant le film

- tenir le iPad de manière stable, de telle manière que toute la trajectoire à filmer soit dans le cadre ;
- se positionner de sorte que le mouvement de l'objet soit filmé de gauche à droite (cf. image ci dessus) ;
- s'assurer que le corps filmé soit bien visible par rapport au fond (corps noir sur fond blanc), de sorte que l'application puisse en reconnaître le mouvement.

e) Mettre le corps en mouvement avec une vitesse constante et débuter le film. Un fois terminé, appuyer sur l'option « *Utiliser* ».

f) Cliquer en haut à gauche sur « *Expériences* » et enregistrer le nouveau film en cliquant sur « *i* » (= *informations*) puis en donnant un nom explicite comme: « **Rouleau Elève X** ».

II. Création des graphiques sur iPad

Le film enregistré peut-être visualisé au ralenti et à répétition.

a) Faire glisser le doigt sur le curseur afin de sélectionner l'image du corps au début de sa trajectoire une fois que sa vitesse est stable (après la poussée).

b) Placer la cible précisément sur l'image du corps (régler sa taille, ni trop grande ni trop petite), puis appuyer sur « *Tracer* ». La cible suit automatiquement le corps dans son mouvement.

c) Définir un repère ayant comme origine le premier point du traçage et l'axe des x orienté horizontalement, comme la vitesse: nous pourrons ainsi étudier le mouvement en ne considérant que cette coordonnée.

d) Définir l'échelle (par exemple avec la mesure de la largeur de la table) puis visualiser les graphiques via l'icône. L'application donne le graphique de la trajectoire (x ; y), le *diagramme horaire* $x(t)$ et celui de la vitesse en fonction du temps $v_x(t)$. Elle donne aussi le diagramme horaire de $y(t)$ et de $v_y(t)$ représentant les petites oscillations perpendiculaires au mouvement, dont nous ne tenons pas compte.

e) Appeler le temps du début de la mesure t_0* et la position initiale $x(t_0) = x_0$.

f) Pour visualiser les données et travailler avec les graphiques:
   - cliquer sur l'icône,
   - puis sur « *Fichier Données* » + « *Ouvrir dans...* »,
   - choisir l'application *Graphical Analysis* (Icône :).

g) L'application *Graphical Analysis* visualise les graphiques du mouvement. En cliquant sur les noms des paramètres observés sur l'axe vertical, les différents graphiques peuvent être sélectionnés ou non. En cliquant sur l'icône en bas à gauche il est possible de choisir le format des points (« *Options graphe* »).

h) Pour visualiser le tableau des données, cliquer sur la première icône en haut à droite et choisir « *Tableau* ».

i) **Important** : envoyer les graphiques terminés et le tableau des données par email à votre adresse favorite afin de pouvoir les joindre à votre analyse par la suite.

* Attention : le temps t_0 n'est pas forcement égal à 0s.

III. Analyse des résultats

a) Quel type de courbe suit mieux les données du graphique de $v_x(t)$ (plateau, droite, parabole, autre…) ? *Justifier.*

b) Quel type de courbe suit mieux les données du *diagramme horaire x(t)* (graphique de *x(t)*) de ce mouvement (plateau, droite, parabole, autre…) ? *Justifier.*

c) À partir de la courbe du *diagramme horaire,* déterminer quelle relation existe-t-il entre $x - x_0$ et $t - t_0$ (proportionnalité directe, inverse, relation quadratique, autre)? *Justifier.*

d) En utilisant le tableau des données du mouvement et le graphique, déterminer
   - la pente et
   - l'ordonnée au temps t_0

   du diagramme horaire, avec les unités.
   Arrondir <u>les données</u> à deux chiffres après la virgule.

e) Ecrire *l'équation horaire* de ce mouvement✦: l'équation mathématique qui représente la fonction *x(t).*

f) À quelles grandeurs physiques* correspondent la pente et l'ordonnée au temps t_0 calculées au point (d) ?

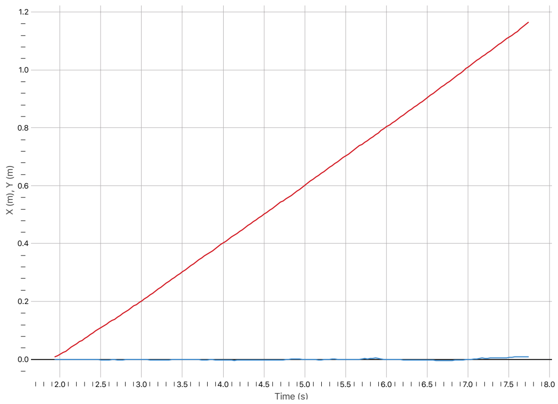
g) Cliquer sur l'icône en bas à gauche  et choisir « *Appliquer une régression* » pour la courbes de *x(t)* (type « *Affine* »). Ensuite, comparer l'équation de cette courbe avec celle écrite au point (e).

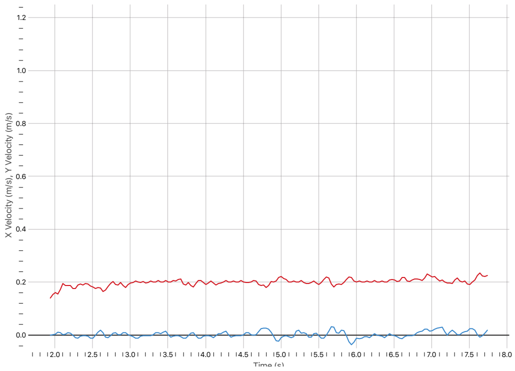
h) Imaginons que le corps puisse continuer ce mouvement à l'infini. Dans ce cas, utiliser l'équation horaire écrite au point (e) pour prédire
   - quelle serait sa position au temps t = 1,0 h et
   - à quel instant il aurait parcouru 2,0 km.

✦ Attention : ici *x* est la variable dépendante (axe *y,* des ordonnées) et *t* celle indépendante (asse *x,* des abscisses).

* Quelques exemples de grandeurs physiques, qu'elles soient des scalaires ou des vecteurs, sont la masse, le temps, la position, la vitesse, la température.

LE MRU- Exemple de corrigé





III Analyse des résultats

a) *Quel type de courbe suit mieux les données du diagramme de la vitesse en fonction du temps $v_x(t)$ (plateau, droite, parabole, autre…) ?*

Plateau : v_x reste *constante* dans le temps, environ 0,2 m/s.

b) *Quel type de courbe suit mieux les données du diagramme horaire x(t) de ce mouvement (plateau, droite, parabole, autre…) ?*

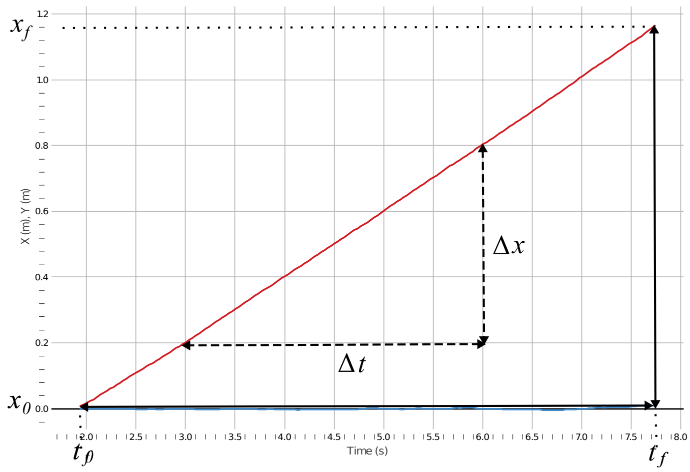
Droite : *x* augmente *linéairement* avec le temps.

c) *À partir du graphique, déterminer quelle relation existe-t-il entre $x - x_0$ et $t - t_0$ (proportionnalité directe, inverse, relation quadratique, autre)?*

Proportionnalité directe : si $t - t_0$ double (devient 3, 4, .. fois plu grand), alors $x - x_0$ double aussi (devient 3, 4, .. fois plu grand).
Remarque : ici nous avons choisi le repère de sorte que x_0 = 0 m, mais cela n'est pas toujours le cas.

d) *À l'aide des données du mouvement, estimer (1) la pente et (2) l'ordonnée au temps t_0 du diagramme horaire x(t), avec les unités. Arrondir les données à deux chiffres après la virgule.*

L'ordonné au temps t_0, *b,* est la coordonnée *x* au temps initial : $b = x(t_0) = x_0 = 0{,}01$ m
La pente est définie comme la distance verticale divisée par la distance horizontale pour n'importe quel triangle. Nous prenons le plus grand possible, comme montré dans la figure, mais n'importe quel autre donne le même résultat (par exemple le triangle indiqué en traitillé), car, grâce à la proportionnalité entre Δx et Δt, leur rapport reste inchangé.



$$\text{Pente} = \frac{x_f - x_0}{t_f - t_0} = \frac{\Delta x}{\Delta t} = v_x$$

Dans ce cas

$$\text{Pente} = v_x = \frac{1{,}16 - 0{,}01}{7{,}74 - 1{,}94} =$$

$$= \frac{1{,}15\ \text{m}}{5{,}8\ \text{s}} = 0{,}20\ \text{m/s}.$$

e) *Ecrire l'équation horaire de ce mouvement: l'équation mathématique de la courbe x(t).*

$$x(t) = v_x \cdot (t-t_0) + x_0$$

=> $x(t) = \underbrace{0{,}2}_{\text{m/s}}(t - \underbrace{1{,}9}_{\text{s}}) + \underbrace{0}_{\text{m}}$ ou $x(t) = \underbrace{0{,}2}_{\text{m/s}}t - \underbrace{0{,}38}_{\text{m}}$

Remarque : 0,38 m est l'ordonnée à l'origine (au temps t = 0 s, en supposant un MRU infini).

f) *À quelles grandeurs physiques correspondent la pente et l'ordonnée au temps t_0 calculées au point d) ?*

Pente = v_x = *vitesse* (instantanée et moyenne, égales car constante) ;
Ordonnée ou position au temps t_0 : $x(t_0) = x_0$.
($x(t) = a(t-t_0) + b$, avec a la **pente** et $b = x(t_0) = x_0$ l'**ordonné au temps t_0**,)

g) *Comparer l'équation de cette courbe avec celle écrite au point e).*

h) *Imaginons que le corps puisse continuer ce mouvement à l'infini. Dans ce cas, utiliser l'équation horaire écrite au point e) pour prédire*

- *quelle serait sa position au temps t = 1 h?*

  t = 1h = 3600s ;

  $$x(3600\ \text{s}) = \underbrace{0{,}2}_{\text{m/s}} \cdot \underbrace{3600}_{\text{s}} - \underbrace{0{,}38}_{\text{m}} = 719{,}6 = 720\ \text{m}$$

- *à quel instant aurait-il parcouru 2000 m ?*

  $x(t)$ = 2,0 km = 2000 m ;

  $$\underbrace{2000}_{\text{m}} = \underbrace{0{,}2}_{\text{m/s}}t - \underbrace{0{,}38}_{\text{m}} \quad \Rightarrow \underbrace{2000{,}38}_{\text{m}} = \underbrace{0{,}2}_{\text{m/s}}t \quad \Rightarrow t = \frac{2000{,}38\text{m}}{0{,}2\text{m/s}} = 10002\ \text{s} = 2{,}8\ \text{h}$$

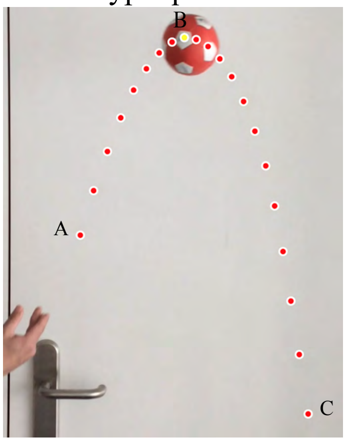
Nom et prénom : Groupe : Date :

Rappel des consignes (à lire intégralement, ainsi que le protocole, avant de commencer):

Veuillez réaliser l'activité (seul ou en binôme) et le rapport manuscrit (un par élève, même si les deux élèves d'un binôme rendent des rapports identiques). Respectez les règles habituelles quant à la présentation et à l'orthographe, notamment : en-tête rempli, pas de crayon (sauf pour les dessins) ni d'effaceur (erreurs éventuelles à biffer proprement), soin de la langue française, protocole à rendre avec le rapport, précision dans les dessins et les résultats (nombre adéquat de chiffres significatifs).

LANCER DE BALLE (accélération)

Utiliser l'application « Video Physics » pour filmer le mouvement d'un objet (une balle de tennis, par exemple) lancé en l'air, de sorte que sa trajectoire soit du même type que celle montrée dans l'image ci-dessous.



Avec la même application, tracer les points du mouvement. Ensuite **fixer une échelle** et un repère (origine et axes). Cette application vous donnera automatiquement (1) le graphique de la trajectoire du mouvement dans le repère choisi, (2) les deux graphiques de *x(t)* et de $v_x(t)$ et (3) les deux graphiques de *y(t)* et de $v_y(t)$.

Cliquer sur « ouvrir le fichier données dans… » (en haut à droite) et choisir l'application « Graphical » pour accéder à la liste des données du mouvement enregistrées : le temps (*t*), les coordonnées de la position à cet instant (*x* et *y*) ainsi que les composantes de la vitesse instantanée au même instant (v_x et v_y).

Choisir le point A au début du mouvement, quand la balle a *déjà quitté les mains* du laceur, le point B au sommet de la trajectoire, et le point C à la fin du mouvement, mais *avant qu'elle ne tombe* (ou soit reprise).

Exercice 1 – Vecteur vitesse instantanée (chapitre 2)

a) À l'aide des données de Graphical (*prendre les données arrondies à trois chiffres après la virgule*), calculer les intensités des vitesses instantanées en chaque point tracé, soit

- au temps t_0 : $\|\vec{v}_0\| = \|\vec{v}(t_0)\| = \|\vec{v}(t_A)\| = \sqrt{v_x^2(t_0) + v_y^2(t_0)} = \ldots$
- au temps t_1 : $\|\vec{v}_1\| = \|\vec{v}(t_1)\| = \sqrt{v_x^2(t_1) + v_y^2(t_1)} = \ldots$
- au temps t_2 : $\|\vec{v}_2\| = \|\vec{v}(t_2)\| = \sqrt{v_x^2(t_2) + v_y^2(t_2)} = \ldots$

  …
- au temps t_n : $\|\vec{v}_n\| = \|\vec{v}(t_n)\| = \|\vec{v}(t_C)\| = \sqrt{v_x^2(t_n) + v_y^2(t_n)} = \ldots$

b) Imprimer une capture d'écran de la trajectoire avec les points tracés et y représenter les vecteurs vitesses instantanées à chaque point. *Imprimer la capture d'écran de sorte qu'elle occupe le plus possible d'espace dans une feuille A4 et choisir une échelle de vitesse adaptée au format (par exemple, si l'impression occupe toute la feuille, l'échelle 1cm <--> 2m/s).*

Exercice 2 – Vecteur accélération moyenne (chapitre 4)

À l'aide des données de Graphical, remplir le tableau suivant (ou reprendre les données du tableau de l'Activité 1). *Prendre les données arrondies à trois chiffres après la virgule.*

Tableau des données du mouvement

Point	***t*** **[s]**	***x*** **[m]**	***y*** **[m]**	v_x **[m/s]**	v_y **[m/s]**
A	$t_A =$	$x_A =$	$y_A =$	$v_{xA} =$	$v_{yA} =$
B	$t_B =$	$x_B =$	$y_B =$	$v_{xB} =$	$v_{yB} =$
C	$t_C =$	$x_C =$	$y_C =$	$v_{xC} =$	$v_{yC} =$

À l'aide du tableau répondre aux points suivants.

a) Ecrire les intensités des vitesses instantanées lors des passages aux point A, B et C, soit

- au temps t_A : $\|\vec{v}_A\| =$ ...
- au temps t_B : $\|\vec{v}_B\| =$ ...
- au temps t_C : $\|\vec{v}_C\| =$ ...

b) Imprimer une capture d'écran de la trajectoire avec les points tracés et y représenter chacune de ces trois vitesses instantanées, avec une échelle de vitesse appropriée. *Imprimer la capture d'écran de sorte qu'elle occupe le plus possible d'espace dans une feuille A4 et choisir l'échelle 1cm <--> 1m/s.*

c) Déterminer graphiquement la *variation de vitesse* entre t_A et t_C , en d'autres mots la *différence entre le vecteur vitesse au temps* t_C *et celui au temps* t_A :

$$\Delta\vec{v}_{AC} \doteq \vec{v}_C - \vec{v}_A \ .$$

d) Déterminer l'intensité $\|\Delta\vec{v}_{AC}\|$ (en utilisant l'échelle ou avec Pythagore à partir de ses composantes).

e) Calculer la durée Δt_{AC}.

f) À l'aide des résultats trouvés aux points d) et e), déterminer l'intensité de l'accélération moyenne entre t_A et t_C, $\|\vec{a}_{mAC}\|$.

g) Sur le même croquis dessiné au point b), dessiner $\vec{a}_{mAC}$, avec l'échelle d'accélération 1cm <-> $2m/s^2$.

LANCER DE BALLE (accélération) - Exemple de corrigé

Exercice 1 – Vecteur vitesse instantanée (chapitre 2)

Données de Graphical :

	Time (s)	X (m)	Y (m)	Vx (m/s)	Vy (m/s)
A ⟶	2.101667	0.164113	0.486723	0.821477	2.61152
	2.135	0.191017	0.57753	0.834162	2.440874
	2.168333	0.219861	0.657233	0.836641	2.179557
	2.201667	0.247614	0.724845	0.818791	1.857887
	2.235	0.274281	0.781373	0.803716	1.50007
	2.268333	0.300858	0.824796	0.796213	1.14388
	2.301667	0.327359	0.857128	0.788792	0.799453
	2.335	0.353782	0.87837	0.772083	0.448369
	2.368333	0.379114	0.887521	0.747731	0.085574
	2.401667	0.403348	0.883573	0.731034	-0.26383
	2.435	0.427511	0.869543	0.724488	-0.603222
	2.468333	0.451591	0.843415	0.720457	-0.943472
	2.501667	0.475601	0.807204	0.713812	-1.297147
	2.535	0.499514	0.75688	0.693742	-1.648208
	2.568333	0.522349	0.69648	0.654512	-1.975611
	2.601667	0.544099	0.624998	0.58762	-2.293582
	2.635	0.561747	0.543461	0.516591	-2.602281
	2.668333	0.577302	0.450849	0.482663	-2.891913
	2.701667	0.592801	0.350171	0.485782	-3.170038
	2.735	0.609246	0.240412	0.50554	-3.472118
C ⟶	2.768333	0.626622	0.119557	0.521792	-3.795179
	2.801667	0.644922	-0.013404	0.513653	-4.073268
	2.835	0.661148	-0.154794	0.497063	-4.27334
	2.868333	0.677319	-0.304124	0.489049	-4.399681

Ici nous choisissons le premier instant $t_0 = t_A = 2{,}10\text{s}$ et $t_n = t_C = 2{,}768\text{s}$, avec $n = 20$.

a) *À l'aide des données de Graphical, calculer les intensités des vitesses instantanées en chaque point tracé.*

Pour cette vidéo, nous prenons les premiers 20 points tracés ($n = 20$)

$$\|\vec{v}_0\| = \|\vec{v}_A\| = \sqrt{v_x^2(t_0) + v_y^2(t_0)} = \sqrt{0{,}821^2 + 2{,}612^2} = 2{,}74\text{m/s}$$

$\|\vec{v}_1\| = \sqrt{0{,}834^2 + 2{,}44^2} = 2{,}58\text{m/s}$ $\|\vec{v}_2\| = \sqrt{0{,}837^2 + 2{,}18^2} = 2{,}34\text{m/s}$

$\|\vec{v}_3\| = \sqrt{0{,}818^2 + 1{,}86^2} = 2{,}03\text{m/s}$ $\|\vec{v}_4\| = \sqrt{0{,}803^2 + 1{,}50^2} = 1{,}70\text{m/s}$

$\|\vec{v}_5\| = \sqrt{0{,}796^2 + 1{,}14^2} = 1{,}39\text{m/s}$ $\|\vec{v}_6\| = \sqrt{0{,}789^2 + 0{,}799^2} = 1{,}12\text{m/s}$

$\|\vec{v}_7\| = \sqrt{0{,}772^2 + 0{,}448^2} = 0{,}89\text{m/s}$ $\|\vec{v}_8\| = \sqrt{0{,}748^2 + 0{,}086^2} = 0{,}75\text{m/s}$

$\|\vec{v}_9\| = \sqrt{0{,}731^2 + (-0{,}264)^2} = 0{,}78\text{m/s}$ $\|\vec{v}_{10}\| = \sqrt{0{,}724^2 + (-0{,}603)^2} = 0{,}94\text{m/s}$

$\|\vec{v}_{11}\| = \sqrt{0{,}720^2 + (-0{,}943)^2} = 1{,}19\text{m/s}$ $\|\vec{v}_{12}\| = \sqrt{0{,}714^2 + (-1{,}30)^2} = 1{,}48\text{m/s}$

$\|\vec{v}_{13}\| = \sqrt{0{,}694^2 + (-1{,}65)^2} = 1{,}79\text{m/s}$ $\|\vec{v}_{14}\| = \sqrt{0{,}655^2 + (-1{,}98)^2} = 2{,}09\text{m/s}$

$\|\vec{v}_{15}\| = \sqrt{0{,}588^2 + (-2{,}29)^2} = 2{,}36\text{m/s}$ $\|\vec{v}_{16}\| = \sqrt{0{,}517^2 + (-2{,}60)^2} = 2{,}65\text{m/s}$

$\|\vec{v}_{17}\| = \sqrt{0{,}483^2 + (-2{,}89)^2} = 2{,}93\text{m/s}$ $\|\vec{v}_{18}\| = \sqrt{0{,}486^2 + (-3{,}17)^2} = 3{,}21\text{m/s}$

$\|\vec{v}_{19}\| = \sqrt{0{,}506^2 + (-3{,}47)^2} = 3{,}51\text{m/s}$ $\|\vec{v}_{20}\| = \|\vec{v}_C\| = \sqrt{0{,}522^2 + (-3{,}80)^2} = 3{,}84\text{m/s}$

b) Imprimer une capture d'écran de la trajectoire avec les points tracés et y représenter les vecteurs vitesses instantanées à chaque point.

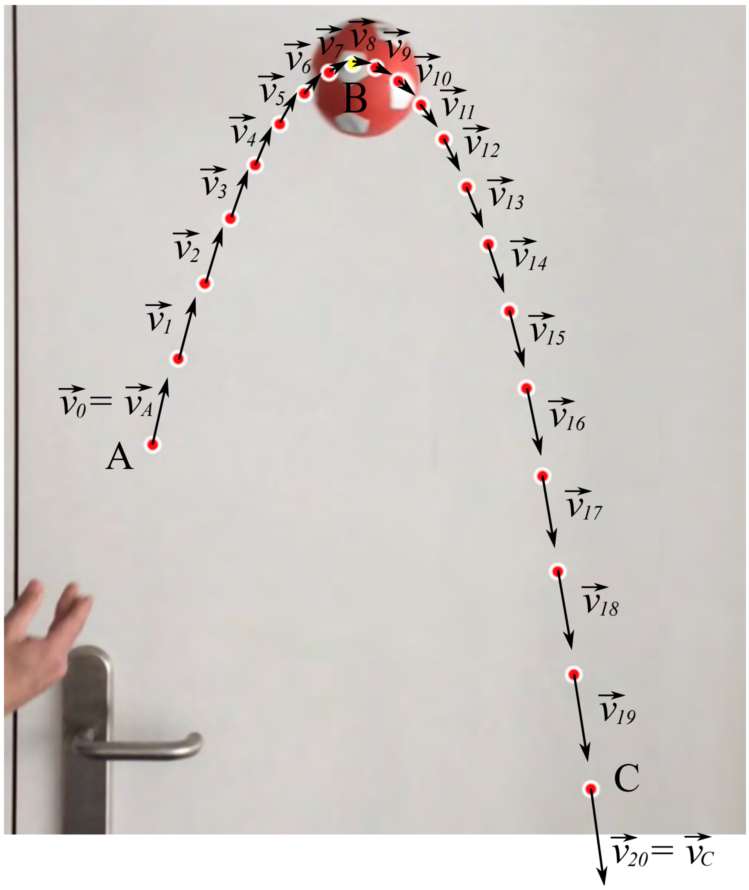
L'échelle de vitesse dépend du format de l'image.
Pour l'échelle 1cm <--> 2m/s :

$\|\vec{v}_0\| = \|\vec{v}_A\| = 2{,}74\text{m/s} \rightarrow\ 1{,}4\text{cm}$
$\|\vec{v}_1\| = 2{,}58\text{m/s} \rightarrow\ 1{,}3\text{cm}$
…

$\|\vec{v}_8\| = \|\vec{v}_B\| = 0{,}75\text{m/s} \rightarrow\ 0{,}4\text{cm}$
…

$\|\vec{v}_{20}\| = \|\vec{v}_C\| = 3{,}84\text{m/s} \rightarrow\ 1{,}9\text{cm}$

Tous les vecteurs doivent avoir la **direction tangente à la trajectoire dans le point correspondant.**



Exercice 2 – Vecteur accélération moyenne (chapitre 4)

Tableau des données du mouvement

Point	***t* [s]**	***x* [m]**	***y* [m]**	**v_x [m/s]**	**v_y [m/s]**
A	t_A = 2,102	x_A = 0,1641	y_A = 0,487	v_{xA} = 0,821	v_{yA} = 2,612
B	t_B = 2,368	x_B = 0,3791	y_B = 0,888	v_{xB} = 0,748	v_{yB} = 0,086
C	t_C = 2,768	x_C = 0,627	y_C = 0,120	v_{xC} = 0,522	v_{yC} = -3,795

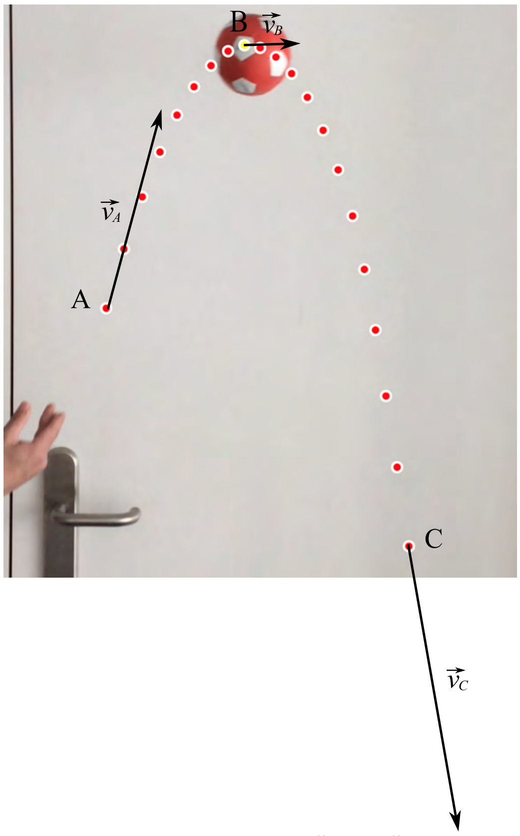
a) *Déterminer les intensités des vitesses instantanées lors des passages aux point A, B et C, soit*

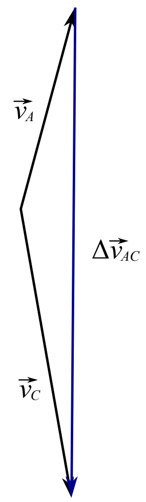
- au temps t_A : $\|\vec{v}_A\| = \sqrt{v_{xA}^2 + v_{yA}^2} = \sqrt{0{,}821^2 + 2{,}612^2} = 2{,}74\text{m/s}$
- au temps t_B : $\|\vec{v}_B\| = \sqrt{v_{xB}^2 + v_{yB}^2} = \sqrt{0{,}748^2 + 0{,}086^2} = 0{,}753\text{m/s}$
- au temps t_C : $\|\vec{v}_C\| = \sqrt{v_{xC}^2 + v_{xC}^2} = \sqrt{0{,}522^2 + (-3{,}80)^2} = 3{,}84\text{m/s}$

b) *Représenter chacune de ces trois vitesses instantanées sur le croquis de la trajectoire, avec une échelle de vitesse appropriée.* En noir sur le graphique ci-dessous.

c) *Déterminer graphiquement la variation de vitesse entre t_A et t_C , en d'autres mots la différence entre le vecteur vitesse au temps t_C et celui au temps t_A :*

$\Delta\vec{v}_{AC} \doteq \vec{v}_C - \vec{v}_A$. En bleu sur le graphique ci-dessous.





Echelle de vitesse utilisée : 1cm <--> 1m/s :

$\|\vec{v}_A\| = 2{,}7\text{m/s} \quad (2{,}7\text{cm})$

$\|\vec{v}_C\| = 3{,}8\text{m/s} \quad (3{,}8\text{cm})$

d) *Déterminer l'intensité $\|\Delta\vec{v}_{AC}\|$ (en utilisant l'échelle ou avec Pythagore, en calculant ses composantes).*

$\|\Delta\vec{v}_{AC}\| = \mathbf{6{,}4m/s} \quad (6{,}4\text{cm})$

De manière alternative (plus précise), on peut calculer l'intensité de $\Delta\vec{v}_{AC}$ à partir de des composantes :

$$\Delta\vec{v}_{AC} \doteq \vec{v}_C - \vec{v}_A = \left(v_{xC} - v_{xA}\,;\, v_{yC} - v_{yA}\right) = \left(0{,}522 - 0{,}821;\ -3{,}795 - 2{,}612\right)$$
$$= \left(-0{,}299\text{m/s}\,;\ -6{,}41\text{m/s}\right)$$

$$\Rightarrow \quad \|\Delta\vec{v}_{AC}\| = \sqrt{(-0{,}299)^2 + (-6{,}41)^2} = \mathbf{6{,}42m/s.}$$

e) *Calculer la durée Δt_{AC}.*

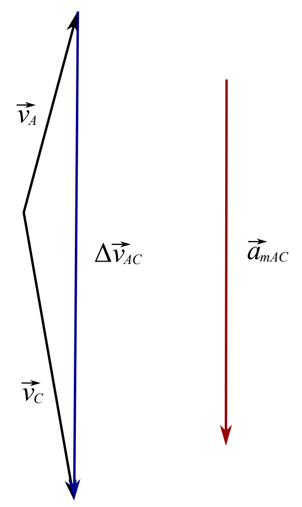
$\Delta t_{AC} = t_C - t_A = 2{,}768 - 2{,}102 = 0{,}666\text{s}$

f) *À l'aide des résultats trouvés aux points d) et e), déterminer l'intensité de l'accélération moyenne entre t_0 et t_2, $\|\vec{a}_{mAC}\|$.*

$$\|\vec{a}_{m12}\| = \frac{\|\Delta\vec{v}_{AC}\|}{\Delta t_{AC}} = \frac{6{,}42\text{m/s}}{0{,}666\text{s}} = \mathbf{9{,}64m/s^2}.$$

g) Dessiner $\vec{a}_{m12}$*, avec l'échelle d'accélération 1cm <-> 2m/s*^{2}*.*

=> 4,8cm avec la même direction et le même sens que $\Delta\vec{v}_{AC}$.



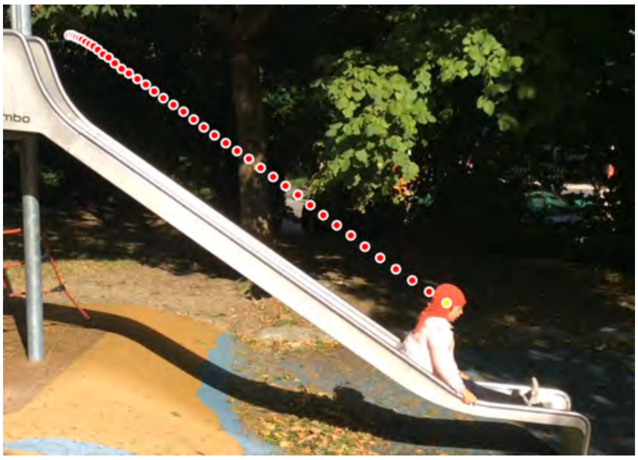
Nom et prénom : Activité réalisée avec : Date :

Rappel des consignes (à lire intégralement, ainsi que le protocole, avant de commencer)

Veuillez réaliser l'activité et le rapport manuscrit (un par élève, même si les deux élèves d'un binôme rendent des rapports identiques). Respectez les règles habituelles quant à la présentation et à l'orthographe, notamment : en-tête rempli, pas de crayon (sauf pour les dessins) ni d'effaceur (erreurs éventuelles à biffer proprement), soin de la langue française, protocole/graphique(s)/données à rendre avec le rapport, précision dans les dessins et les résultats (nombre pertinent de chiffres significatifs).

LE MRUA

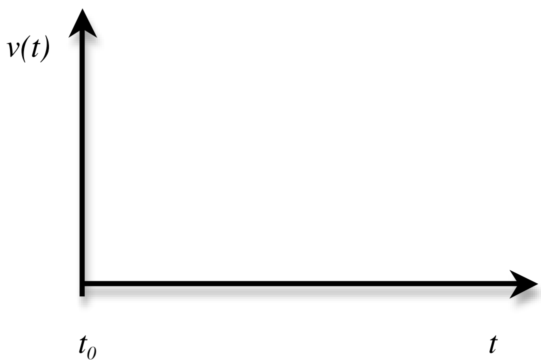
Le but de cette activité est d'étudier le mouvement d'un corps qui descend un plan incliné, comme un enfant sur un toboggan ou un chariot sur un rail, *avant* le freinage.

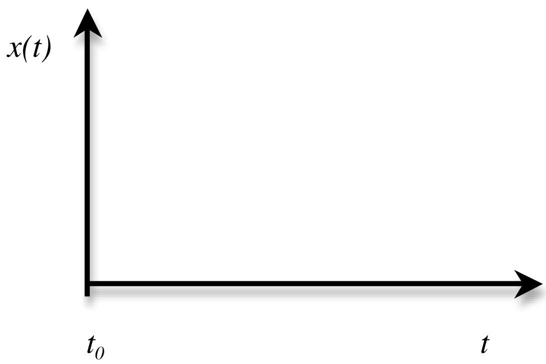


I. Prévisions

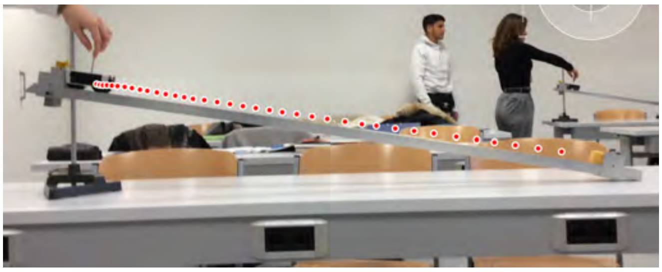
a) Quel type de mouvement s'attend-on dans cette situation (MU, MR, MRU, autre à spécifier)? *Justifier.*

b) Prévoir l'allure (qualitative) des graphiques de la vitesse et de la position du corps en fonction du temps à partir de l'instant du début de la descente, qu'on appellera t_0, et avant le freinage. *Justifier*.





II. Prise des mesures avec l'iPad



a) Mettre en marche le iPad (*mot de passe: 0987*).

b) Appeler le programme « Video Physics » (Icône:).

c) Débuter une nouvelle Expérience (+) et sélectionner « *Faire un film* ».

d) Durant le film
   - tenir le iPad de manière stable, de telle manière que toute la trajectoire à filmer soit dans le cadre ;
   - se positionner de sorte que le mouvement de l'objet soit filmé de gauche à droite (cf. image ci dessus) ;
   - s'assurer que le corps filmé soit bien visible par rapport au fond (p. ex. corps noir sur fond blanc), de sorte que l'application puisse en reconnaître le mouvement.

e) Mettre le corps en mouvement et débuter le film. Arrêter de filmer immédiatement après que le corps ait parcouru le plan incliné. Ensuite, appuyer sur l'option « *Utiliser* ».

f) Cliquer en haut à gauche sur « *Expériences* » et enregistrer le nouveau film en cliquant sur « *i* » (= *informations*) puis en donnant un nom explicite comme: «**Toboggan Elève X** ».

III. Création des graphiques sur iPad

Le film enregistré peut-être visualisé au ralenti et à répétition.

a) Faire glisser le doigt sur le curseur afin de sélectionner l'image du corps au début de sa trajectoire (quand sa vitesse est nulle).

b) Placer la cible précisément sur l'image du corps (régler sa taille, ni trop grande ni trop petite), puis appuyer sur « *Tracer* ». La cible suit automatiquement le corps dans son mouvement.

c) Ne garder que les points de la trajectoire avant la phase de freinage, les autres points pouvant être supprimés en les sélectionnant (ils deviennent alors bleus) et en cliquant « *Supprimer* ».

d) Définir un repère ayant comme origine le premier point du traçage et l'axe des x orienté dans la direction du plan incliné: nous pourrons ainsi étudier le mouvement en ne considérant que cette coordonnée.

e) Définir l'échelle (par exemple avec la mesure de la longueur du plan) puis visualiser les graphiques via l'icône . L'application donne le graphique de la trajectoire $(x\ ;\ y)$, le *diagramme horaire* $x(t)$ et celui de la vitesse en fonction du temps $v_x(t)$. Elle donne aussi le diagramme horaire $y(t)$ et celui de $v_y(t)$, représentant les petites oscillations perpendiculaires au mouvement, dont nous ne tenons pas compte.

f) Appeler le temps du début de la mesure t_0* et la position initiale $x(t_0) = x_0$.

g) <u>Pour visualiser les données</u> et travailler avec les graphiques:
   - cliquer sur l'icône ,
   - puis sur « *Fichier Données* » + « *Ouvrir dans…* »,
   - choisir l'application *Graphical Analysis* (Icône :).

h) L'application *Graphical Analysis* visualise les graphiques du mouvement. En cliquant sur les noms des paramètres observés sur l'axe vertical, les différents graphiques peuvent être sélectionnés ou non. En cliquant sur l'icône en bas à gauche il est possible de choisir le format des points (« *Options graphe* ») ou d'ajouter une courbe de tendance.

i) Pour visualiser le tableau des données, cliquer sur la première icône en haut à droite et choisir « *Tableau* ».

j) **Important** : envoyer <u>les graphiques terminés</u> et <u>le tableau</u> des données par email à votre adresse favorite afin de pouvoir les joindre à votre analyse par la suite.

IV. Analyse des résultats

i) Vitesse en fonction du temps

a) Quel type de courbe suit mieux l'allure des données du graphique de $v_x(t)$ (plateau, droite, parabole, autre…) ?

b) Quelle relation entre Δv_x et Δt traduit-t-elle (proportionnalité directe, inverse, …)?

c) En utilisant le tableau des données et le graphique, déterminer
   - la pente et
   - l'ordonnée au temps t_0

   du graphique de la <u>vitesse en fonction du temps</u> $v_x(t)$, avec les unités.
   Arrondir <u>les données</u> à deux chiffres après la virgule.

d) Ecrire l'équation de la *fonction* $v_x(t)$ pour ce mouvement✦.

e) À quelles grandeurs physiques❖ correspondent la pente et l'ordonnée au temps t_0 calculées au point (c) ?

f) Cliquer sur l'icône en bas à gauche et choisir « *Appliquer une régression* » pour la courbes de $v_x(t)$ (type « *Affine* »). Ensuite, comparer l'équation de cette courbe avec celle écrite au point (d).

* Le temps t_0 n'est pas forcement égal à 0s.
✦ Ici v_x est la variable dépendante (axe *y,* des ordonnées) et *t* celle indépendante (asse *x,* des abscisses).
❖ Quelques exemples de grandeurs physiques, qu'elles soient des scalaires ou des vecteurs, sont la masse, le temps, la position, la vitesse, la température.

ii) Diagramme horaire (position en fonction du temps)

g) Quel type de courbe suit mieux l'allure des données du *diagramme horaire x(t)* (plateau, droite, parabole, autre…) ?

h) Quelle relation entre x et Δt traduit-t-elle (proportionnalité directe, inverse, …)?

i) Cliquer sur l'icône en bas à gauche et choisir « *Appliquer une régression* » pour la courbe de *x(t)*. Choisir la courbe cohérente avec la réponse donnée au point (g). Par exemple :
   - Droite par l'origine : « *Linéaire* »
   - Droite qui ne passe pas par l'origine : « *Affine* »
   - Parabole : « *Quadratique* »
   - …

j) Ecrire l'*équation horaire* de la *fonction x(t)* de ce mouvement donnée par l'application*, avec un nombre pertinent de chiffres significatifs dans les paramètres.

k) À quelles grandeurs physiques correspondent les valeurs des paramètres de cette courbe?

V. Conclusions

- Revenir sur les prévisions de départ et les confronter aux résultats.
- Qu'avez-vous appris grâce à vos mesures et à votre analyse ?

.

* Ici x est la variable dépendante (axe y, des ordonnées) et t celle indépendante (asse x, des abscisses).

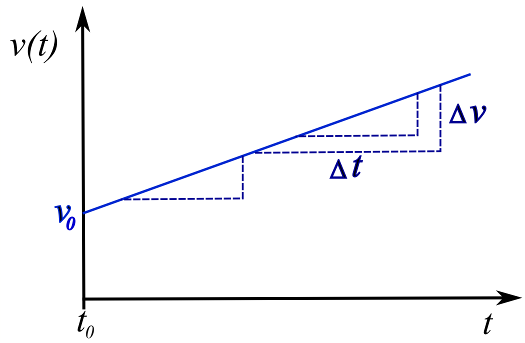
LE MRUA - Exemple de corrigé

I. Prévisions

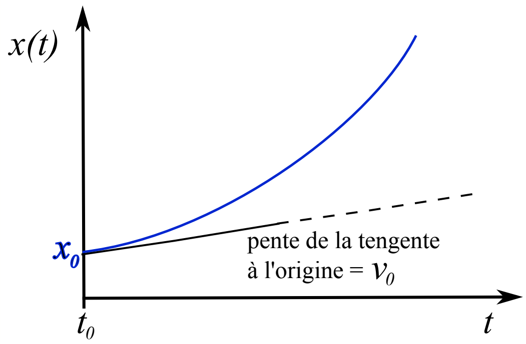
a) Quel type de mouvement décrit mieux cette situation (MU, MR, MRU, autre à spécifier)?

La vitesse ne change pas de direction, mais elle change d'intensité : elle est nulle au départ et elle augmente. On peut supposer qu'elle augmente proportionnellement à la durée à partir du début de la descente : un MRUA.

b) Prévoir quel type de courbe suivront les diagrammes de la vitesse et de la position du corps en fonction du temps : tracer l'allure (qualitative) des graphiques v(t) et x(t), à partir du début de la descente, qu'on appellera t_0, et avant le freinage.



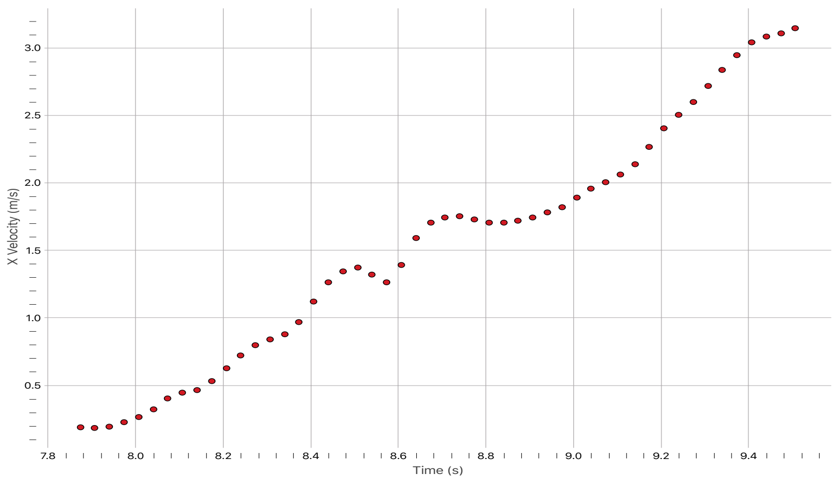
Dans un MRUA, la variation de vitesse est proportionnelle à la durée correspondante : $\Delta v/\Delta t = a =$ constante.



Dans le diagramme horaire, la vitesse étant donnée par la pente de la droite tangente à chaque instant, elle augmente de manière uniforme, il s'agit donc d'une fonction ***convexe*** (une parabole) :

IV. Analyse des résultats

i) Vitesse en fonction du temps



a) *Quel type de courbe suit mieux l'allure des données du diagramme de la vitesse en fonction du temps $v_x(t)$ (plateau, droite, parabole, autre…) ?* Une ligne droite.

b) *Quelle relation entre v_x et t traduit-t-elle (proportionnalité directe, inverse, relation quadratique, …)?* Une proportionnalité directe **:** $\Delta v_x = \text{costante} \cdot \Delta t$. On peut aussi dire que v_x et t sont liées par une relation *linéaire* ou *affine*.

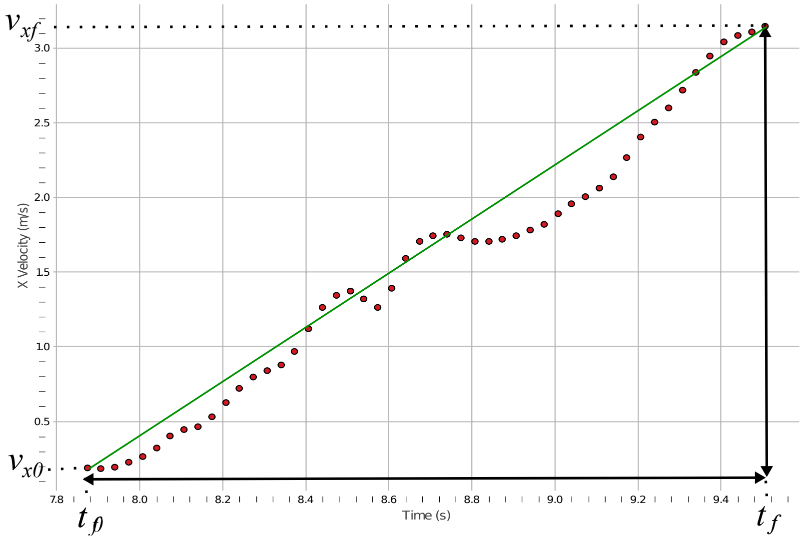
c) *+ e) À l'aide des données du mouvement, estimer (1) la pente et (2) l'ordonnée à l'origine du diagramme horaire $v_x(t)$, avec les unités. Arrondir les données à deux chiffres après la virgule. À quelles grandeurs physiques correspondent la pente et l'ordonnée à l'origine calculées au point f) ci-dessus ?*

La *pente a* correspond à l'*accélération a_x* = accélération, qu'on assume constante (graphique d'une droite). Nous pouvons donc calculer l'accélération moyenne entre le temps initial (t_0) et final (t_f), en utilisant les données du tableau (en annexe au corrigé).

$$a = a_x = \frac{v_{xf} - v_{x0}}{t_f - t_0} = \frac{3{,}15 - 0{,}19}{9{,}51 - 7{,}87} = \frac{2{,}96 \text{ m/s}}{1{,}64 \text{ s}} = 1{,}8 \text{ m/s}^2.$$

La pente calculée dans n'importe quel autre intervalle sera la même, dans la limite de précision de quelque dixième de m/s^2 (à *deux chiffres significatifs* près, à cause des variations de la vitesse non parfaitement uniformes).

L'*ordonnée au temps t_0* (= 7,87 s) est la *vitesse au temps initial* : $b = v_x(t_0) = v_{x0}$ = 0,19 m/s.

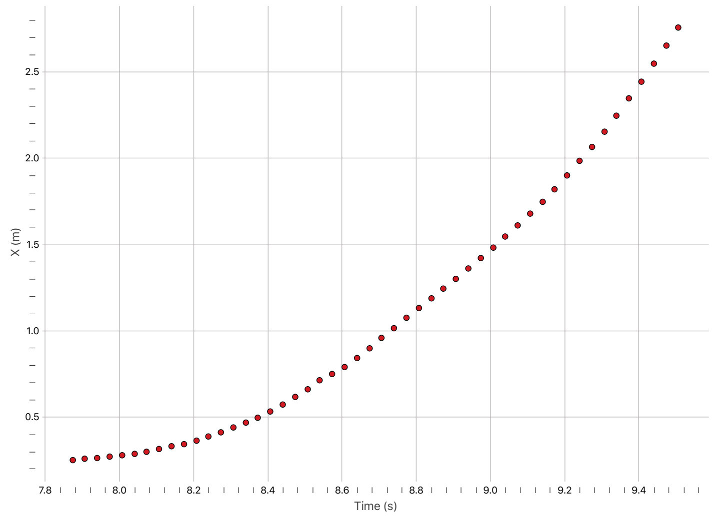


d) $v_x(t) = a\cdot(t-t_0) + b$ => $v_x(t) = a_x \cdot (t-t_0) + v_{x0}$

$$\Rightarrow \quad v_x(t) = \underbrace{1{,}80}_{\text{m/s}^2}\cdot(t-\underbrace{7{,}87}_{\text{s}}) + \underbrace{0{,}19}_{\text{m/s}} \quad \text{ou} \quad x(t) = \underbrace{1{,}8}_{\text{m/s}^2}t - \underbrace{14}_{\text{m/s}}$$

-14 m/s = $v(t = 0$ s) est l'ordonné à l'origine (0 s $\neq t_0$).
Il s'agit de la vitesse que l'enfant aurait eu à l'instant t = 0s (7,87s avant le début de la descente) s'il avait eu le mouvement de MRUA depuis cet instant.
Attention : résultats numériques à 2 chiffre significatifs près (fluctuations à l'augmentation uniforme de la vitesse).

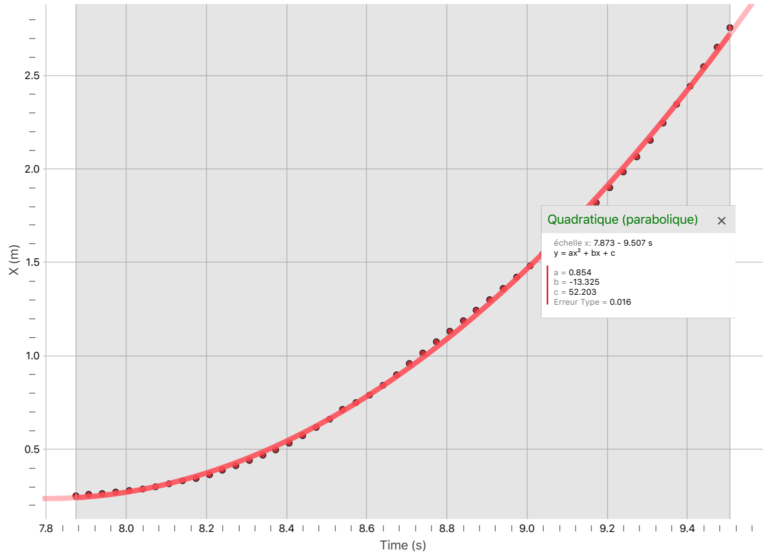
ii) diagramme horaire (position en fonction du temps)



g) Quel type de courbe suit mieux l'allure des données du diagramme horaire x(t) (plateau, droite, parabole, autre…) ? Une parabole.

h) Quelle relation entre x et Δt traduit-t-elle (proportionnalité directe, inverse, relation quadratique, …)? Une relation quadratique : $\Delta x = \text{costante}\cdot\Delta t^2 + \text{costante}\cdot\Delta t$
ou $x(t) = a(t-t_0)^2 + b(t-t_0) + c$, où les paramètres a, b et c sont à déterminer.

i)



j)+k) Avec la notation ci-dessus
a = ½a_x [m/s^2] = 0,854

=> a_x = 2 · 0,854 m/s^2 = 1,7 m/s^2

$x(t) = 0{,}85\ t^2 - 13\ t + 52$

La valeur b = -13 m/s = v (t = 0 s). Ces deux valeurs sont en accord avec celles trouvées dans le point *(i)* (-14 m/s et 1,8 m/s^2), à *deux chiffres significatifs près*.

c = 52 m = x (t = 0 s) : l'ordonnée au temps t = 0 s si le mouvement avait eu la même accélération constante depuis cet instant.

Time (s)	X (m)	Y (m)	Vx (m/s)	Vy (m/s)
7.873333	0.250302	0.417948	0.190875	0.158581
7.906667	0.257019	0.423954	0.184695	0.131015
7.94	0.262154	0.42778	0.192143	0.093763
7.973333	0.268825	0.429544	0.227219	0.07394
8.006667	0.277557	0.432844	0.264406	0.052718
8.04	0.285764	0.432546	0.322687	0.053391
8.073333	0.298095	0.435321	0.402496	0.086135
8.106667	0.314024	0.43757	0.446797	0.137846
8.14	0.328942	0.445479	0.46573	0.16264
8.173333	0.343334	0.449789	0.530816	0.147007
8.206667	0.363386	0.455111	0.625042	0.131711
8.24	0.384974	0.45837	0.722704	0.118975
8.273333	0.412222	0.46264	0.798536	0.114022
8.306667	0.43947	0.46691	0.838288	0.082186
8.34	0.468254	0.469119	0.878814	0.024207
8.373333	0.496512	0.467729	0.966976	-0.011638
8.406667	0.53043	0.46735	1.119517	-0.015549
8.44	0.571544	0.46592	1.264006	0.009277
8.473333	0.616782	0.467562	1.342602	0.065165
8.506667	0.662019	0.469204	1.372048	0.161917
8.54	0.71138	0.473919	1.317847	0.367349
8.573333	0.750513	0.496663	1.261218	0.4828
8.606667	0.788596	0.512212	1.391726	0.422395
8.64	0.84107	0.525658	1.590216	0.31378
8.673333	0.898152	0.53292	1.703407	0.197722
8.706667	0.95677	0.538119	1.743393	0.104607
8.74	1.014863	0.53972	1.751275	0.022306
8.773333	1.074492	0.53926	1.728366	-0.040186
8.806667	1.129998	0.535728	1.70731	-0.058545
8.84	1.187565	0.533731	1.706974	-0.029405
8.873333	1.243596	0.533796	1.71735	-0.000298
8.906667	1.301689	0.535398	1.740864	-0.017514
8.94	1.359256	0.533401	1.779301	-0.058345
8.973333	1.420421	0.530879	1.819928	-0.084185
9.006667	1.479525	0.526821	1.888922	-0.083547
9.04	1.546349	0.52531	1.958354	-0.079909
9.073333	1.611112	0.522262	2.002451	-0.092476
9.106667	1.679473	0.518689	2.059452	-0.090085
9.14	1.747834	0.515115	2.13798	-0.055623
9.173333	1.820319	0.514614	2.26539	-0.01146
9.206667	1.898463	0.515124	2.404726	0.009525
9.24	1.982267	0.516644	2.504072	-0.012643
9.273333	2.065545	0.514566	2.598231	-0.049365
9.306667	2.154483	0.513499	2.715937	-0.092589
9.34	2.246493	0.508308	2.838798	-0.131973
9.373333	2.344162	0.504128	2.947577	-0.152457
9.406667	2.443368	0.497886	3.038839	-0.156603
9.44	2.548234	0.492655	3.083065	-0.12846
9.473333	2.649502	0.487949	3.108121	-0.064904
9.506667	2.755418	0.489913	3.144758	0.002472

Nom et prénom : Activité réalisée avec : Date :

Rappel des consignes (à lire intégralement, ainsi que le protocole, avant de commencer)

Veuillez réaliser l'activité et le rapport. Respectez les règles habituelles quant à la présentation et à l'orthographe, notamment : en-tête rempli, pas de crayon (sauf pour les dessins) ni d'effaceur (erreurs éventuelles à biffer proprement), soin de la langue française, protocole/graphique(s)/données à rendre avec le rapport, précision dans les dessins et les résultats (nombre pertinent de chiffres significatifs).

LE SAUT

Le but de cette activité est d'étudier le mouvement vertical du *centre de masse* C d'une personne pendant un saut sur place vertical.

Ce mouvement s'articule en deux parties:
- La phase de *poussée* : tant que le les pieds sont en contact avec le sol ;
- La *chute libre* : dès que les pieds ne sont plus en contact avec le sol et donc la seule force qui agit sur la personne est la force de gravité (interaction à distance avec la Terre). **Attention** : au début de cette deuxième phase la personne continue de monter, même s'il n'y a plus de poussée.

Pendant toute la durée du mouvement, nous négligeons la résistance de l'air.

I. Prise des mesures avec l'iPad

a) Choisir un objet que la personne peut tenir près de son centre de masse, qui soit bien visible par rapport au fond (par exemple un morceau de papier blanc sur un T-shirt noir).

b) Mettre en marche le iPad (*mot de passe: 0987*).

c) Appeler le programme « Video Physics » (Icône:).

d) Débuter une nouvelle Expérience (+) et sélectionner « *Faire un film* ».

e) Durant le film tenir le iPad de manière stable et immobile, de telle manière que toute la trajectoire à filmer soit dans le cadre; s'assurer que le corps filmé soit bien visible par rapport au fond.

f) Débuter le film et l'arrêter immédiatement après que la personne ait touché le sol. Ensuite, appuyer sur l'option « *Utiliser* ».

g) Cliquer en haut à gauche sur « *Expériences* » et enregistrer le nouveau film en cliquant sur « *i* » (= *informations*) puis en donnant <u>un nom explicite</u> comme: «**Saut Elève X** ».

II. Création des graphiques et extraction des données

Le film enregistré peut-être visualisé au ralenti et à répétition. Le but ici est d'analyser la trajectoire de C depuis son point le plus bas (le début de l'ascension) jusqu'à l'instant où la personne termine sa chute libre (avant que les pieds ne touchent à nouveau le sol).

a) Faire glisser le doigt sur le curseur afin de sélectionner l'image de l'objet suivi au début de sa trajectoire, dans son point le plus bas.

b) Placer la cible précisément sur l'image de l'objet (régler sa taille, ni trop grande ni trop petite), puis appuyer sur « *Tracer* ». La cible suit automatiquement l'objet dans son mouvement.

c) Ne garder que les points de la trajectoire <u>avant que la personne ne touche le sol</u>, les autres points pouvant être supprimés en les sélectionnant (ils deviennent alors bleus) et en cliquant « *Supprimer* ».

d) Définir <u>un repère</u> ayant comme origine le premier point du traçage et l'axe des *y* orienté dans la direction verticale: nous pourrons ainsi étudier le mouvement en ne considérant que cette coordonnée.

e) Définir <u>l'échelle</u> (par exemple avec la taille de la personne) puis visualiser les graphiques via l'icône . L'application donne le graphique de la trajectoire $(x\,;\,y)$, le diagramme horaire $y(t)$ et celui de la vitesse en fonction du temps $v_y(t)$. Elle donne aussi le diagramme horaire de $x(t)$ et de $v_x(t)$, représentant les oscillations perpendiculaires au mouvement, dont nous ne terrons pas compte.

f) Pour visualiser les données et travailler avec les graphiques:
   - cliquer sur l'icône ,
   - puis sur « *Fichier Données* » + « *Ouvrir dans…* »,
   - choisir l'application *Graphical Analysis* (Icône :).

g) L'application *Graphical Analysis* visualise les graphiques du mouvement. En cliquant sur les noms des paramètres observés sur l'axe vertical, les différents graphiques peuvent être sélectionnés ou non. En cliquant sur l'icône en bas à gauche il est possible de choisir le format des points (« *Options graphe* »). Pour visualiser le tableau des données, cliquer sur la première icône en haut à droite et choisir « *Tableau* ».

h) Nous appelons le temps du début de la mesure t_0* (et la position initiale $y(t_0) = y_0$), t_1 le <u>l'instant où les pieds quittent le sol</u> et t_2 le <u>dernier instant</u> avant que la personne ne touche à nouveau le sol. De plus, nous appelons y_{max} la hauteur maximale atteinte lors du saut et t_{max} l'instant correspondant : $y_{max} = y(t_{max})$.

i) Dans le tableau des données, repérer t_0, t_1, t_{max} et t_2 ; les noter dans le tableau récapitulatif suivant. *Arrondir les données à 2 chiffres après la virgule.*

t **[s]**	***y*** **[m]**	v_y **[m/s]**
$t_0 =$	$y_0 =$	$v_{y0} =$
$t_1 =$	$y_1 =$	$v_{y1} =$
$t_{max} =$	$y_{max} =$	$v_y(t_{max}) =$
$t_2 =$	$y_2 =$	$v_{y2} =$

j) **Important** : envoyer les graphiques terminés et le tableau des données à votre adresse email afin de pouvoir les joindre à votre analyse par la suite.

III. Analyse

i) Phase de poussée (entre t_0 et t_1)

Le but ici est de déterminer quelle est la force (supposée constante) exercée par la personne sur le sol $\vec{F}_{p/sol}$ pendant la poussée. Nous prenons comme positif le sens vers le haut, défini par l'orientation de l'axe *y*.

a) En observant les graphiques du mouvement, quel type de mouvement a-t-on entre t_0 et t_1? *Justifier.*

b) Utiliser les données du tableau rempli au point II (i) pour calculer *l'accélération moyenne* entre t_0 et t_1. En déduire la *force résultante* dans cette phase.

c) À partir de la masse de la personne, calculer sa *force de pesanteur* (attention au signe !).

d) De plus que la force de pesanteur, quelle(s) autre(s) force(s) agit(ssent) sur la personne entre t_0 et t_1? De quel signe ?

* Le temps t_0 n'est pas forcement égal à 0 s.

e) Dessiner le schéma des forces agissantes sur la personne entre t_0 et t_1, appliquées au même point C, et tracer la force résultante en rouge. Pas d'échelle à définir, mais les forces de même intensité doivent avoir la même longueur.

f) En utilisant la formule qui lie la force résultante aux autres forces et les valeurs obtenus pour $\vec{F}_{rés}$ et $\vec{F}_g$, déterminer $\vec{F}_{sol/\mathbf{personne}}$ (le signe en définit le sens).

g) En déduire $\vec{F}_{personne/\mathbf{sol}}$ (le signe en définit le sens). Justifier en utilisant les lois de Newton appropriées.

ii) Phase de chute libre (entre t_1 et t_2)

h) Dessiner le schéma des forces agissantes sur la personne entre t_1 et t_2, appliquées à C, et tracer la force résultante en rouge (sans échelle). Quelle est la différence entre ce diagramme et celui dessiné pour la phase de poussée ? (Point III (e))

i) Pendant cette phase de *chute libre* quelle sont les valeurs (théoriquement)
   - de la force résultante et
   - de l'accélération

   de C ? *Attention au signe.*

j) Utiliser les données du tableau rempli au point II (i) pour calculer la valeur expérimentale de l'accélération entre t_1 et t_2 . Comparer cette valeur avec celle prédite au point III (i).

k) En connaissant la vitesse initiale (v_{y1} du tableau au point II(i)) et l'accélération entre t_1 et t_2 , utiliser les équations du MRUA pour calculer :
   - le temps $t_{max\ pred}$ pour atteindre la hauteur maximale et
   - la hauteur maximale $y_{max\ pred}$.

   (Cf. l'exemple 27 du cours ou de l'exercice du jet d'eau.)

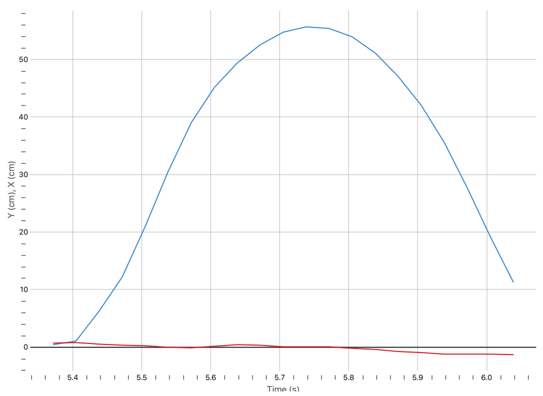
l) Comparer les prévisions théoriques faites au point III (k) avec les données de y_{max} et de t_{max} du tableau au point II (i). Quelle est la précision de vos prédictions ?

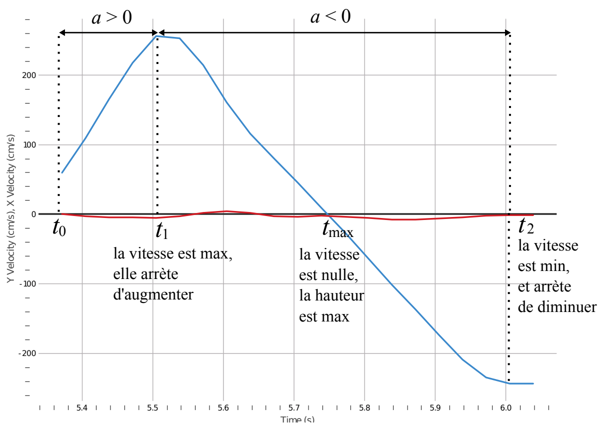
LE SAUT - Exemple de corrigé

Exemple de mesures

Time (s)	X (cm)	Y (cm)	VX (cm/s)	VY (cm/s)
5.371667	0.673641	0.380284	-0.111874	59.270175
5.405	0.751194	1.064852	-2.729756	109.243505
5.438333	0.517813	6.244227	-4.662729	165.343323
5.471667	0.376024	12.189445	-4.858927	217.179152
5.505	0.21845	21.100331	-5.14489	255.923739
5.538333	-0.037338	30.489041	-3.055137	252.745883
5.571667	-0.097209	39.017769	1.773296	214.344373
5.605	0.142651	45.156357	4.529009	160.943623
5.638333	0.392696	49.381612	2.058642	115.806403
5.671667	0.361342	52.553005	-2.774593	80.223547
5.705	0.04808	54.766203	-3.705682	45.458706
5.738333	0.028948	55.641595	-2.238314	9.43104
5.771667	0.015927	55.368987	-3.562073	-26.452033
5.805	-0.182317	53.94736	-5.673719	-64.09324
5.838333	-0.372923	51.090733	-7.626769	-101.574154
5.871667	-0.748751	47.085087	-7.757241	-136.972529
5.905	-0.927643	42.028126	-6.445498	-173.718543
5.938333	-1.194565	35.535655	-4.501918	-209.345051
5.971667	-1.263532	27.800535	-1.769299	-234.443725
6.005	-1.232759	19.300592	-1.092813	-243.209819
6.038333	-1.300199	11.278472	-1.370992	-243.370749

t_0 (5.371667), v_{y1} (255.923739), y_{max} (55.641595), v_{y2} (-243.209819)





II.

(i) Tableau récapitulatif :

t **[s]**	***y*** **[m]**	v_y **[m/s]**
$t_0 = 5{,}37$	$y_0 = 0{,}0038$	$v_{y0} = 0{,}5927$
$t_1 = 5{,}51$	$y_1 = 0{,}2110$	$v_{y1} = 2{,}5592$
$t_{max} = 5{,}74$	$y_{max} = 0{,}5564$	$v_y(t_{max}) = 0{,}0943$
$t_2 = 6{,}01$	$y_2 = 0{,}1930$	$v_{y2} = -2{,}4321$

III. Analyse

i) Phase de poussée (entre t_0 et t_1)

a) *En observant les graphiques du mouvement, quel type de mouvement a-t-on entre t_0 et t_1?*

Il s'agit d'un MRUA car la vitesse augmente *proportionnellement* à la durée. Avec a positive (vers le haut).

Utiliser les données du tableau rempli au point II (i) pour calculer l'accélération moyenne entre t_0 et t_1. En déduire la force résultante dans cette phase. Le mouvement a seulement de composante y, nous délaissons la flèche indiquant la grandeur vectorielle :

$$a = \frac{v_{y1} - v_{y0}}{t_1 - t_0} = \frac{255{,}92 - 59{,}27}{5{,}51 - 5{,}37} = \frac{196{,}65 \text{ cm/s}}{0{,}14 \text{ s}} = \frac{1{,}9665 \text{ m/s}}{0{,}14 \text{ s}} = 14 \text{ m/s}^2.$$

Dans notre cas, la personne a une masse m = 35kg, donc pour la 2$^{\text{ème}}$ loi de Newton

$F_{rés} = ma = 35 \text{ kg} \cdot 14 \text{ m/s}^2 = 490 \text{ N} = 4{,}9 \cdot 10^2 \text{ N}$.

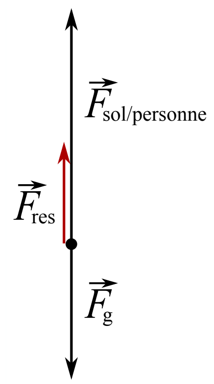
Résultat arrondi à 2 chiffres significatifs, car 0,14 s a 2 chiffres significatifs.

b) *À partir de la masse de la personne, calculer sa force de pesanteur.*

$F_g = mg = 35 \text{ kg} \cdot (-9{,}81 \text{ m/s}^2) = -343 \text{ N} = -3{,}4 \cdot 10^2 \text{ N}$. Négative car vers le bas.

c) *De plus que la force de pesanteur, quelle(s) autre(s) force(s) agit(ssent) sur la personne entre t_0 et t_1? De quel signe ?*

d) *Dessiner le schéma des forces agissantes sur la personne entre t_0 et t_1, appliquées à C, et tracer la force résultante en rouge. Pas d'échelle à définir, mais les forces de même intensité doivent avoir la même longueur.*



$$\vec{F}_{res} = \underbrace{\vec{F}_g}_{<0} + \underbrace{\vec{F}_{sol/personne}}_{>0}.$$

En utilisant la formule qui lie la force résultante aux autres forces et les valeurs obtenus pour $\vec{F}_{rés}$ et $\vec{F}_g$, déterminer $\vec{F}_{sol/\textbf{personne}}$ (le signe en définit le sens). $\vec{F}_{res} = \vec{F}_g + \vec{F}_{sol/personne}$

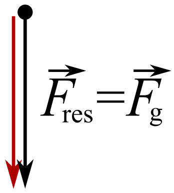
$$\Rightarrow \quad \vec{F}_{sol/personne} = \vec{F}_{res} - \vec{F}_g = 490 - (-343) = 490 + 343 = 833 \text{ N} = 8{,}3 \cdot 10^2 \text{ N}.$$

e) *En déduire $\vec{F}_{personne/\textbf{sol}}$ (le signe en définit le sens). Justifier en utilisant les lois de Newton.*

Pour la **<u>3$^{\text{ème}}$ loi de Newton</u>** (action/réaction)

$\vec{F}_{personne/sol} = -\vec{F}_{sol/personne} = -8{,}3 \cdot 10^2$ N, négative, vers le bas.

ii) Chute libre (entre t_1 et t_2)



Dessiner le schéma des forces agissantes sur la personne <u>entre t_1 et t_2</u>, appliquées à C, tracer la force résultante en rouge (sans échelle). Quelle est la différence entre ce diagramme et celui dessiné pour la phase de poussée ? (Point III (e))

$\vec{F}_{res} = \vec{F}_g = mg = -343 \text{ N} = -3{,}4 \cdot 10^2 \text{ N}$

=>1,7cm vers le bas

Par rapport à la phase de poussée il n'y a plus la force du sol sur la personne (positive), car il n'y a plus le contact entre les pieds et le sol.

h) Pendant la phase de chute libre quelle sont les valeurs (théoriquement)

- *de la force résultante et*
- *de l'accélération*

de C ? (Attention au signe !)

$\vec{F}_{res} = \vec{F}_g \Rightarrow \quad ma = mg \Rightarrow \quad a = g = -9{,}81 \text{ m/s}^2$, négative, donc vers le bas.

Utiliser les données du tableau rempli au point II(i) pour calculer l'accélération moyenne entre t_1 et t_2 . Comparer cette valeur avec celle prédite au point (i).

$$a = \frac{v_{y2} - v_{y1}}{t_2 - t_1} = \frac{-243{,}21 - 255{,}92}{6{,}01 - 5{,}51} = \frac{-499{,}13 \text{ cm/s}}{0{,}50 \text{ s}} = \frac{-4{,}99913 \text{ m/s}}{0{,}50 \text{ s}} = -9{,}98 = -10 \text{ m/s}^2.$$

i) + l)

Equations du MRUA : 1) $y(t) = 1/2\ a\ \Delta t^2 + v_{y1} \Delta t + y_1$ et 2) $v_y(t) = v_{y1} + a\ \Delta t$

avec : $a = g = -9{,}81 \text{ m/s}^2$ (=> chute libre) ;

$v_{y1} = 2{,}5592$ m/s ; $y_1 = 0{,}211$ m ; $t_1 = 5{,}51$ s (voir tableau ci-dessus) .

Equation à poser (eq. 2) ci-dessus): $v_y = 0$ pour $y = y_{max}$

=> $v = v_{y1} + a\ \Delta t_{max} = 0$

=> $0 = 2{,}56 + (-10) \cdot \Delta t_{max}$ => $\Delta t_{max} = \dfrac{-2{,}56 \text{ m/s}}{-10 \text{ m/s}^2} = 0{,}256$ s ;

=> $t_{max\ pred} = \Delta t_{max} + t_1 = 0{,}256 + 5{,}51 = 5{,}77$ s $= 5{,}8$ s.

En accord avec la valeur mesurée à deux chiffres significatifs près (écart de 0,03 s par rapport à la valeur du tableau, ok au 0,5%).

=> $y_{max\ pred} = 1/2\ a\ \Delta t_{max\ pred}^2 + v_{y1}\ \Delta t_{max\ pred} + y_1$

$= 0{,}5 \cdot (-10) \cdot 0{,}256^2 + 2{,}56 \cdot 0{,}256 + 0{,}211 =$

$= -0{,}32768 + 0{,}65536 + 0{,}211 = 0{,}539 \text{ m} = 54 \text{ cm}$

En accord avec la valeur mesurée à deux chiffres significatifs près (écart de 1,64 cm par rapport à la valeur du tableau, ok au 3%.

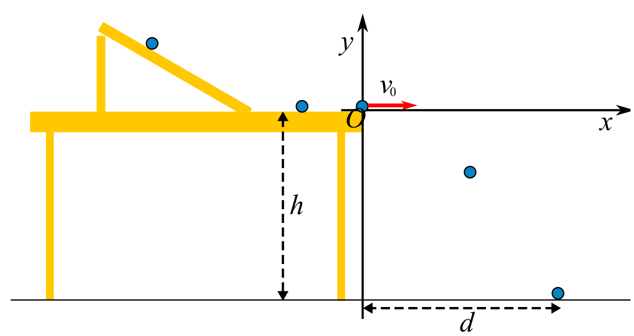
Nom et prénom : Activité réalisée avec : Date :

Consignes (à lire intégralement, ainsi que le protocole, avant de commencer) :

Veuillez réaliser l'activité et le rapport. Respectez les règles habituelles quant à la présentation et à l'orthographe, notamment : en-tête rempli, pas de crayon (sauf pour les dessins) ni d'effaceur (erreurs éventuelles à biffer proprement), soin de la langue française, protocole/graphique(s)/données à rendre avec le rapport, précision dans les dessins et les résultats (nombre pertinent de chiffres significatifs).

PROJECTILE

Le but de cette activité est d'étudier le mouvement d'une balle de golf qui décolle horizontalement du bord d'une table et chute au sol, comme montré dans le schéma. On fait l'hypothèse que les forces de frottement sont négligeables.



I. Prévisions

i) Quels types de mouvements s'attend-on dans les directions verticales et horizontales du jet de la balle (cf. cours) ?

ii) Quels sont les facteurs qui déterminent le **temps de vol** de la bille ?

iii) Quels sont les facteurs qui déterminent la **portée** de la trajectoire de la balle? (le déplacement horizontal jusqu'au point de chute).

II. Prise des mesures avec l'iPad

a) Mesurer la **hauteur** h de la table au-dessus du sol.

b) Faire quelques essais de jet avec la balle. On peut se servir de la rampe pour donner différentes vitesses initiales horizontales v_0 à la balle.

c) Mettre en marche le iPad (*mot de passe: 0987*).

d) Appeler le programme « Video Physics » (Icône:).

e) Débuter une nouvelle Expérience (+) et sélectionner « *Faire un film* ».

f) Lâcher la balle depuis une position donnée sur la rampe et débuter le film. Arrêter de filmer immédiatement après l'impact de la balle au sol. Ensuite appuyer sur l'option « *Utiliser* ».

ATTENTION : Tenir le iPad de manière stable et immobile, horizontale et face ou mouvement. Se positionner de sorte que le mouvement de la balle soit filmé de gauche à droite (cf. image ci dessous).

g) Cliquer en haut à gauche sur « *Expériences* » et enregistrer le nouveau film en cliquant sur « *i* » (= *informations*) puis en donnant un nom explicite comme: « **Projectile Elève X** »

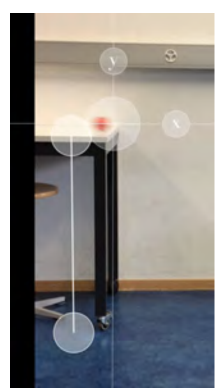
III. Création des graphiques sur iPad

Le film enregistré peut-être visualisé au ralenti et à répétition. Le but ici est d'analyser la trajectoire de la balle depuis son départ de la table jusqu'à son impact au sol.

a) Faire glisser le doigt sur le curseur afin de sélectionner l'image de la balle au moment de son décollage.

b) Placer la cible précisément sur l'image de la balle au décollage (régler sa taille, ni trop grande ni trop petite), puis appuyer sur « *Tracer* ». La cible doit suivre automatiquement la balle jusqu'à son impact au dernier moment avant son impact au sol.

c) Ne garder que les points de la trajectoire dès l'envol avant l'impact au sol (en *chute libre*), les autres points pouvant être supprimés en les sélectionnant (ils deviennent alors bleus) et en cliquant « *Supprimer* ».



d) Définir le repère ayant comme origine la position de la balle au bord de la table et ayant l'axe des x sur la trajectoire horizontale avant la chute, comme montré dans l'image.

e) Définir l'échelle, en utilisant par exemple la hauteur de la table, puis visualiser les graphiques de $x(t)$, $y(t)$ et $v_y(t)$ via l'icône .

f) Pour visualiser les données et travailler avec les graphiques:
   - cliquer sur l'icône ,
   - puis sur « *Fichier Données* » + « *Ouvrir dans…* »,
   - choisir l'application *Graphical Analysis* (Icône :)

- L'application *Graphical* visualise les graphiques du mouvement. En cliquant sur les noms des paramètres observés sur l'axe vertical, les différents graphiques peuvent être sélectionnés ou non. En cliquant sur l'icône en bas à gauche ( ) il est possible de choisir le format des points (« *Options graphe* ») ou d'ajouter une courbe de tendance.

- Pour visualiser le tableau des données, cliquer sur la première icône en haut à droite et choisir « *Tableau* ».

IV. Analyse des résultats

Le but ici est d'analyser la trajectoire de la balle depuis son départ de la table jusqu'à son impact au sol.

i) Mouvement le long des axes

a) Quel type de courbe suit mieux les données des graphiques de $x(t)$, de $y(t)$ de $v_x(t)$ et de $v_y(t)$ (plateau, droite, parabole, autre…) ? *Justifier.*

b) Cliquer sur l'icône en bas à gauche et choisir « *Appliquer une régression* » pour les courbes* de $\boldsymbol{x(t)}$**,** de $\boldsymbol{y(t)}$ de $\boldsymbol{v_y(t)}$ (il n'est pas nécessaire d'interpoler le graphique de $v_x(t)$). Choisir la courbe cohérente avec la réponse donnée au point précédent.

ii) Durée de vol et portée

Répéter la prise des mesure (étapes II et III) pour au moins 2 autres vitesses horizontales initiales $v_0 = v_{0x}$, et déterminer à chaque fois

- la durée de vol $t_{final} = t$
- la portée $x_{final} = d$

c) Remplir le tableau suivant (pas besoin de faires les graphiques).

Mesure [unité]	1	2	3	(4)	(5)
$v_0 = v_{0x}$ [ ]					
$d = x_{sol}-x_0$ [ ]					
t [ ]					
d/v_0 [ ]					

d) En comparant les différentes mesures de t ainsi que les rapports $\frac{d}{v_0}$, que remarquez vous ?

* **Important**: envoyez les graphiques terminés et le tableau des données par email à votre adresse, afin de pouvoir les analyser d'avantage au moment d'écrire le rapport de laboratoire.

e) Calculer la moyenne arithmétique t_{obs} de la durée de vol entre les différentes mesures.

f) Déterminer par un calcul théorique la durée de vol t_{th} d'un objet que l'on laisserait tomber au sol en chute libre verticale depuis une hauteur ***h***.

g) Comparer les résultats des deux point précédents.

iii) Graphique de la portée en fonction de v_0

h) À partir des mesures de (v_0, d), dessiner sur une feuille le graphique de d en fonction v_0.

i) Que vaut d si $v_0 = 0$ m/s ? Ajouter ce couple de données au graphique.

j) Ajouter à la main la droite de régression pour les données du graphique moyennant une fonction du type $v_0 = \mathbf{m} \cdot d + \mathbf{n}$. Ecrire l'équation de cette droite.

k) Quelle signification physique peut-on attribuer à la pente **m** de cette droite ?

V. Conclusions

- Revenir sur les hypothèses de départ et les confronter aux résultats de mesure et d'analyse.

- Qu'avez-vous appris grâce à vos mesures et à votre analyse ?

TEST DE PHYSIQUE

Cinématique et dynamique

Nom : **Sexe :** **F** **M**

Groupe : **Enseignant :**

Date :

QCM : **25 questions**

Durée : **45 minutes**

- Chaque question comporte toujours exactement une réponse correcte.
- Chaque réponse correcte rapporte un point et il n'y a pas de déduction pour les réponses erronées.

Bon travail !

1) Dans un repère orthonormé du plan gradué en mètres (m), un point P est caractérisé par sa position $\vec{r} = (2\text{m};\ 2\text{m})$.

   Parmi les options ci-dessous, laquelle exprime la norme de ce vecteur ?

   (A) 2m

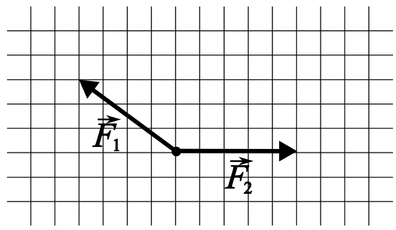
   (B) $\sqrt{8}$m

   (C) 4m

   (D) (2 ; 2)

   (E) 8m^2

2) Un objet subit les deux forces représentées dans la figure ci-contre. Ces deux forces ont la même intensité.



   Dans ces conditions, la force résultante sur l'objet

   (A) est plus intense que $\vec{F}_1$, et cela se déduit en utilisant le théorème de Pythagore.

   (B) est moins intense que $\vec{F}_1$, parce que en faisant la somme graphiquement on trouve un vecteur plus petit.

   (C) est plus intense que $\vec{F}_1$, parce que la somme de deux vecteurs donne toujours un vecteur plus grand que les vecteurs qui sont additionnés.

   (D) a la même intensité que $\vec{F}_1$, et cela se déduit en utilisant le théorème de Pythagore.

   (E) est plus intense que $\vec{F}_1$, parce que la distance entre les deux bouts des flèches est plus grande que la longueur du vecteur $\vec{F}_1$.

3) Dans un repère orthonormé du plan gradué en mètres (m), un point P est caractérisé par sa position $\vec{r} = (\text{-3m};\ +4\text{m})$.
   Quel est l'angle formé par cette position avec la direction positive de l'axe *x*?

   (A) 126,87°

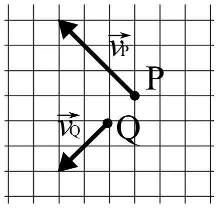
   (B) 53,13°

   (C) 143,13°

   (D) 135°

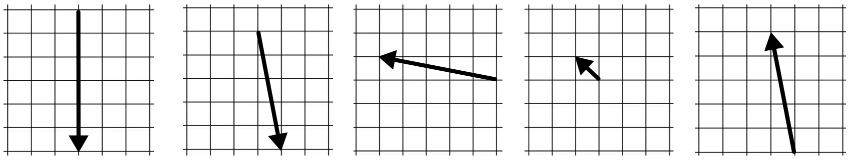
   (E) -53,13°

4) La figure ci-contre représente les vitesses de deux corps à un instant donné, le premier au point P et le deuxième au point Q.



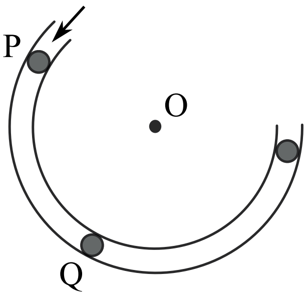
Parmi les options ci-dessous, choisissez celle qui représente la vitesse avec laquelle le corps en P voit se déplacer le corps en Q.

(A) (B) (C) (D) (E)



UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX QUATRE QUESTIONS SUIVANTES (5, 6, 7 ET 8).

La figure ci-contre illustre un tube sans frottements ayant la forme d'un arc de cercle de centre O. Le tube est fixé à une table horizontale, et la figure est une vue du dessus de la table.
Une balle parcourt le tube du point P au point R avec une vitesse d'intensité constante.



5) La vitesse instantanée de la balle au point P, $\vec{v}_P$, peut se représenter

(A) par une flèche qui part du point P et se termine nécessairement au point R.

(B) par une flèche qui part du point P et se termine nécessairement au point Q.

(C) par une flèche tangente à la trajectoire au point P.

(D) par une flèche dirigée du point P au point R, mais qui ne se termine pas nécessairement au point R.

(E) par aucune flèche, car la vitesse instantanée est une grandeur scalaire.

6) La vitesse moyenne de la balle du point P au point R , $\vec{v}_{mPR}$, peut se représenter

(A) par une flèche tangente à la trajectoire au point Q.

(B) par une flèche tangente à la trajectoire au point P.

(C) par une flèche qui part du point P et se termine nécessairement au point R.

(D) par une flèche qui part du point R et se termine nécessairement au point P.

(E) par une flèche dirigée du point P au point R, mais qui ne se termine pas nécessairement au point R.

(F) par aucune flèche, car il s'agit d'une quantité scalaire.

7) Dans son mouvement du point P au point Q, l'accélération moyenne de la balle $\vec{a}_{mPQ}$ peut se représenter

(A) par une flèche tangente à la trajectoire au point P.

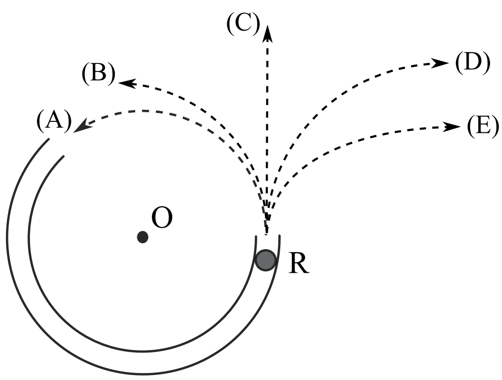
(B) par une flèche tangente à la trajectoire au point Q.

(C) par une flèche dirigée du point P au point Q.

(D) par une flèche perpendiculaire au segment PQ.

(E) par aucune flèche : l'accélération vaut zéro parce que l'intensité de sa vitesse est constante.

8) On néglige tout frottement de la table et de l'air. Laquelle des 5 lignes en traitillé dans la figure ci-dessous représente le mieux la trajectoire que la balle suivra à sa sortie en R?



9) Un cycliste a effectué l'ascension d'un col à la vitesse scalaire moyenne de 30km/h, puis la descente, par le même chemin, à la vitesse scalaire moyenne de 60km/h. La vitesse scalaire moyenne totale du voyage a été

(A) 45km/h.

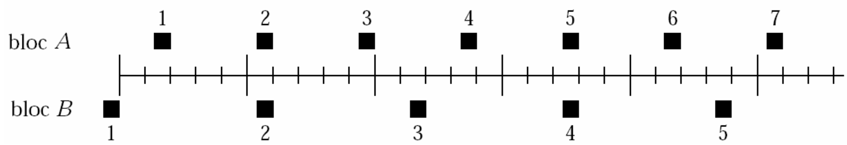
(B) moins que 45km/h.

(C) plus que 45km/h.

(D) nulle.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

10) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



À propos de l'accélérations de ces deux blocs on peut dire que

(A) l'accélération de A est plus grande que l'accélération de B.

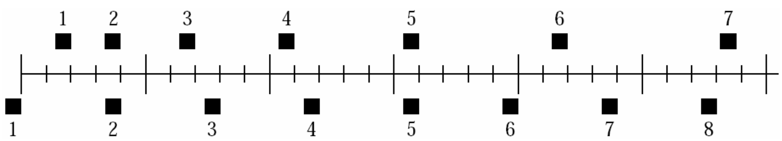
(B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro.

(C) l'accélération de B est plus grande que l'accélération de A.

(D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

11) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de 0,20s. Les blocs se déplacent vers la droite.



Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse?

(A) Non.

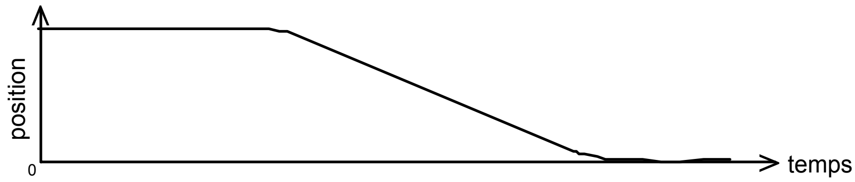
(B) Oui, à l'instant 2.

(C) Oui, à l'instant 5.

(D) Oui, à l'instant 2 et 5.

(E) Oui, à un certain temps dans l'intervalle entre les instants 3 et 4.

12) Voici le diagramme horaire du mouvement d'un objet.



Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?

(A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête.

(B) Initialement l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête.

(C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête.

(D) Au début, l'objet ne bouge pas. Par la suite il recule et il s'arrête.

(E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.

13) En se référant au diagramme horaire suivant, représentant le mouvement d'un objet, la vitesse à l'instant t = 2s est

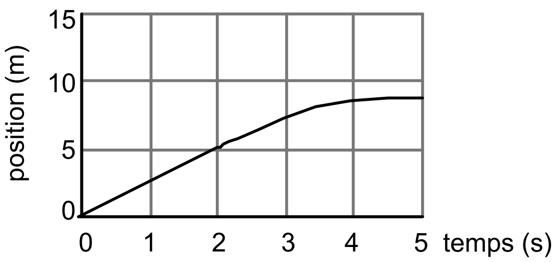
(A) 0,4m/s

(B) 2,0m/s

(C) 2,5m/s

(D) 5,0m/s

(E) 10,0m/s



14) Un corps se déplace avec un mouvement rectiligne selon le graphique ci-dessous. Combien de mètres parcourt-il durant la durée comprise entre t = 4s et t = 8s ?

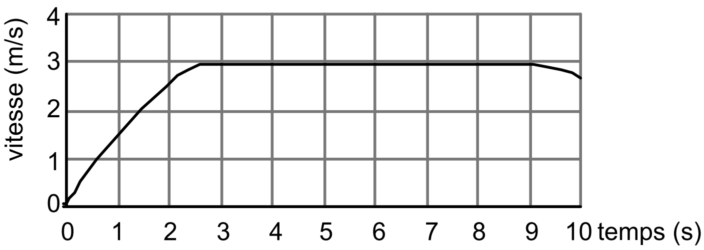
(A) 0,75m

(B) 3,0m

(C) 4,0m

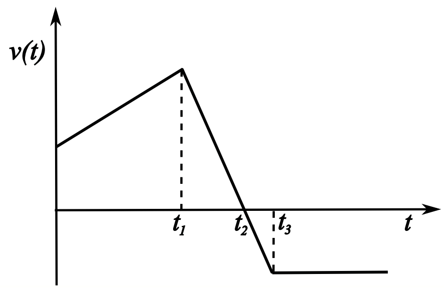
(D) 8,0m

(E) 12,0m



UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX DEUX QUESTIONS SUIVANTES (15 ET 16).

Le graphique ci-contre représente la vitesse d'un vélo en mouvement rectiligne pendant un certain intervalle de temps.



15) Le vélo a un mouvement rectiligne et uniforme

(A) seulement pour $t < t_1$.

(B) seulement pour $t_1 < t < t_3$.

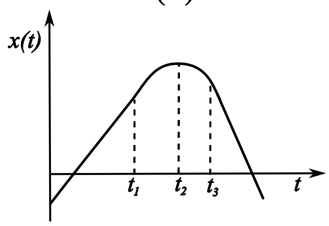
(C) seulement pour $t > t_3$.

(D) pour $t < t_1$ et pour $t_1 < t < t_3$, avec un changement de vitesse à l'instant t_1.

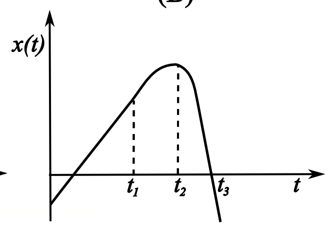
(E) jamais.

16) Parmi les options ci-dessous, choisissez celle qui pourrait représenter le diagramme horaire du mouvement du vélo.

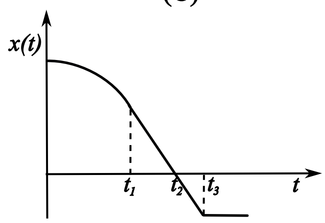
(A)



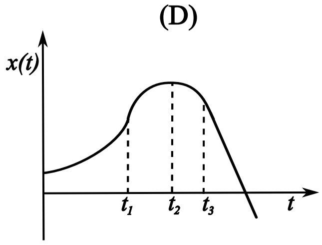
(B)



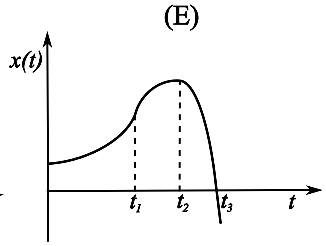
(C)



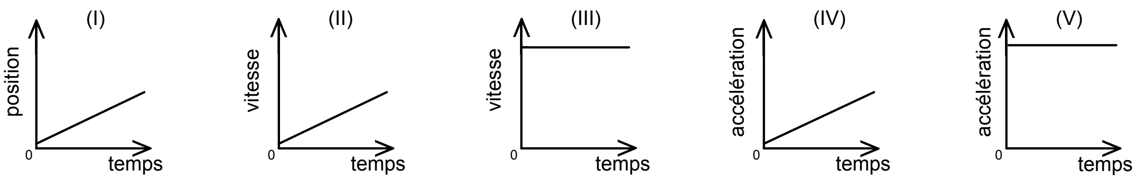
(D)



(E)



17) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.



Lequel ou lesquels représente(ent) un mouvement à vitesse constante ?

(A) I, II et IV.

(B) I et III.

(C) II et V.

(D) IV seulement.

(E) V seulement.

18) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut.

L'accélération du caillou est maximale

(A) dans l'instant juste après avoir été lancé.

(B) dans l'instant juste avant d'être repris.

(C) dans les deux instants juste après avoir été lancé et juste avant d'être repris. Dans ces deux instants l'accélération possède la même valeur.

(D) au moment où sa hauteur est maximale.

(E) il n'y a pas d'accélération maximale, elle est constante pendant toute la durée du vol.

19) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air.

Le temps pris par les balles pour atteindre le sol est

(A) la moitié pour la balle plus lourde que pour la balle plus légère.

(B) la moitié pour la balle plus légère que pour la balle plus lourde.

(C) pareil pour les deux balles.

(D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié.

(E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.

20) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air.

Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est

(A) la moitié que pour la balle lâchée depuis plus bas.

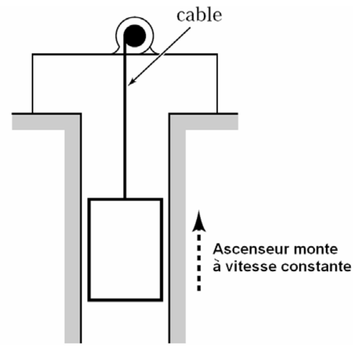
(B) le même que pour la balle lâchée depuis plus bas.

(C) le double que pour la balle lâchée depuis plus bas.

(D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double.

(E) plus grand que le double que pour la balle lâchée depuis plus bas.

21) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'il est illustré dans la figure suivante. Tous les frottements sont négligeables.



Dans cette situation, les forces appliquées sur l'ascenseur sont telles que

(A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas.

(B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas.

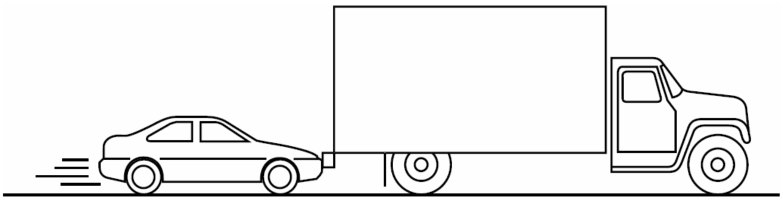
(C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas.

(D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas.

(E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.

UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX DEUX QUESTIONS SUIVANTES (22 ET 23).

Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, tel qu'illustré dans la figure suivante



22) Pendant que la voiture, poussant toujours le camion, augmente sa vitesse jusqu'à sa vitesse de croisière,

(A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) le moteur de la voiture est en marche, alors la voiture exerce une force sur le camion, par contre, puisque le moteur du camion est à l'arrêt, le camion n'exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.

23) Une fois que le système voiture + camion atteint la vitesse de croisière constante désirée:

(A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) le moteur de la voiture est en marche, alors la voiture exerce une force sur le camion, par contre, puisque le moteur du camion est à l'arrêt, le camion n'exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.

24) Au milieu d'une patinoire, deux patineurs, Ana et Bob, sont debout face à face. Ana, qui pèse 60 kg, pousse soudainement Bob, qui pèse 80 kg.

Pendant la poussée

(A) Bob accélère mais Ana reste immobile.

(B) Ana accélère mais Bob reste immobile.

(C) Ana et Bob accélèrent en sens opposés mais avec des accélérations de même intensité.

(D) Ana et Bob accélèrent en sens opposés mais Ana accélère plus que Bob.

(E) Ana et Bob accélèrent en sens opposés mais Bob accélère plus qu'Ana.

25) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement. Dans ces conditions,

(A) les deux billes atteignent la même vitesse.

(B) la bille plus lourde atteint une vitesse exactement trois fois plus grande que bille plus légère.

(C) la bille plus légère atteint une vitesse exactement trois plus grande que la bille plus lourde.

(D) la bille plus lourde atteint une vitesse plus grande que bille plus légère, mais pas exactement trois fois plus grande.

(E) la bille plus légère atteint une vitesse plus grande que la bille plus lourde, mais pas exactement trois fois plus grande.

TEST DE PHYSIQUE

Cinématique et dynamique

Nom : **Sexe :** **F** **M**

Groupe : **Enseignant :**

Date :

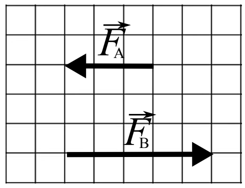
QCM : **25 questions**

Durée : **45 minutes**

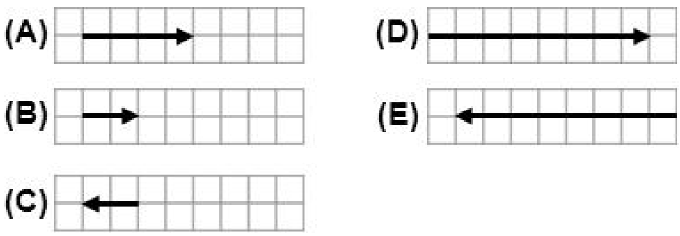
- Chaque question comporte toujours exactement une réponse correcte.
- Chaque réponse correcte rapporte un point et il n'y a pas de déduction pour les réponses erronées.

Bon travail !

1) La figure ci-contre représente les deux vecteurs $\vec{F}_A$ et $\vec{F}_B$.



Parmi les options ci-dessous, choisissez celle qui représente le vecteur différence $\vec{F}_A - \vec{F}_B$.



2) Dans un repère orthonormé du plan gradué en mètres (m), un point P est caractérisé par sa position $\vec{r} = (2\text{m}; 2\text{m})$.

Parmi les options ci-dessous, laquelle exprime la norme de ce vecteur ?

(A) 2m

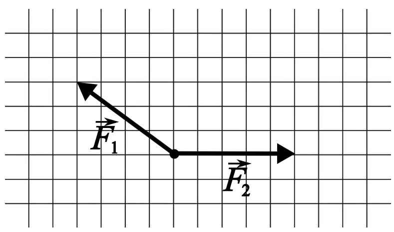
(B) $\sqrt{8}$m

(C) 4m

(D) (2 ; 2)

(E) 8m^2

3) Un objet subit les deux forces représentées dans la figure ci-contre. Ces deux forces ont la même intensité.



Dans ces conditions, la force résultante sur l'objet

(A) est plus intense que $\vec{F}_1$, et cela se déduit en utilisant le théorème de Pythagore.

(B) est moins intense que $\vec{F}_1$, parce que en faisant la somme graphiquement on trouve un vecteur plus petit.

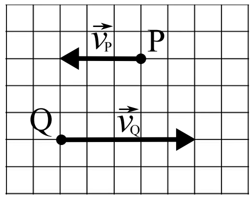
(C) est plus intense que $\vec{F}_1$, parce que la somme de deux vecteurs donne toujours un vecteur plus grand que les vecteurs qui sont additionnés.

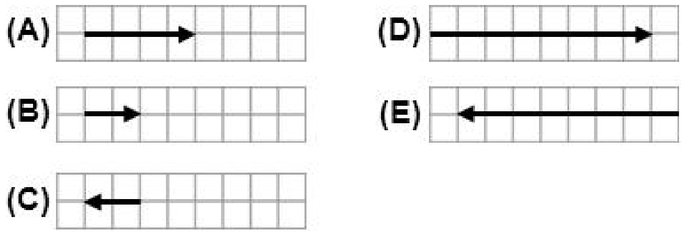
(D) a la même intensité que $\vec{F}_1$, et cela se déduit en utilisant le théorème de Pythagore.

(E) est plus intense que $\vec{F}_1$, parce que la distance entre les deux bouts des flèches est plus grande que la longueur du vecteur $\vec{F}_1$.

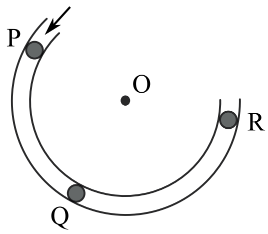
4) La figure ci-dessous représente les vitesses de deux corps à un instant donné, le premier au point P et le deuxième au point Q.

Parmi les options ci-dessous, choisissez celle qui représente la vitesse avec laquelle le corps en P voit se déplacer le corps en Q.

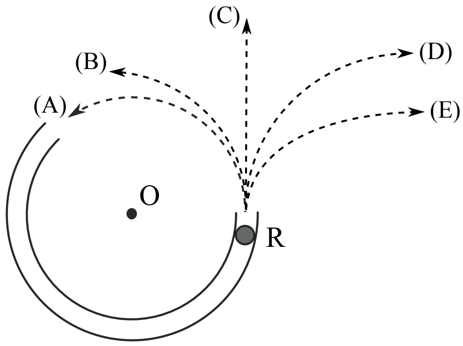




5) La figure ci-contre illustre un tube sans frottements ayant la forme d'un arc de cercle de centre O. Le tube est fixé à une table horizontale, et la figure est une vue du dessus de la table. Une balle parcourt le tube du point P au point R avec une vitesse d'intensité constante. On néglige tout frottement de la table et de l'air.



Laquelle des 5 lignes en traitillé dans la figure ci-dessous représente le mieux la trajectoire que la balle suivra à sa sortie en R?



6) Un cycliste a effectué l'ascension d'un col à la vitesse scalaire moyenne de 30km/h, puis la descente, par le même chemin, à la vitesse scalaire moyenne de 60km/h. La vitesse scalaire moyenne totale du voyage a été

(A) 45km/h.

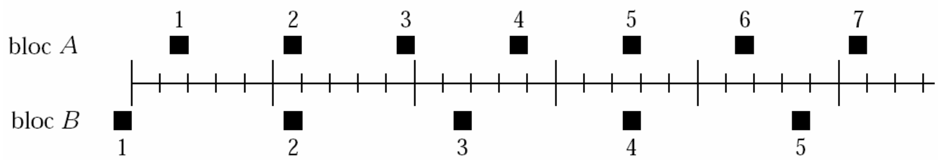
(B) moins que 45km/h.

(C) plus que 45km/h.

(D) nulle.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

7) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



À propos de l'accélérations de ces deux blocs on peut dire que

(A) l'accélération de A est plus grande que l'accélération de B.

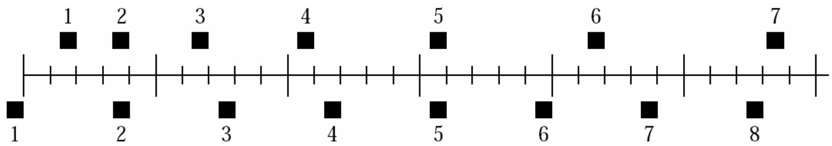
(B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro.

(C) l'accélération de B est plus grande que l'accélération de A.

(D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

8) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de 0,20s. Les blocs se déplacent vers la droite.



Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse?

(A) Non.

(B) Oui, à l'instant 2.

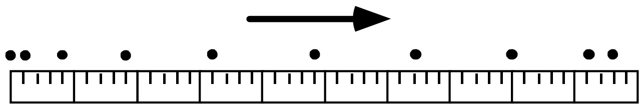
(C) Oui, à l'instant 5.

(D) Oui, à l'instant 2 et 5.

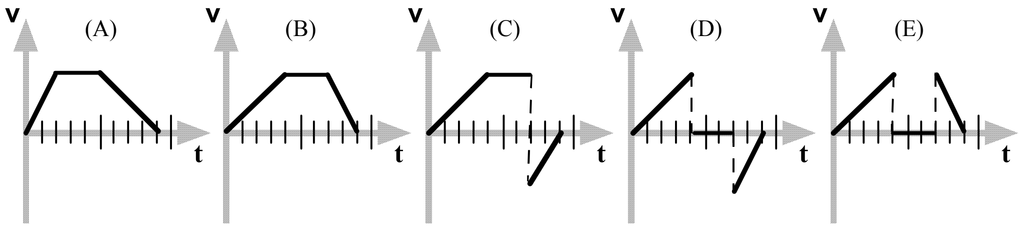
(E) Oui, à un certain temps dans l'intervalle entre les instants 3 et 4.

UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX DEUX QUESTIONS SUIVANTES (9 ET 10).

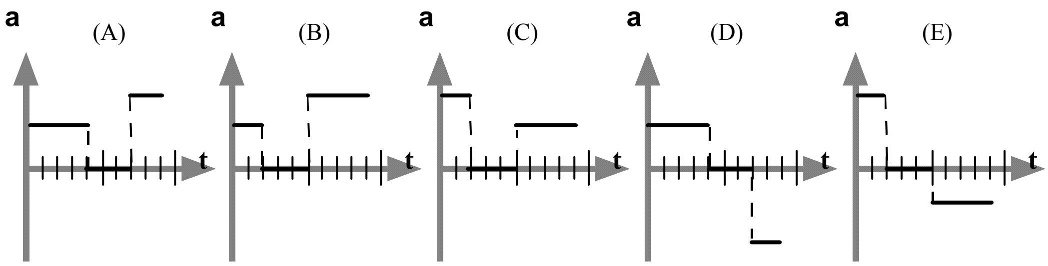
Les points de la figure ci-dessous représentent la position d'un objet à des intervalles de temps égaux. L'objet se déplace vers la droite sur une surface horizontale.



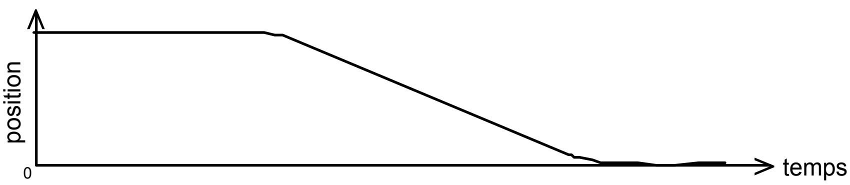
9) Lequel de ces graphiques représente le mieux la vitesse de l'objet en fonction du temps ?



10) Lequel de ces graphiques représente le mieux l'accélération de l'objet en fonction du temps ?



11) Voici le diagramme horaire du mouvement d'un objet.



Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?

(A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête.

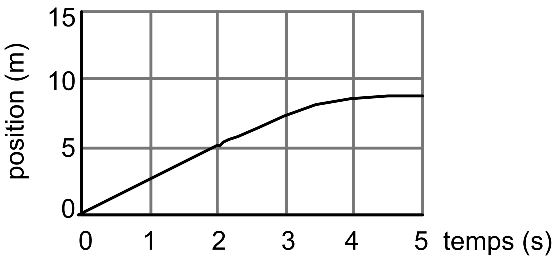
(B) Initialement l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête.

(C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête.

(D) Au début, l'objet ne bouge pas. Par la suite il recule et il s'arrête.

(E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.

12) En se référant au diagramme horaire suivant, représentant le mouvement d'un objet, la vitesse à l'instant t = 2s est



(A) 0,4m/s

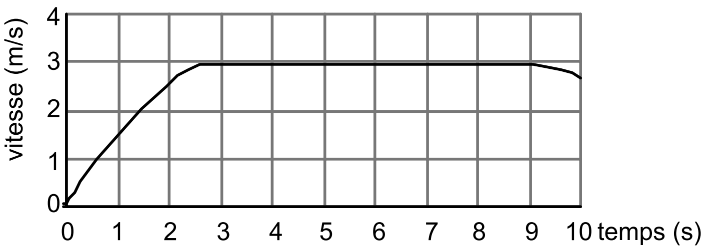
(B) 2,0m/s

(C) 2,5m/s

(D) 5,0m/s

(E) 10,0m/s

13) Un corps se déplace avec un mouvement rectiligne selon le graphique ci-dessous. Combien de mètres parcourt-il durant la durée comprise entre t = 4s et t = 8s ?



(A) 0,75m

(B) 3,0m

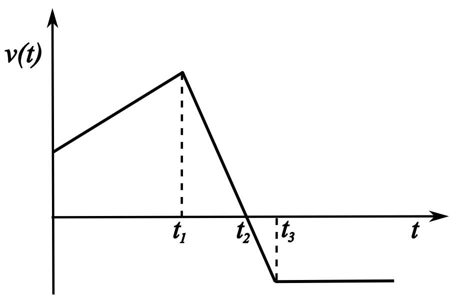
(C) 4,0m

(D) 8,0m

(E) 12,0m

UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX DEUX QUESTIONS SUIVANTES (14 ET 15).

Le graphique ci-contre représente la vitesse d'un vélo en mouvement rectiligne pendant un certain intervalle de temps.



14) Le vélo a un mouvement rectiligne et uniforme

(A) seulement pour $t < t_1$.

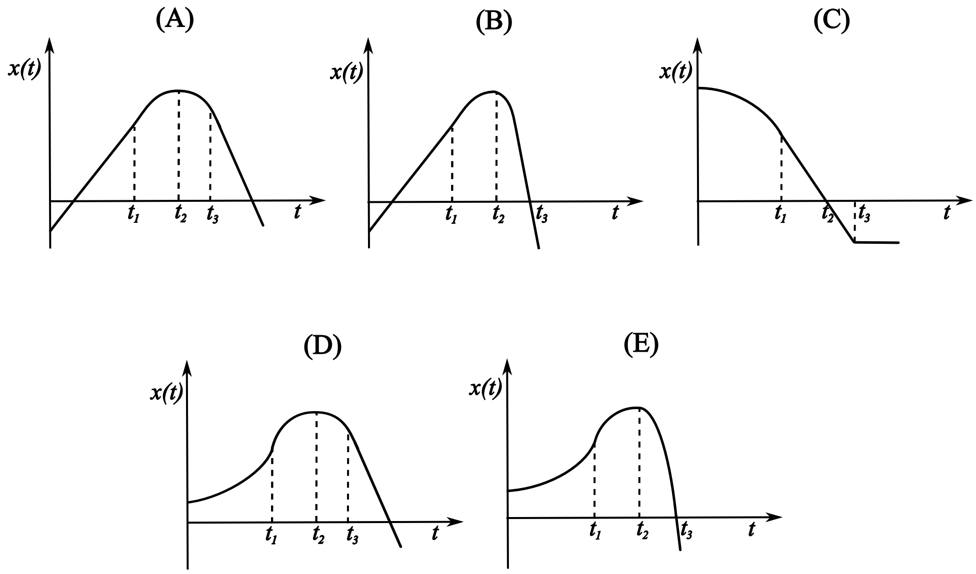
(B) seulement pour $t_1 < t < t_3$.

(C) seulement pour $t > t_3$.

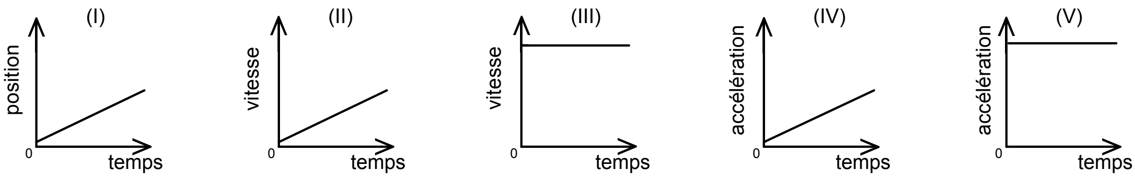
(D) pour $t < t_1$ et pour $t_1 < t < t_3$, avec un changement de vitesse à l'instant t_1.

(E) jamais.

15) Parmi les options ci-dessous, choisissez celle qui pourrait représenter le diagramme horaire du mouvement du vélo.



16) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.



Lequel ou lesquels représente(ent) un mouvement à vitesse constante ?

(A) I, II et IV

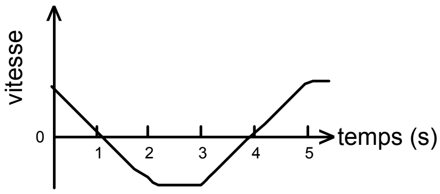
(B) I et III

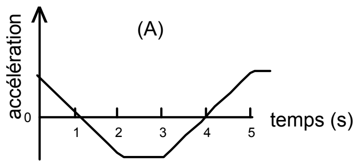
(C) II et V

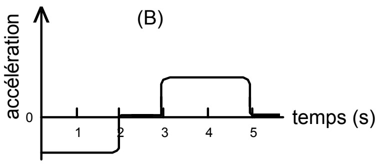
(D) IV seulement

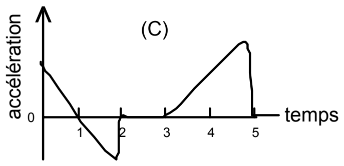
(E) V seulement

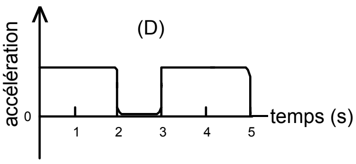
17) Le graphique ci-contre montre le diagramme de vitesse d'un corps en mouvement rectiligne, pendant une durée de 5 secondes. Lequel de ces graphiques représente le mieux l'accélération en fonction du temps durant le même intervalle de temps ?

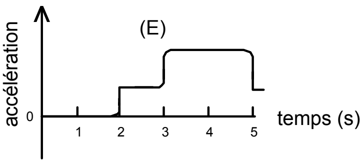












18) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut.

L'accélération du caillou est maximale

(A) dans l'instant juste après avoir été lancé.

(B) dans l'instant juste avant d'être repris.

(C) dans les deux instants juste après avoir été lancé et juste avant d'être repris. Dans ces deux instants l'accélération possède la même valeur.

(D) au moment où sa hauteur est maximale.

(E) il n'y a pas d'accélération maximale, elle est constante pendant toute la durée du vol.

19) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air.

Le temps pris par les balles pour atteindre le sol est

(A) la moitié pour la balle plus lourde que pour la balle plus légère.

(B) la moitié pour la balle plus légère que pour la balle plus lourde.

(C) pareil pour les deux balles.

(D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié.

(E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.

20) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air.

Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est

(A) la moitié que pour la balle lâchée depuis plus bas.

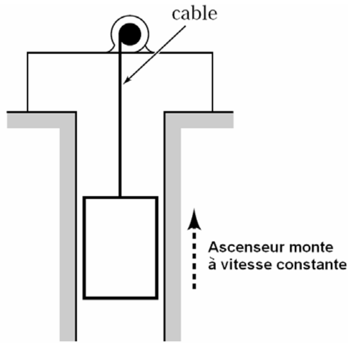
(B) le même que pour la balle lâchée depuis plus bas.

(C) le double que pour la balle lâchée depuis plus bas.

(D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double.

(E) plus grand que le double que pour la balle lâchée depuis plus bas.

21) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'il est illustré dans la figure suivante. Tous les frottements sont négligeables.



Dans cette situation, les forces appliquées sur l'ascenseur sont telles que

(A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas.

(B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas.

(C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas.

(D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas.

(E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.

22) Un gros camion entre en collision avec une petite voiture compacte. Pendant la collision

(A) le camion exerce une force plus intense sur la voiture que la voiture sur le camion.

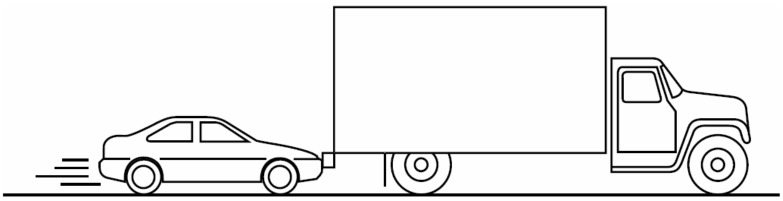
(B) la voiture exerce une force plus intense sur le camion que le camion sur la voiture.

(C) aucun des deux n'exerce de force sur l'autre. La voiture se fait frapper simplement parce qu'elle est devant le camion.

(D) le camion exerce une force sur la voiture mais la voiture n'exerce pas de force sur le camion.

(E) le camion exerce une force aussi intense sur la voiture que la voiture sur le camion.

23) Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, tel qu'illustré dans la figure suivante



Une fois que le système voiture + camion atteint la vitesse de croisière constante désirée:

(A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) le moteur de la voiture est en marche, alors la voiture exerce une force sur le camion, par contre, puisque le moteur du camion est à l'arrêt, le camion n'exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.

24) Au milieu d'une patinoire, deux patineurs, Ana et Bob, sont debout face à face. Ana, qui pèse 60 kg, pousse soudainement Bob, qui pèse 80 kg.

Pendant la poussée

(A) Bob accélère mais Ana reste immobile.

(B) Ana accélère mais Bob reste immobile.

(C) Ana et Bob accélèrent en sens opposés mais avec des accélérations de même intensité.

(D) Ana et Bob accélèrent en sens opposés mais Ana accélère plus que Bob.

(E) Ana et Bob accélèrent en sens opposés mais Bob accélère plus qu'Ana.

25) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement. Dans ces conditions,

(A) les deux billes atteignent la même vitesse.

(B) la bille plus lourde atteint une vitesse exactement trois fois plus grande que bille plus légère.

(C) la bille plus légère atteint une vitesse exactement trois plus grande que la bille plus lourde.

(D) la bille plus lourde atteint une vitesse plus grande que bille plus légère, mais pas exactement trois fois plus grande.

(E) la bille plus légère atteint une vitesse plus grande que la bille plus lourde, mais pas exactement trois fois plus grande.

TEST DE PHYSIQUE

Cinématique et dynamique

Nom et prénom : **Date :**

Groupe : **Enseignant :**

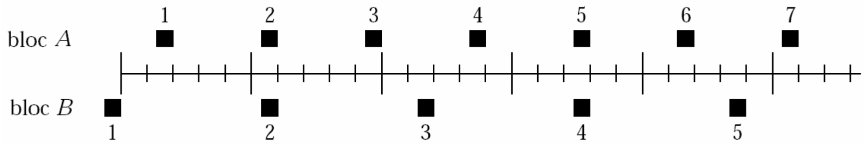
QCM : **14 questions**

Durée : **20 minutes**

- Chaque question comporte toujours exactement une réponse correcte.
- Chaque réponse correcte rapporte un point et il n'y a pas de déduction pour les réponses erronées.

Bon travail !

1) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



À propos de l'accélération de ces deux blocs on peut dire que

(A) l'accélération de A est plus grande que l'accélération de B.

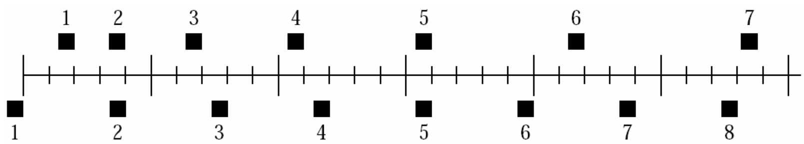
(B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro.

(C) l'accélération de B est plus grande que l'accélération de A.

(D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

2) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse?

(A) Non.

(B) Oui, à l'instant 2.

(C) Oui, à l'instant 5.

(D) Oui, aux instants 2 et 5.

(E) Oui, à un certain instant dans l'intervalle entre les instants 3 et 4.

3) Un cycliste a effectué l'ascension d'un col à la vitesse scalaire moyenne de 30km/h, puis la descente, par le même chemin, à la vitesse scalaire moyenne de 60km/h. La vitesse scalaire moyenne totale du voyage a été

(A) 45km/h.

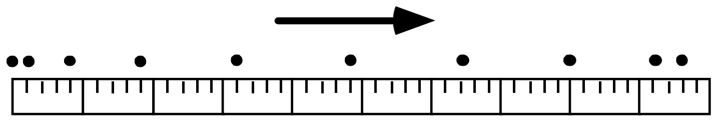
(B) moins que 45km/h.

(C) plus que 45km/h.

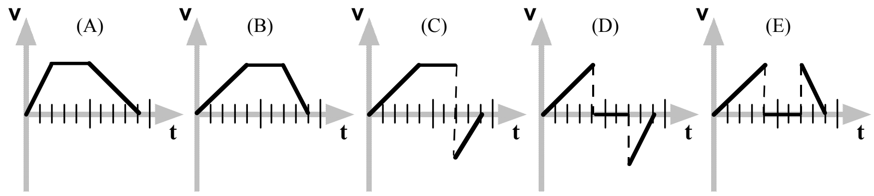
(D) nulle.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

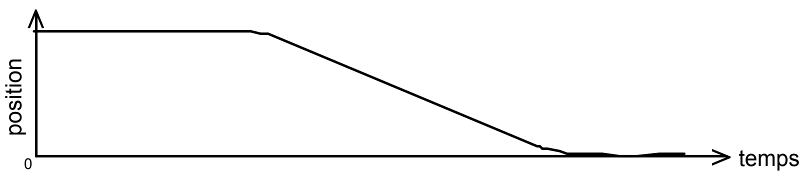
4) Les points de la figure ci-dessous représentent la position d'un objet à des intervalles de temps égaux. L'objet se déplace vers la droite sur une surface horizontale.



Lequel de ces graphiques représente le mieux la vitesse de l'objet en fonction du temps ?



5) Voici le diagramme horaire du mouvement d'un objet.



Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?

(A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête.

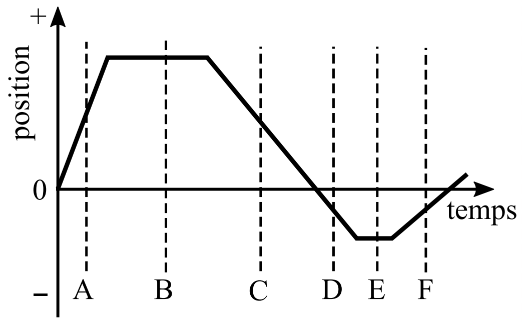
(B) Au début l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête.

(C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête.

(D) Au début l'objet ne bouge pas. Par la suite il recule et il s'arrête.

(E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.

6) Voici le diagramme du mouvement d'une voiture.



À quel couple d'instants la vitesse de la voiture est la même ?

(A) A et C

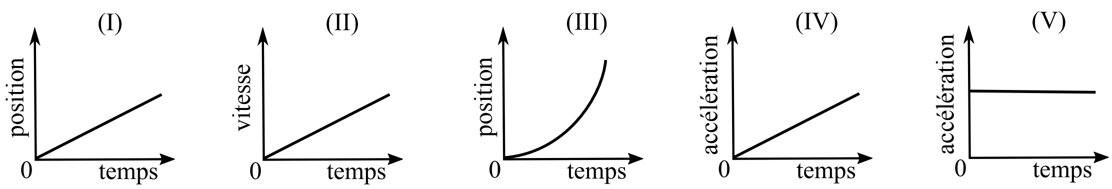
(B) A et D

(C) C et D

(D) C et F

(E) D et F

7) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.



Lequel de ces graphiques représente un mouvement à vitesse constante ?

(A) I

(B) II

(C) III

(D) IV

(E) V

8) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut.

L'accélération du caillou

(A) est maximale dans l'instant juste après avoir été lancé.

(B) est maximale dans l'instant juste avant d'être repris.

(C) est maximale dans les deux instants juste après avoir été lancé et juste avant d'être repris.

(D) est maximale au moment où sa hauteur est maximale.

(E) est constante pendant toute la durée du vol.

9) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air.

Le temps pris par les balles pour atteindre le sol est

(A) la moitié pour la balle plus lourde que pour la balle plus légère.

(B) la moitié pour la balle plus légère que pour la balle plus lourde.

(C) le même pour les deux balles.

(D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié.

(E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.

10) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air.

Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est

(A) la moitié que pour la balle lâchée depuis plus bas.

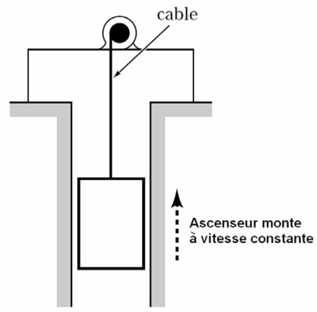
(B) le même que pour la balle lâchée depuis plus bas.

(C) le double que pour la balle lâchée depuis plus bas.

(D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double.

(E) plus grand que le double que pour la balle lâchée depuis plus bas.

11) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'il est illustré dans la figure suivante. Tous les frottements sont négligeables.



Dans cette situation, les forces appliquées sur l'ascenseur sont telles que

(A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas.

(B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas.

(C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas.

(D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas.

(E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.

12) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement.

Dans ces conditions,

(A) les deux billes atteignent la même vitesse.

(B) la bille plus lourde atteint une vitesse exactement trois fois plus grande que bille plus légère.

(C) la bille plus légère atteint une vitesse exactement trois plus grande que la bille plus lourde.

(D) la bille plus lourde atteint une vitesse plus grande que bille plus légère, mais pas exactement trois fois plus grande.

(E) la bille plus légère atteint une vitesse plus grande que la bille plus lourde, mais pas exactement trois fois plus grande.

13) Un gros camion entre en collision avec une petite voiture compacte.

Pendant la collision

(A) le camion exerce une force plus intense sur la voiture que la voiture sur le camion.

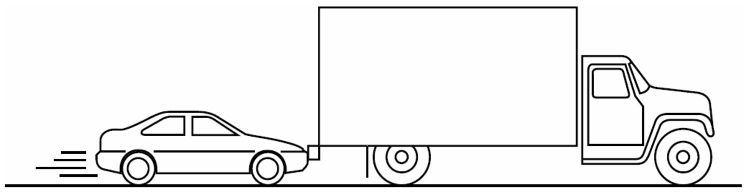
(B) la voiture exerce une force plus intense sur le camion que le camion sur la voiture.

(C) aucun des deux n’exerce de force sur l’autre. La voiture se fait frapper simplement parce qu’elle est devant le camion.

(D) Le camion exerce une force sur la voiture mais la voiture n’exerce pas de force sur le camion.

(E) Le camion exerce une force aussi intense sur la voiture que la voiture sur le camion.

14) Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, tel qu’illustré dans la figure suivante



Pendant que la voiture, poussant toujours le camion, augmente sa vitesse jusqu’à sa vitesse de croisière

(A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) la voiture exerce une force sur le camion, par contre le camion n’exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n’exercent de forces l’un sur l’autre.

TEST DE PHYSIQUE

Cinématique et dynamique

Nom et prénom : **Date :**

Groupe :

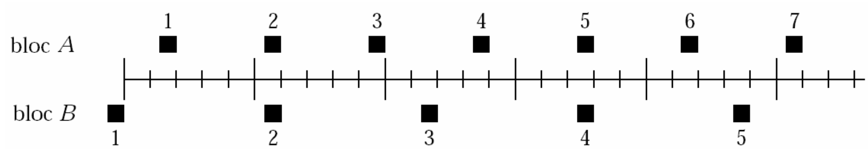
QCM : 20 questions

Durée : 30 minutes

- Chaque question comporte toujours exactement une réponse correcte.
- Chaque réponse correcte rapporte un point et il n'y a pas de déduction pour les réponses erronées.

Bon travail !

1) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



À propos de l'accélération de ces deux blocs on peut dire que

(A) l'accélération de A est plus grande que l'accélération de B.

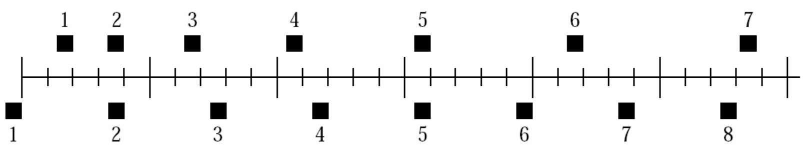
(B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro.

(C) l'accélération de B est plus grande que l'accélération de A.

(D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

2) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse?

(A) Non.

(B) Oui, à l'instant 2.

(C) Oui, à l'instant 5.

(D) Oui, aux instants 2 et 5.

(E) Oui, à un certain instant dans l'intervalle entre les instants 3 et 4.

3) Un cycliste a effectué l'ascension d'un col à la vitesse scalaire moyenne de 30km/h, puis la descente, par le même chemin, à la vitesse scalaire moyenne de 60km/h. La vitesse scalaire moyenne totale du voyage a été

(A) 45km/h.

(B) Moins que 45km/h.

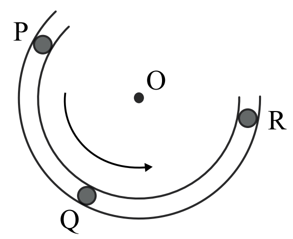
(C) Plus que 45km/h.

(D) Nulle.

(E) Les informations fournies ne sont pas suffisantes pour répondre à la question.

UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX TROIS QUESTIONS SUIVANTES (4, 5 ET 6).

La figure ci-contre illustre un tube sans frottements ayant la forme d'un arc de cercle de centre O. Le tube est fixé à une table horizontale, et la figure est une vue du dessus de la table.
Une balle parcourt le tube du point P au point R avec une vitesse d'intensité constante.



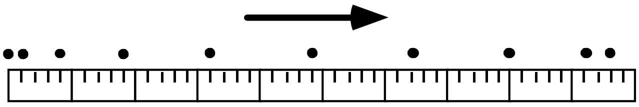
4) La vitesse instantanée de la balle au point P, $\vec{v}_P$, peut se représenter
   (A) par une flèche qui part du point P et se termine nécessairement au point R.
   (B) par une flèche qui part du point P et se termine nécessairement au point Q.
   (C) par une flèche tangente à la trajectoire au point P.
   (D) par une flèche dirigée du point P au point R, mais qui ne se termine pas nécessairement au point R.
   (E) par aucune flèche, car la vitesse instantanée est une grandeur scalaire.

5) La vitesse moyenne de la balle entre le point P et le point R, $\vec{v}_{mPR}$, peut se représenter
   (A) par une flèche tangente à la trajectoire au point Q.
   (B) par une flèche tangente à la trajectoire au point P.
   (C) par une flèche qui part du point P et se termine nécessairement au point R.
   (D) par une flèche dirigée du point P au point R, mais qui ne se termine pas nécessairement au point R.
   (E) par aucune flèche, car il s'agit d'une quantité scalaire.

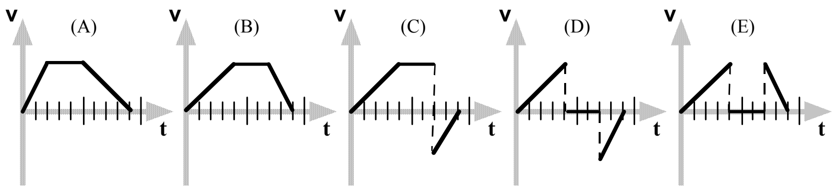
6) Dans son mouvement du point P au point Q, l'accélération moyenne de la balle $\vec{a}_{mPQ}$ peut se représenter
   (A) par une flèche tangente à la trajectoire au point P.
   (B) par une flèche tangente à la trajectoire au point Q.
   (C) par une flèche dirigée du point P au point Q.
   (D) par une flèche perpendiculaire au segment PQ.
   (E) par aucune flèche : l'accélération vaut zéro parce que l'intensité de sa vitesse est constante.

UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX DEUX QUESTIONS SUIVANTES (7 ET 8).

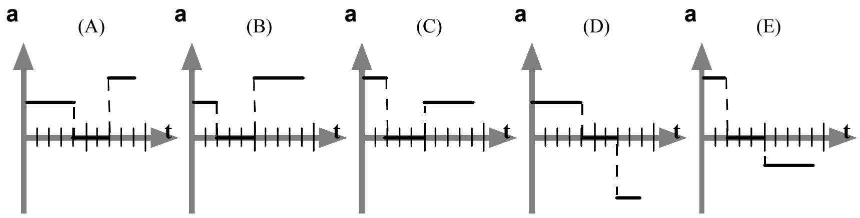
Les points de la figure ci-dessous représentent la position d'un objet à des intervalles de temps égaux. L'objet se déplace vers la droite sur une surface horizontale.



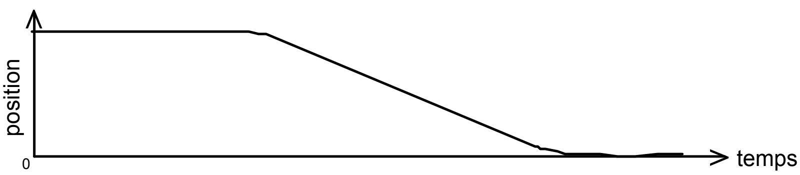
7) Lequel de ces graphiques représente le mieux la vitesse de l'objet en fonction du temps ?



8) Lequel de ces graphiques représente le mieux l'accélération de l'objet en fonction du temps ?



9) Voici le diagramme horaire du mouvement d'un objet.



Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?

(A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête.

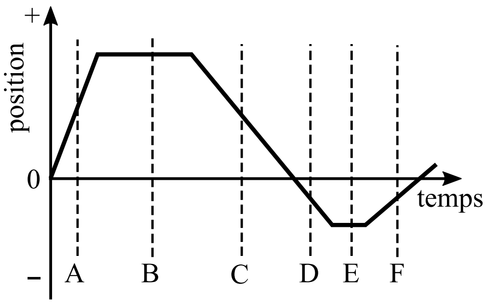
(B) Au début l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête.

(C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête.

(D) Au début l'objet ne bouge pas. Par la suite il recule et il s'arrête.

(E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.

10) Voici le diagramme du mouvement d'une voiture.



À quel couple d'instants la vitesse de la voiture est la même ?

(A) A et C

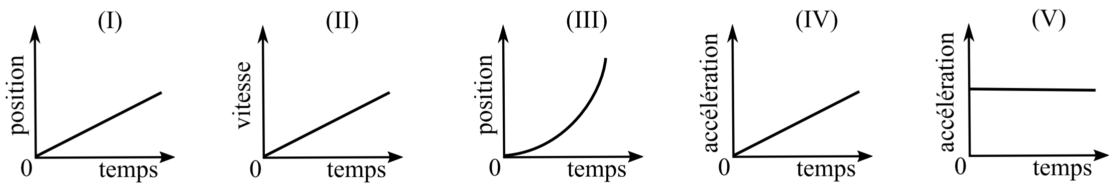
(B) A et D

(C) C et D

(D) C et F

(E) D et F

11) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.



Lequel de ces graphiques représente un mouvement à vitesse constante ?

(A) I

(B) II

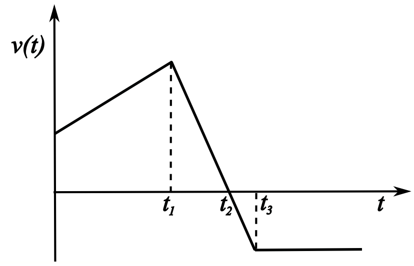
(C) III

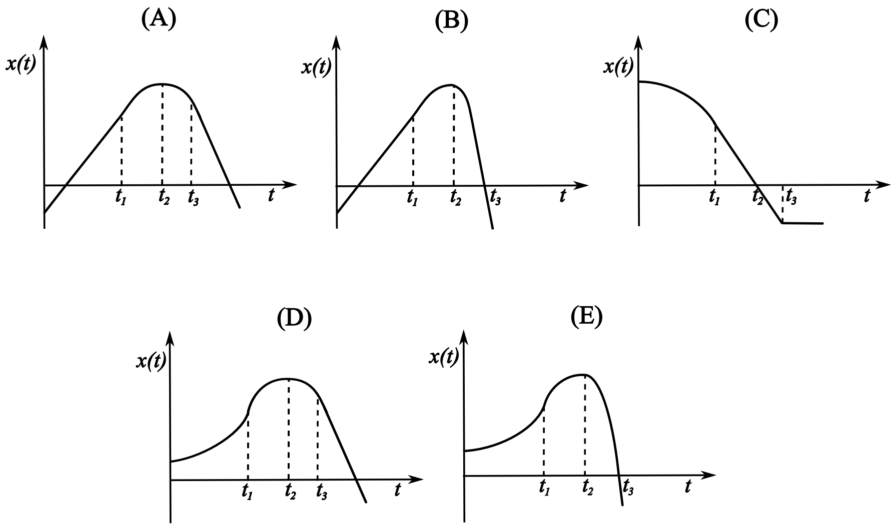
(D) IV

(E) V

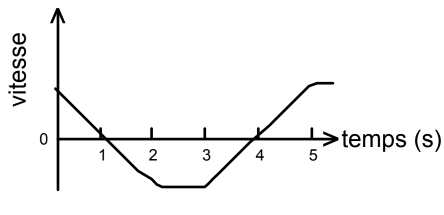
12) Le graphique ci-contre représente la vitesse d'un vélo en mouvement rectiligne pendant un certain intervalle de temps.

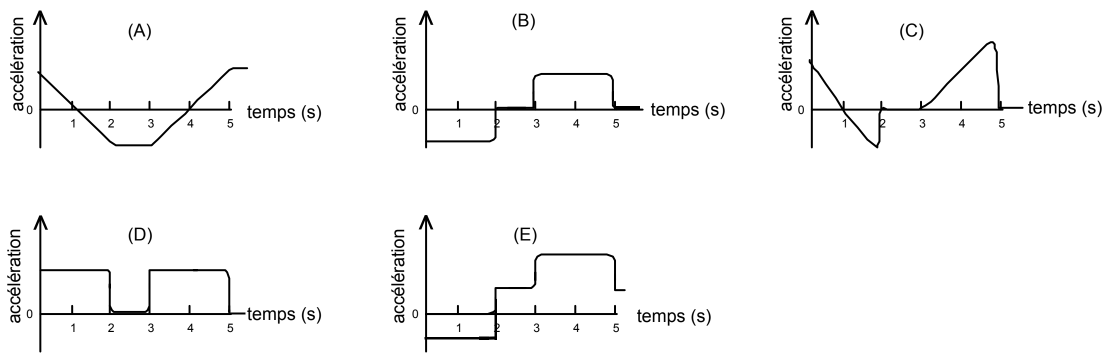
Parmi les options ci-dessous, choisissez celle qui pourrait représenter le diagramme horaire du mouvement du vélo.





13) Le graphique ci-contre montre le diagramme de vitesse d'un corps en mouvement rectiligne, pendant une durée de 5 secondes. Lequel de ces graphiques représente le mieux l'accélération en fonction du temps durant le même intervalle de temps ?





14) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut.

L'accélération du caillou

(A) est maximale dans l'instant juste après avoir été lancé.

(B) est maximale dans l'instant juste avant d'être repris.

(C) est maximale dans les deux instants juste après avoir été lancé et juste avant d'être repris.

(D) est maximale au moment où sa hauteur est maximale.

(E) est constante pendant toute la durée du vol.

15) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air.

Le temps pris par les balles pour atteindre le sol est

(A) la moitié pour la balle plus lourde que pour la balle plus légère.

(B) la moitié pour la balle plus légère que pour la balle plus lourde.

(C) le même pour les deux balles.

(D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié.

(E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.

16) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air.

Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est

(A) la moitié que pour la balle lâchée depuis plus bas.

(B) le même que pour la balle lâchée depuis plus bas.

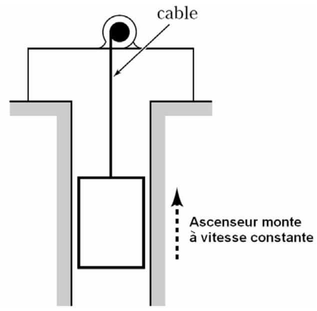
(C) le double que pour la balle lâchée depuis plus bas.

(D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double.

(E) plus grand que le double que pour la balle lâchée depuis plus bas.

17) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'illustré dans la figure suivante. Tous les frottements sont négligeables.

Dans cette situation, les forces appliquées sur l'ascenseur sont telles que



(A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas.

(B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas.

(C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas.

(D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas.

(E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.

18) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement.

Dans ces conditions,

(A) les deux billes atteignent la même vitesse.

(B) la bille plus lourde atteint une vitesse exactement trois fois plus grande que bille plus légère.

(C) la bille plus légère atteint une vitesse exactement trois plus grande que la bille plus lourde.

(D) la bille plus lourde atteint une vitesse plus grande que bille plus légère, mais pas exactement trois fois plus grande.

(E) la bille plus légère atteint une vitesse plus grande que la bille plus lourde, mais pas exactement trois fois plus grande.

19) Un gros camion entre en collision avec une petite voiture compacte.

Pendant la collision

(A) le camion exerce une force plus intense sur la voiture que la voiture sur le camion.

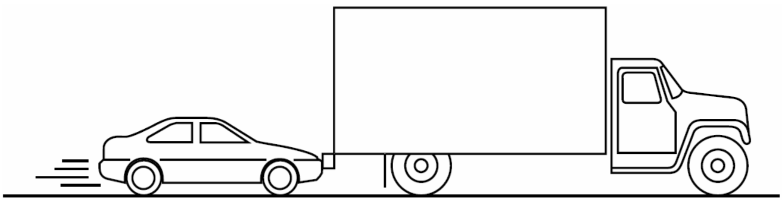
(B) la voiture exerce une force plus intense sur le camion que le camion sur la voiture.

(C) aucun des deux n'exerce de force sur l'autre. La voiture se fait frapper simplement parce qu'elle est devant le camion.

(D) le camion exerce une force sur la voiture mais la voiture n'exerce pas de force sur le camion.

(E) le camion exerce une force aussi intense sur la voiture que la voiture sur le camion.

20) Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, tel qu'illustré dans la figure suivante



Pendant que la voiture, poussant toujours le camion, augmente sa vitesse jusqu'à sa vitesse de croisière

(A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) la voiture exerce une force sur le camion, par contre le camion n'exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Nom et prénom:	Enseignant(e):
Langue maternelle:	Groupe: Date :

COMMENT AVEZ-VOUS TROUVE LE DERNIER SEMESTRE DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner **votre avis**, concernant le cours de physique notamment **du <u>semestre passé</u>**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	1	Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières.	①	②	③	④	⑤	⑥
	2	Je pense que pendant les derniers mois mes camarades ont trouvé que j'étais bon(ne) en physique.	①	②	③	④	⑤	⑥
	3	Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités.	①	②	③	④	⑤	⑥
	4	J'ai pu résoudre les problèmes de physique pendant les cours des derniers mois.	①	②	③	④	⑤	⑥
	5	J'aime apprendre des choses que je ne connais pas.	①	②	③	④	⑤	⑥
	6	Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	7	Je trouve fascinant d'apprendre des nouvelles choses.	①	②	③	④	⑤	⑥
	8	Si j'ai des problèmes avec les applications pour tablettes ou smartphones, je me sens démuni(e).	①	②	③	④	⑤	⑥
	9	Je trouve fascinants les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	10	Les problèmes du cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école.	①	②	③	④	⑤	⑥
	11	Les applications pour tablettes ou smartphones ne me semblent pas utiles pour apprendre.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	pas d'accord du tout	pas d'accord	plutôt pas d'accord	plutôt d'accord	d'accord	tout à fait d'accord
	12	Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école.	①	②	③	④	⑤	⑥
	13	Je m'attends à ce que mes résultats en physique soient bons à l'avenir.	①	②	③	④	⑤	⑥
	14	Je voudrais en savoir davantage sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	15	J'ai bien compris les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	16	J'aime essayer de résoudre des problèmes qui m'intriguent.	①	②	③	④	⑤	⑥
	17	Les derniers mois, mes résultats en physique ont été satisfaisants pour moi.	①	②	③	④	⑤	⑥
	18	Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	19	Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	20	Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	21	Je suis nul(le) en physique.	①	②	③	④	⑤	⑥
	22	Lorsque j'apprends quelque chose de nouveau, je veux en savoir davantage sur ce sujet.	①	②	③	④	⑤	⑥
	23	Je voudrais mieux comprendre les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	24	Les applications pour smartphones et tablettes m'aident à comprendre des choses.	①	②	③	④	⑤	⑥
	25	J'ai fait des recherches dans des livres, dans les journaux, sur le web, etc. pour en savoir plus sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	26	J'aime faire des recherches sur les choses que je ne comprends pas.	①	②	③	④	⑤	⑥
	27	En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	28	J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois.	①	②	③	④	⑤	⑥
	29	Pendant les heures du cours de physique des derniers mois je me suis ennuyé.	①	②	③	④	⑤	⑥
	30	Je veux toujours examiner les choses en profondeur.	①	②	③	④	⑤	⑥
	31	Parfois les applications pour tablettes ou smartphones font des choses que je ne comprends pas.	①	②	③	④	⑤	⑥
	32	Je suis à l'aise avec l'utilisation des applications pour smartphones et tablettes.	①	②	③	④	⑤	⑥
	33	Je ne vois pas de liens entre les sujets traités dans le cours de physique et la vie de tous les jours.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	34	J'utilise des applications pour smartphones/tablettes pour effectuer des mesures, comme le temps (chronomètre), le nombre de pas (entrainement physique), etc.	①	②	③	④	⑤	⑥
	35	Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique.	①	②	③	④	⑤	⑥
	36	Pendant les derniers mois, j'ai bien aimé le cours de physique.	①	②	③	④	⑤	⑥
	37	Le cours de physique des derniers mois a traité des situations de la vie quotidienne.	①	②	③	④	⑤	⑥

Encore une information :

J'utilise des applications pour Smartphones ou tablettes

▢ très souvent ▢ souvent ▢ de temps en temps ▢ rarement ▢ jamais

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Nom et prénom :	Groupe: Date :

COMMENT AVEZ-VOUS TROUVE LES DERNIERS MOIS DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner votre avis, concernant le cours de physique notamment **<u>dans les cinq derniers mois</u>**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	1	Pendant les derniers mois, j'ai bien aimé le cours de physique.	①	②	③	④	⑤	⑥
	2	Je voudrais en savoir davantage sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	3	Je me suis engagé(e) activement lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	4	Les problèmes traités au cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école.	①	②	③	④	⑤	⑥
	5	Lors des expériences de physique des derniers mois, j'ai eu un regard critique sur les idées testées.	①	②	③	④	⑤	⑥
	6	Lors du cours de physique des derniers mois, j'ai reçu des informations suffisantes pour effectuer les expériences.	①	②	③	④	⑤	⑥
	7	Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités.	①	②	③	④	⑤	⑥
	8	J'ai bien compris les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	9	Les activités expérimentales du cours de physique des derniers mois étaient simples à effectuer.	①	②	③	④	⑤	⑥
	10	Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières.	①	②	③	④	⑤	⑥
	11	Pendant les derniers mois, on m'a demandé d'expliquer comment j'avais résolu des problèmes de physique.	①	②	③	④	⑤	⑥
	12	Les derniers mois, mes résultats en physique ont été satisfaisants pour moi.	①	②	③	④	⑤	⑥
	13	Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	14	Je pense que, pendant les derniers mois, mes camarades ont trouvé que j'étais bon(ne) en physique.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	15	J'ai pu résoudre les problèmes de physique pendant les cours des derniers mois.	①	②	③	④	⑤	⑥
	16	J'étais concentré(e) lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	17	Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école.	①	②	③	④	⑤	⑥
	18	J'aime apprendre des choses que je ne connais pas.	①	②	③	④	⑤	⑥
	19	Je suis nul(le) en physique.	①	②	③	④	⑤	⑥
	20	Lors des activités au cours de physique des derniers mois, j'ai essayé de relier ce que j'étais en train d'apprendre à mes connaissances antérieures en physique.	①	②	③	④	⑤	⑥
	21	Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	22	Pendant les derniers mois, j'ai expliqué mes idées sur les sujets du cours de physique à mes camarades.	①	②	③	④	⑤	⑥
	23	J'ai participé activement aux cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	24	Je voudrais mieux comprendre les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	25	J'aime faire des recherches sur les choses que je ne comprends pas.	①	②	③	④	⑤	⑥
	26	Je trouve fascinant d'apprendre des nouvelles choses.	①	②	③	④	⑤	⑥
	27	Lors du cours de physique des derniers mois, j'ai eu de la peine à comprendre les notions de physique des expériences.	①	②	③	④	⑤	⑥
	28	J'aime essayer de résoudre des problèmes qui m'intriguent.	①	②	③	④	⑤	⑥
	29	Lors des expériences de physique des derniers mois, j'ai essayé de différencier les choses importantes de celles moins importantes.	①	②	③	④	⑤	⑥
	30	Pendant les derniers mois, j'ai souvent discuté avec des camarades sur la résolution des problèmes de physique.	①	②	③	④	⑤	⑥
	31	Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	32	En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	33	Je trouve fascinants les sujets traités au cours de physique des derniers mois .	①	②	③	④	⑤	⑥
	34	Pendant les heures du cours de physique des derniers mois je me suis ennuyé(e).	①	②	③	④	⑤	⑥
	35	J'ai fait des recherches dans des livres, dans les journaux, sur le web, etc. pour en savoir plus sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	36	Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec le matériel ou sa mise en place.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	37	Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	38	J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois.	①	②	③	④	⑤	⑥
	39	Lors du cours de physique des derniers mois, j'ai pu démarrer les activités rapidement.	①	②	③	④	⑤	⑥
	40	Le cours de physique des derniers mois a traité de situations de la vie quotidienne	①	②	③	④	⑤	⑥
	41	Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique.	①	②	③	④	⑤	⑥
	42	Je ne vois pas de liens entre les sujets traités dans le cours de physique et la vie de tous les jours.	①	②	③	④	⑤	⑥
	43	Lorsque j'apprends quelque chose de nouveau, je veux en savoir davantage sur ce sujet.	①	②	③	④	⑤	⑥
	44	Je veux toujours examiner les choses en profondeur.	①	②	③	④	⑤	⑥
	45	Je m'attends à ce que mes résultats en physique soient bons à l'avenir.	①	②	③	④	⑤	⑥
	46	Lors des expériences du cours de physique des derniers mois, j'ai eu des problèmes à utiliser les instruments de mesure.	①	②	③	④	⑤	⑥
	47	Pendant les cours de physique des derniers mois, j'ai posé souvent des questions.	①	②	③	④	⑤	⑥

Combien d'heures par semaine, en moyenne, as-tu travaillé avec un répétiteur pour la physique pendant les derniers mois?

▢ 0 ▢1-2 ▢3-4 ▢ 5 ou plus

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Nom et prénom :	Groupe: Date :

COMMENT AVEZ-VOUS TROUVE LES DERNIERS MOIS DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner votre avis, concernant le cours de physique notamment **dans les cinq derniers mois**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	1	Pendant les derniers mois, on m'a demandé d'expliquer comment j'avais résolu des problèmes de physique.	①	②	③	④	⑤	⑥
	2	Pendant les derniers mois, j'ai bien aimé le cours de physique.	①	②	③	④	⑤	⑥
	3	Lorsque j'apprends quelque chose de nouveau, je veux en savoir davantage sur ce sujet.	①	②	③	④	⑤	⑥
	4	Lors du cours de physique des derniers mois, j'ai pu démarrer les activités rapidement.	①	②	③	④	⑤	⑥
	5	Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec l'utilisation des applications pour tablettes.	①	②	③	④	⑤	⑥
	6	Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	7	Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec le matériel ou sa mise en place.	①	②	③	④	⑤	⑥
	8	Lors des expériences du cours de physique des derniers mois, j'ai eu des problèmes à utiliser les instruments de mesure.	①	②	③	④	⑤	⑥
	9	Lors des activités au cours de physique des derniers mois, j'ai essayé de relier ce que j'étais en train d'apprendre à mes connaissances antérieures de physique.	①	②	③	④	⑤	⑥
	10	Je suis nul(le) en physique.	①	②	③	④	⑤	⑥
	11	Je trouve pratique d'utiliser des tablettes pour les activités de physique.	①	②	③	④	⑤	⑥
	12	J'ai bien compris les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	13	Je voudrais en savoir davantage sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	14	Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	pas d'accord du tout	pas d'accord	plutôt pas d'accord	plutôt d'accord	d'accord	tout à fait d'accord
	15	Les problèmes traités au cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école.	①	②	③	④	⑤	⑥
	16	Le cours de physique des derniers mois a traité de situations de la vie quotidienne	①	②	③	④	⑤	⑥
	17	Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	18	En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	19	Je ne vois pas de liens entre les sujets traités dans le cours de physique et la vie de tous les jours.	①	②	③	④	⑤	⑥
	20	Lors des activités de physique des derniers mois, j'ai eu des problèmes en effectuant les mesures avec les tablettes.	①	②	③	④	⑤	⑥
	21	Je pense que, pendant les derniers mois, mes camarades ont trouvé que j'étais bon(ne) en physique.	①	②	③	④	⑤	⑥
	22	Je m'attends à ce que mes résultats en physique soient bons à l'avenir.	①	②	③	④	⑤	⑥
	23	Je voudrais mieux comprendre les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	24	Pendant les heures du cours de physique des derniers mois je me suis ennuyé(e).	①	②	③	④	⑤	⑥
	25	Je veux toujours examiner les choses en profondeur.	①	②	③	④	⑤	⑥
	26	J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois.	①	②	③	④	⑤	⑥
	27	L'utilisation des tablettes m'a aidé à mieux comprendre les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	28	Pendant les cours de physique des derniers mois, j'ai posé souvent des questions.	①	②	③	④	⑤	⑥
	29	Je me suis engagé(e) activement lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	30	Lors les activités de physique des derniers mois, j'ai trouvé difficile de comprendre les instructions pour utiliser les applications pour tablettes.	①	②	③	④	⑤	⑥
	31	J'ai participé activement aux cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	32	Pendant les derniers mois, j'ai expliqué mes idées sur les sujets du cours de physique à mes camarades.	①	②	③	④	⑤	⑥
	33	Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique.	①	②	③	④	⑤	⑥
	34	J'aime apprendre des choses que je ne connais pas.	①	②	③	④	⑤	⑥
	35	Pendant les derniers mois, j'ai souvent discuté avec des camarades sur la résolution des problèmes de physique.	①	②	③	④	⑤	⑥
	36	Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités.	①	②	③	④	⑤	⑥
	37	Lors du cours de physique des derniers mois, j'ai eu de la peine à comprendre les notions de physique des expériences.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	38	Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	39	Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	40	J'ai pu résoudre les problèmes de physique pendant les cours des derniers mois.	①	②	③	④	⑤	⑥
	41	Lors des expériences de physique des derniers mois, j'ai essayé de différencier les choses importantes de celles moins importantes.	①	②	③	④	⑤	⑥
	42	Les activités expérimentales du cours de physique des derniers mois étaient simples à effectuer.	①	②	③	④	⑤	⑥
	43	J'étais concentré(e) lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	44	Lors du cours de physique des derniers mois, j'ai reçu des informations suffisantes pour effectuer les expériences.	①	②	③	④	⑤	⑥
	45	Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école.	①	②	③	④	⑤	⑥
	46	J'ai fait des recherches dans des livres, dans les journaux, sur le web, etc. pour en savoir plus sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	47	Lors des activités de physique des derniers mois, j'ai reçu des informations suffisantes pour utiliser les applications pour les tablettes.	①	②	③	④	⑤	⑥
	48	Lors des activités de physique des derniers mois, les applications pour tablettes étaient difficiles à utiliser.	①	②	③	④	⑤	⑥
	49	J'aime faire des recherches sur les choses que je ne comprends pas.	①	②	③	④	⑤	⑥
	50	Je trouve fascinants les sujets traités au cours de physique des derniers mois .	①	②	③	④	⑤	⑥
	51	Lors des expériences de physique des derniers mois, j'ai eu un regard critique sur les idées testées.	①	②	③	④	⑤	⑥
	52	Je trouve fascinant d'apprendre des nouvelles choses.	①	②	③	④	⑤	⑥
	53	Les derniers mois, mes résultats en physique ont été satisfaisants pour moi.	①	②	③	④	⑤	⑥
	54	J'aime essayer de résoudre des problèmes qui m'intriguent.	①	②	③	④	⑤	⑥

Combien d'heures par semaine, en moyenne, as-tu travaillé avec un répétiteur pour la physique pendant les derniers mois?

▢ 0 ▢1-2 ▢3-4 ▢ 5 ou plus

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Réponses Anonymes	Date :

COMMENT AVEZ-VOUS TROUVE LES DERNIERS MOIS DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner votre avis, concernant le cours de physique notamment **dans les cinq derniers mois**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

	Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
1	Pendant le cours de physique des derniers mois, l'enseignant(e) a pris du temps pour nous aider quand nous avions des problèmes avec les tâches assignées.	①	②	③	④	⑤	⑥
2	Pendant le cours de physique des derniers mois, les explications de l'enseignant(e) nous ont aidés à mieux comprendre les sujets traités.	①	②	③	④	⑤	⑥
3	Pendant le cours de physique des derniers mois, l'enseignant(e) donnait l'impression d'être passionné(e) par la physique.	①	②	③	④	⑤	⑥
4	Pendant le cours de physique des derniers mois, l'enseignant(e) nous encourageait.	①	②	③	④	⑤	⑥
5	Pendant le cours de physique des derniers mois, l'enseignant(e) s'est déplacé(e) dans la classe pour répondre à nos questions.	①	②	③	④	⑤	⑥

TEST DE PHYSIQUE

Cinématique et dynamique

Nom et prénom : **Date :**

Groupe : **Enseignant·e :**

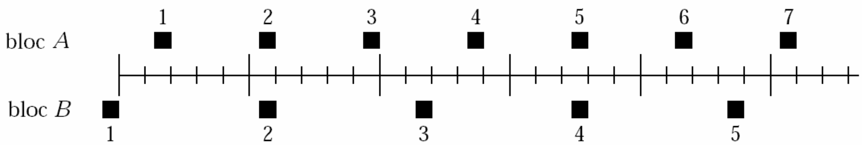
QCM : **16 questions**

Durée : **25 minutes**

- Chaque question comporte une seule réponse correcte.
- Chaque réponse correcte rapporte un point et il n'y a pas de déduction pour les réponses erronées.

Bon travail !

1) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



À propos de l'accélération de ces deux blocs on peut dire que

(A) l'accélération de A est plus grande que l'accélération de B.

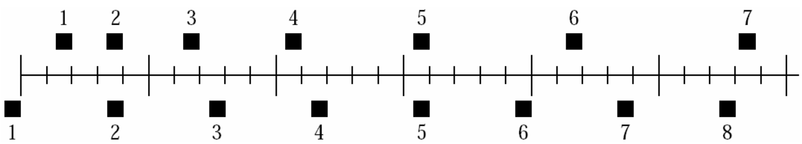
(B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro.

(C) l'accélération de B est plus grande que l'accélération de A.

(D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

2) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse?

(A) Non.

(B) Oui, à l'instant 2.

(C) Oui, à l'instant 5.

(D) Oui, aux instants 2 et 5.

(E) Oui, à un certain instant dans l'intervalle entre les instants 3 et 4.

3) Un cycliste a effectué l'ascension d'un col à la vitesse de 30km/h, puis la descente, par le même chemin, à 60km/h. La vitesse moyenne totale du voyage a été

(A) 45km/h.

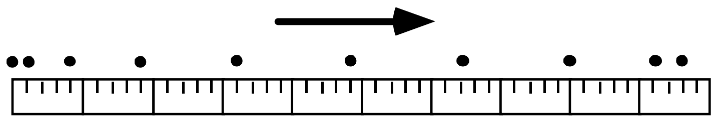
(B) moins que 45km/h.

(C) plus que 45km/h.

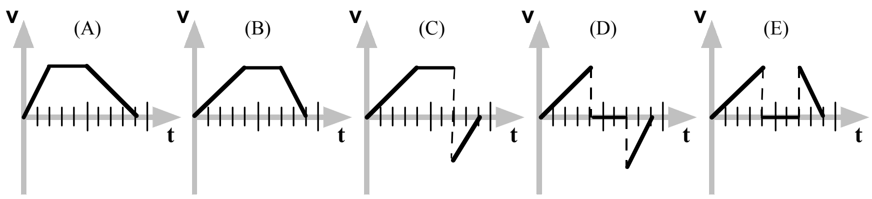
(D) nulle.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

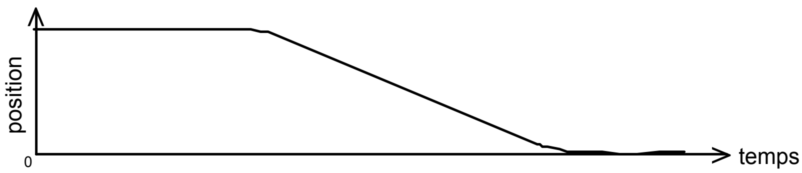
4) Les points de la figure ci-dessous représentent la position d'un objet à des intervalles de temps égaux. L'objet se déplace vers la droite sur une surface horizontale.



Lequel de ces graphiques représente le mieux la vitesse de l'objet en fonction du temps ?



5) Voici le diagramme horaire du mouvement d'un objet.



Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?

(A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête.

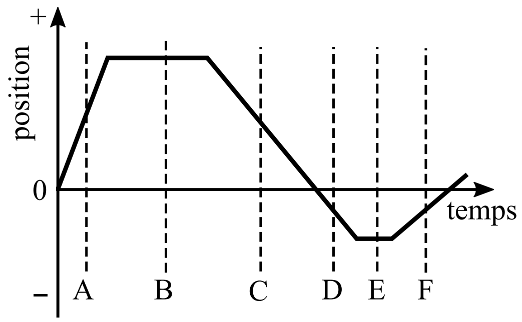
(B) Au début l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête.

(C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête.

(D) Au début l'objet ne bouge pas. Par la suite il recule et il s'arrête.

(E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.

6) Voici le diagramme du mouvement d'une voiture.



À quel couple d'instants la vitesse de la voiture est la même ?

(A) A et C

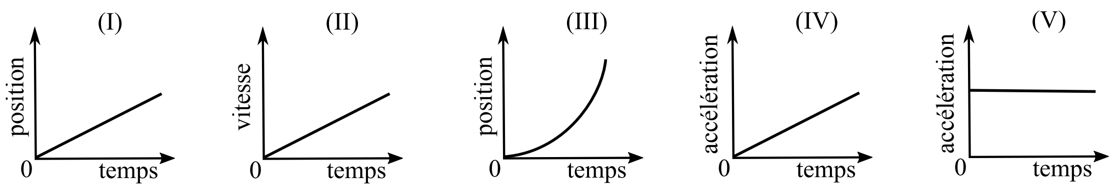
(B) A et D

(C) C et D

(D) C et F

(E) D et F

7) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.



Lequel de ces graphiques représente un mouvement à vitesse constante ?

(A) I

(B) II

(C) III

(D) IV

(E) V

8) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air.

Le temps pris par les balles pour atteindre le sol est

(A) la moitié pour la balle plus lourde que pour la balle plus légère.

(B) la moitié pour la balle plus légère que pour la balle plus lourde.

(C) le même pour les deux balles.

(D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié.

(E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.

9) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air.

Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est

(A) la moitié que pour la balle lâchée depuis plus bas.

(B) le même que pour la balle lâchée depuis plus bas.

(C) le double que pour la balle lâchée depuis plus bas.

(D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double.

(E) plus grand que le double que pour la balle lâchée depuis plus bas.

10) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut.

L'accélération du caillou

(A) est maximale dans l'instant juste après avoir été lancé.

(B) est maximale dans l'instant juste avant d'être repris.

(C) est maximale dans les deux instants juste après avoir été lancé et juste avant d'être repris.

(D) est maximale au moment où sa hauteur est maximale.

(E) est constante pendant toute la durée du vol.

11) Un boulet de canon est tiré du haut d'une falaise, tel qu'illustré ci-dessous. On néglige le frottement de l'air. Laquelle des courbes suivantes décrit mieux la trajectoire du boulet de canon ?

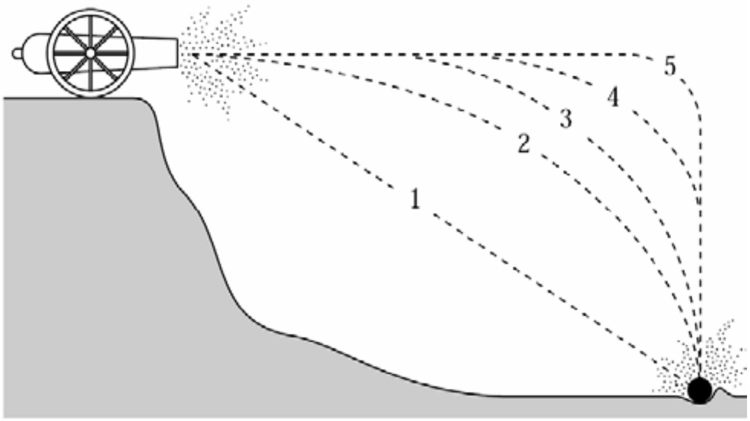
(A) 1

(B) 2

(C) 3

(D) 4

(E) 5



12) Une boule de quilles tombe accidentellement de la soute à bagages d'un avion volant horizontalement à vitesse constante. On néglige le frottement de l'air. D'après une personne au sol regardant l'avion, laquelle des courbes suivantes représente mieux la trajectoire de la boule de quilles après qu'elle ait quitté l'avion ?

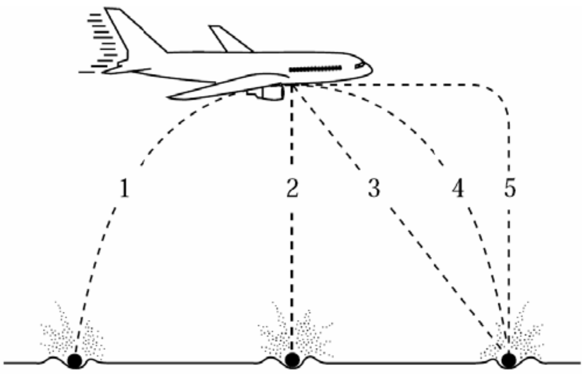
(A) 1

(B) 2

(C) 3

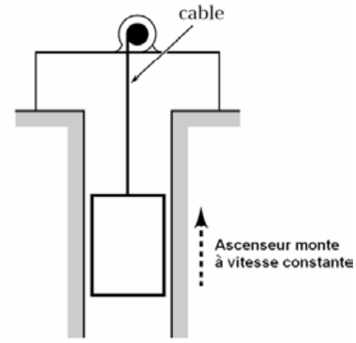
(D) 4

(E) 5



13) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'il est illustré dans la figure suivante. Tous les frottements sont négligeables.

Dans cette situation, les forces appliquées sur l'ascenseur sont telles que



(A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas.

(B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas.

(C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas.

(D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas.

(E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.

14) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement.

Dans ces conditions,

(A) les deux billes atteignent la même vitesse.

(B) la bille plus lourde atteint une vitesse trois fois plus grande que bille plus légère.

(C) la bille plus légère atteint une vitesse trois plus grande que la bille plus lourde.

(D) la bille plus lourde atteint une vitesse neuf fois plus grande que bille plus légère.

(E) la bille plus légère atteint une vitesse neuf fois plus grande que bille plus lourde.

15) Un gros camion entre en collision avec une petite voiture compacte.

Pendant la collision

(A) le camion exerce une force plus intense sur la voiture que la voiture sur le camion.

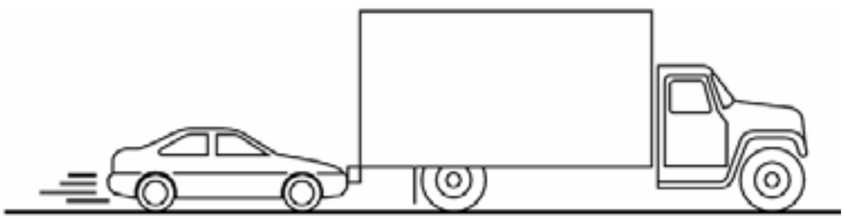
(B) la voiture exerce une force plus intense sur le camion que le camion sur la voiture.

(C) aucun des deux n'exerce de force sur l'autre. La voiture se fait frapper simplement parce qu'elle est devant le camion.

(D) Le camion exerce une force sur la voiture mais la voiture n'exerce pas de force sur le camion.

(E) Le camion exerce une force aussi intense sur la voiture que la voiture sur le camion.

16) Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, tel qu'illustré dans la figure suivante



Pendant que la voiture, poussant toujours le camion, augmente sa vitesse jusqu'à sa vitesse de croisière

(A) la force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) la voiture exerce une force sur le camion, par contre le camion n'exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.

TEST DE PHYSIQUE

Cinématique et dynamique

Nom et prénom : **Date :**

Groupe : **Enseignant·e :**

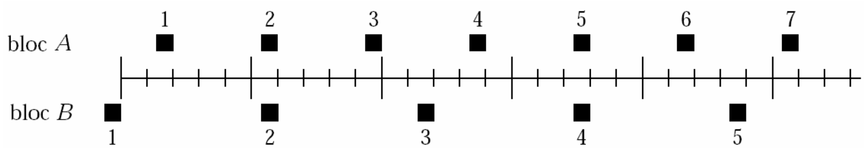
QCM : 19 questions

Durée : 30 minutes

- Chaque question comporte une seule réponse correcte.
- Chaque réponse correcte rapporte un point et il n'y a pas de déduction pour les réponses erronées.

Bon travail !

1) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



À propos de l'accélération de ces deux blocs on peut dire que :

(A) l'accélération de A est plus grande que l'accélération de B.

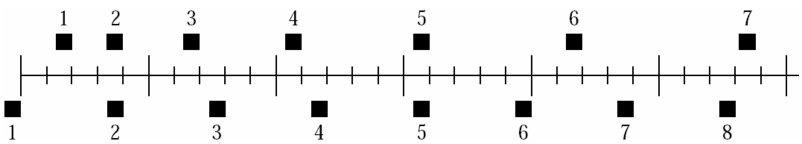
(B) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont plus grandes que zéro.

(C) l'accélération de B est plus grande que l'accélération de A.

(D) l'accélération de A est égale à l'accélération de B. Ces deux accélérations sont nulles.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

2) Les carrés numérotés de la figure suivante représentent la position de deux blocs à des intervalles de temps de 0,20s. Les blocs se déplacent vers la droite.



Y a-t-il un point de leur trajectoire où les blocs ont la même vitesse?

(A) Non.

(B) Oui, à l'instant 2.

(C) Oui, à l'instant 5.

(D) Oui, aux instants 2 et 5.

(E) Oui, à un certain instant dans l'intervalle entre les instants 3 et 4.

3) Un cycliste a effectué l'ascension d'un col à la vitesse scalaire moyenne de 30km/h, puis la descente, par le même chemin, à la vitesse scalaire moyenne de 60km/h. La vitesse scalaire moyenne totale du voyage a été

(A) 45km/h.

(B) Moins que 45km/h.

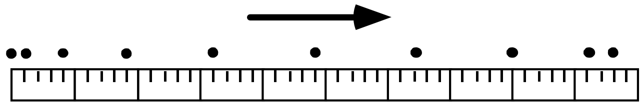
(C) Plus que 45km/h.

(D) Nulle.

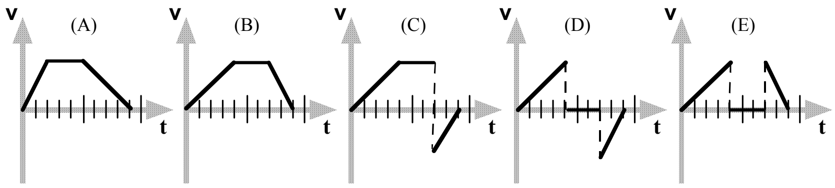
(E) Les informations fournies ne sont pas suffisantes pour répondre à la question.

UTILISEZ L'ENONCE ET LA FIGURE CI-DESSOUS POUR REPONDRE AUX DEUX QUESTIONS SUIVANTES (4 ET 5).

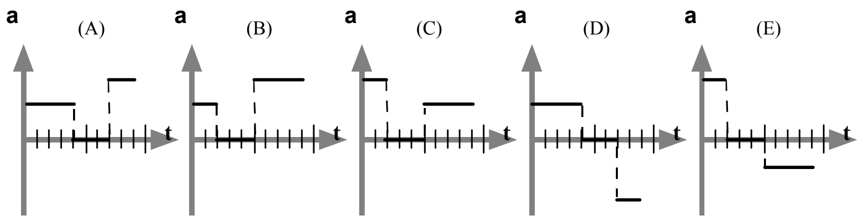
Les points de la figure ci-dessous représentent la position d'un objet à des intervalles de temps égaux. L'objet se déplace vers la droite sur une surface horizontale.



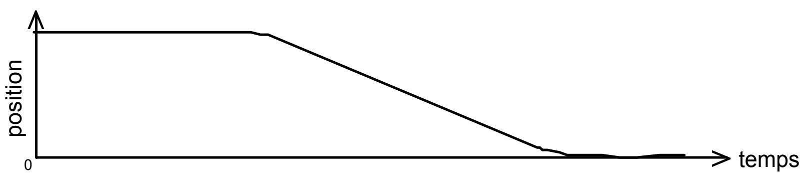
4) Lequel de ces graphiques représente le mieux la vitesse de l'objet en fonction du temps ?



5) Lequel de ces graphiques représente le mieux l'accélération de l'objet en fonction du temps ?



6) Voici le diagramme horaire du mouvement d'un objet.



Quelle affirmation est la bonne interprétation qualitative de ce mouvement ?

(A) L'objet roule sur une surface plane. Puis il descend une pente et finalement s'arrête.

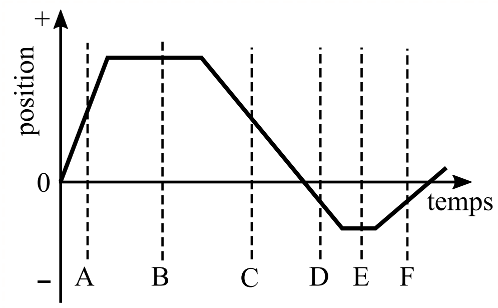
(B) Au début l'objet ne bouge pas. Ensuite, il roule vers le bas d'une pente et s'arrête.

(C) L'objet se déplace avec une vitesse constante. Il ralentit et finalement s'arrête.

(D) Au début l'objet ne bouge pas. Par la suite il recule et il s'arrête.

(E) L'objet se déplace sur une surface plane, il recule en descendant une pente et par la suite il continue de se déplacer.

7) Voici le diagramme du mouvement d'une voiture.



À quel couple d'instants la vitesse de la voiture est la même ?

(A) A et C

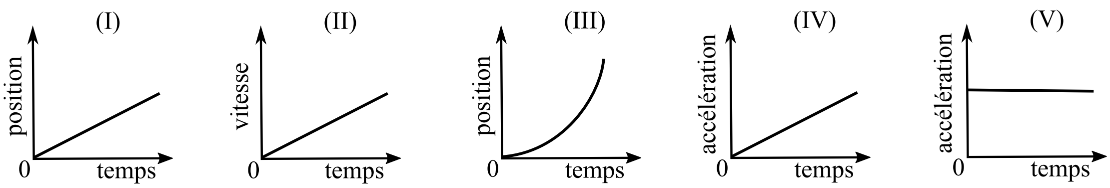
(B) A et D

(C) C et D

(D) C et F

(E) D et F

8) Les graphiques suivants décrivent des mouvements rectilignes. Observez les différentes grandeurs sur les axes.



Lequel de ces graphiques représente un mouvement à vitesse constante ?

(A) I

(B) II

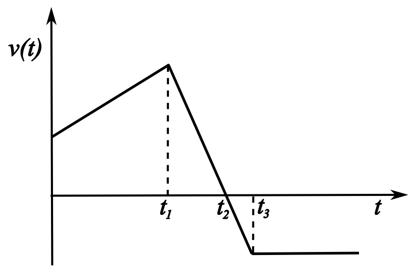
(C) III

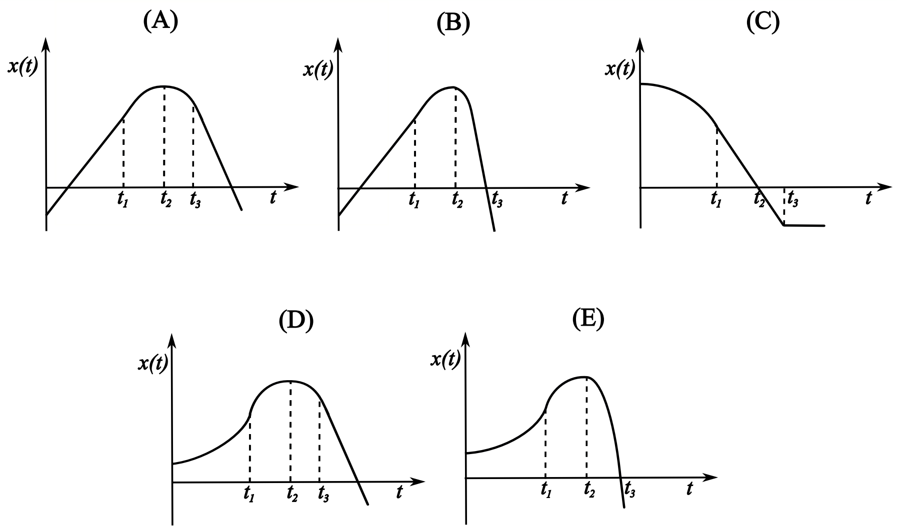
(D) IV

(E) V

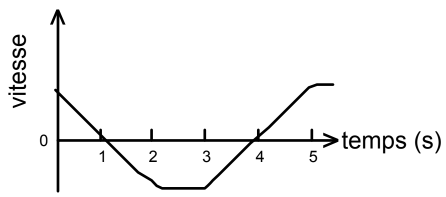
9) Le graphique ci-contre représente la vitesse d'un vélo en mouvement rectiligne pendant un certain intervalle de temps.

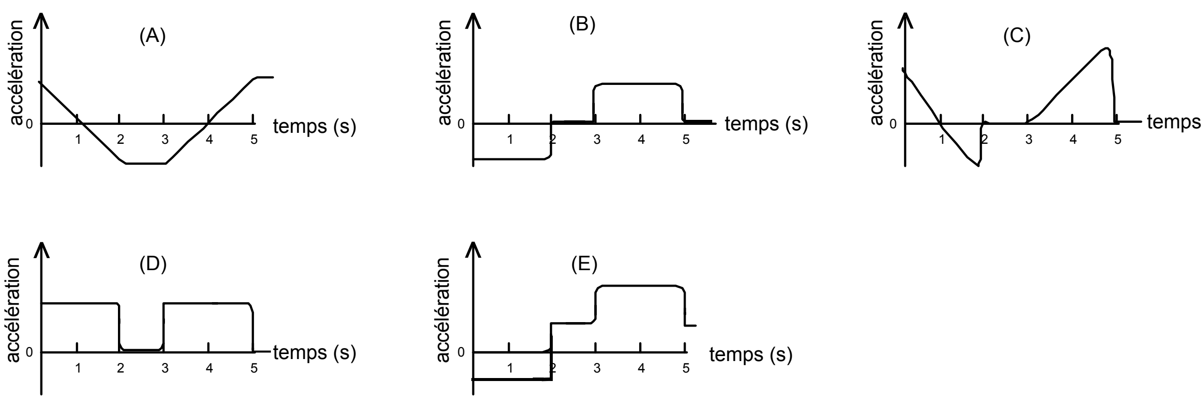
Parmi les options ci-dessous, choisissez celle qui pourrait représenter le diagramme horaire du mouvement du vélo.





10) Le graphique ci-contre montre le diagramme de vitesse d'un corps en mouvement rectiligne, pendant une durée de 5 secondes. Lequel de ces graphiques représente le mieux l'accélération en fonction du temps durant le même intervalle de temps ?





11) Au même instant, on laisse tomber deux balles métalliques du premier étage d'un immeuble. Une des deux balles est deux fois plus lourde que l'autre. On néglige le frottement de l'air.

Le temps pris par les balles pour atteindre le sol est

(A) la moitié pour la balle plus lourde que pour la balle plus légère.

(B) la moitié pour la balle plus légère que pour la balle plus lourde.

(C) le même pour les deux balles.

(D) bien inférieur pour la balle plus lourde, mais pas nécessairement la moitié.

(E) bien inférieur pour la balle plus légère, mais pas nécessairement la moitié.

12) Au même instant, on laisse tomber deux balles métalliques identiques, mais une des deux balles est lâchée d'une hauteur deux fois plus grande. On néglige le frottement de l'air.

Pour la balle lâchée depuis plus haut, le temps pris pour atteindre le sol est

(A) la moitié que pour la balle lâchée depuis plus bas.

(B) le même que pour la balle lâchée depuis plus bas.

(C) le double que pour la balle lâchée depuis plus bas.

(D) plus grand que pour la balle lâchée depuis plus bas, mais moins que le double.

(E) plus grand que le double que pour la balle lâchée depuis plus bas.

13) Un enfant lance un caillou en l'air verticalement et il le rattrape lorsqu'il tombe. Considérez le mouvement du caillou en vol, pendant qu'il n'est pas en contact avec la main de l'enfant. On néglige le frottement de l'air et on considère comme positive la direction verticale vers le haut.

L'accélération du caillou

(A) est maximale dans l'instant juste après avoir été lancé.

(B) est maximale dans l'instant juste avant d'être repris.

(C) est maximale dans les deux instants juste après avoir été lancé et juste avant d'être repris.

(D) est maximale au moment où sa hauteur est maximale.

(E) est constante pendant toute la durée du vol.

14) Un boulet de canon est tiré du haut d'une falaise, tel qu'illustré ci-dessous. On néglige le frottement de l'air. Laquelle des courbes suivantes décrit mieux la trajectoire du boulet ?

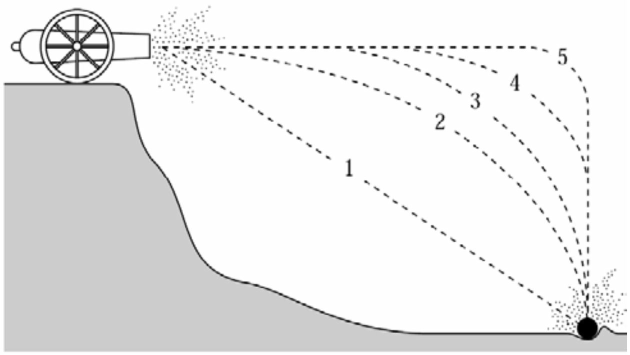
(A) 1

(B) 2

(C) 3

(D) 4

(E) 5



15) Une boule de quilles tombe accidentellement de la soute à bagages d'un avion volant horizontalement à vitesse constante. On néglige le frottement de l'air. D'après une personne au sol regardant l'avion, laquelle des courbes suivantes représente mieux la trajectoire de la boule de quilles après qu'elle ait quitté l'avion ?

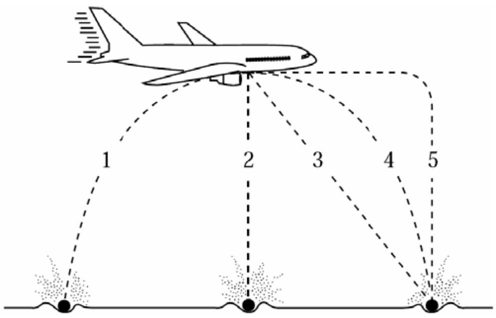
(A) 1

(B) 2

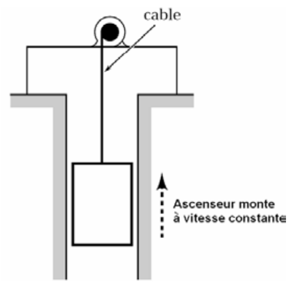
(C) 3

(D) 4

(E) 5



16) Un câble d'acier tire un ascenseur pour qu'il monte à vitesse constante, tel qu'illustré dans la figure suivante. Tous les frottements sont négligeables. Dans cette situation, les forces appliquées sur l'ascenseur sont telles que



(A) la force du câble dirigée vers le haut est plus intense que la force de la gravité dirigée vers le bas.

(B) l'intensité de la force du câble dirigée vers le haut est égale à l'intensité de la force de la gravité dirigée vers le bas.

(C) la force du câble dirigée vers le haut est moins intense que la force de la gravité dirigée vers le bas.

(D) la force du câble dirigée vers le haut est plus intense que la somme de la force de la gravité dirigée vers le bas et de la force causée par l'air dirigée vers le bas.

(E) il n'y a pas de forces agissant sur l'ascenseur, car sa vitesse est constante.

17) On propulse avec la même force et pendant la même durée deux billes initialement au repos. Les deux billes ont le même diamètre et l'une est trois fois plus lourde que l'autre. On néglige tout frottement.

Dans ces conditions,

(A) les deux billes atteignent la même vitesse.

(B) la bille plus lourde atteint une vitesse trois fois plus grande que bille plus légère.

(C) la bille plus légère atteint une vitesse trois plus grande que la bille plus lourde.

(D) la bille plus lourde atteint une vitesse neuf fois plus grande que bille plus légère.

(E) la bille plus légère atteint une vitesse neuf fois plus grande que bille plus lourde.

18) Un gros camion entre en collision avec une petite voiture compacte.
Pendant la collision

(A) le camion exerce une force plus intense sur la voiture que la voiture sur le camion.

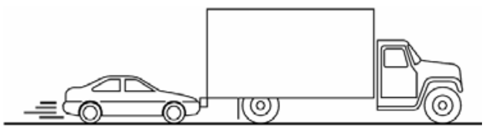
(B) la voiture exerce une force plus intense sur le camion que le camion sur la voiture.

(C) aucun des deux n'exerce de force sur l'autre. La voiture se fait frapper simplement parce qu'elle est devant le camion.

(D) le camion exerce une force sur la voiture mais la voiture n'exerce pas de force sur le camion.

(E) le camion exerce une force aussi intense sur la voiture que la voiture sur le camion.

19) Un gros camion tombe en panne sur la route. Pour retourner en ville, il se fait pousser par une voiture, tel qu'illustré dans la figure suivante



Pendant que la voiture, poussant toujours le camion, augmente sa vitesse jusqu'à sa vitesse de croisière

(A) La force avec laquelle la voiture pousse le camion a la même intensité que la force du camion sur la voiture.

(B) la force avec laquelle la voiture pousse le camion est moins intense que la force du camion sur la voiture.

(C) la force avec laquelle la voiture pousse le camion est plus intense que la force du camion sur la voiture.

(D) la voiture exerce une force sur le camion, par contre le camion n'exerce pas de force sur la voiture.

(E) ni la voiture ni le camion n'exercent de forces l'un sur l'autre.

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Nom et prénom: Langue maternelle:	Groupe: Date :

COMMENT AVEZ-VOUS TROUVE LE DERNIER SEMESTRE DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner **votre avis**, concernant le cours de physique notamment **du semestre passé**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	1	Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières.	①	②	③	④	⑤	⑥
	2	Je pense que pendant les derniers mois mes camarades ont trouvé que j'étais bon(ne) en physique.	①	②	③	④	⑤	⑥
	3	Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités.	①	②	③	④	⑤	⑥
	4	J'ai pu résoudre les problèmes de physique pendant les cours des derniers mois.	①	②	③	④	⑤	⑥
	5	J'aime apprendre des choses que je ne connais pas.	①	②	③	④	⑤	⑥
	6	Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	7	Je trouve fascinant d'apprendre des nouvelles choses.	①	②	③	④	⑤	⑥
	8	Si j'ai des problèmes avec les applications pour tablettes ou smartphones, je me sens démuni(e).	①	②	③	④	⑤	⑥
	9	Je trouve fascinants les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	10	Les problèmes du cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école.	①	②	③	④	⑤	⑥
	11	Les applications pour tablettes ou smartphones ne me semblent pas utiles pour apprendre.	①	②	③	④	⑤	⑥
	12	Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école.	①	②	③	④	⑤	⑥
	13	Je voudrais en savoir davantage sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	pas d'accord du tout	pas d'accord	plutôt pas d'accord	plutôt d'accord	d'accord	tout à fait d'accord
	14	J'ai bien compris les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	15	Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	16	Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	17	Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	18	Je suis nul(le) en physique.	①	②	③	④	⑤	⑥
	19	Lorsque j'apprends quelque chose de nouveau, je veux en savoir davantage sur ce sujet.	①	②	③	④	⑤	⑥
	20	J'aimerais approfondir les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	21	Les applications pour smartphones et tablettes m'aident à compren-dre des choses.	①	②	③	④	⑤	⑥
	22	J'aime faire des recherches sur les choses que je ne comprends pas.	①	②	③	④	⑤	⑥
	23	En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	24	J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois.	①	②	③	④	⑤	⑥
	25	Je veux toujours examiner les choses en profondeur.	①	②	③	④	⑤	⑥
	26	Je suis à l'aise avec l'utilisation des applications pour smartphones et tablettes.	①	②	③	④	⑤	⑥
	27	Je ne vois pas de liens entre les sujets traités dans le cours de physi-que et la vie de tous les jours.	①	②	③	④	⑤	⑥
	28	J'utilise des applications pour smartphones/tablettes pour effectuer des mesures, comme le temps (chronomètre), le nombre de pas (en-trainement physique), etc.	①	②	③	④	⑤	⑥
	29	Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique.	①	②	③	④	⑤	⑥
	30	Pendant les derniers mois, j'ai bien aimé le cours de physique.	①	②	③	④	⑤	⑥

Encore une information :

J'utilise des applications pour Smartphones ou tablettes

▢ très souvent ▢ souvent ▢ de temps en temps ▢ rarement ▢ jamais

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Nom et prénom :	Groupe: Date :

COMMENT AVEZ-VOUS TROUVE LES DERNIERS MOIS DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner votre avis, concernant le cours de physique notamment **dans les six derniers mois**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	1	Pendant les derniers mois, j'ai bien aimé le cours de physique.	①	②	③	④	⑤	⑥
	2	Je voudrais en savoir davantage sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	3	Je me suis engagé(e) activement lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	4	Les problèmes traités au cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école.	①	②	③	④	⑤	⑥
	5	Lors des expériences de physique des derniers mois, j'ai eu un regard critique sur les idées testées.	①	②	③	④	⑤	⑥
	6	Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités.	①	②	③	④	⑤	⑥
	7	J'ai bien compris les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	8	Les activités expérimentales du cours de physique des derniers mois étaient simples à effectuer.	①	②	③	④	⑤	⑥
	9	Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières.	①	②	③	④	⑤	⑥
	10	Pendant les derniers mois, j'ai débattu sur les sujets traités en classe.	①	②	③	④	⑤	⑥
	11	Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	12	Je pense que, pendant les derniers mois, mes camarades ont trouvé que j'étais bon(ne) en physique.	①	②	③	④	⑤	⑥
	13	J'ai pu résoudre les problèmes de physique pendant les cours des derniers mois.	①	②	③	④	⑤	⑥
	14	J'étais concentré(e) lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	15	Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école.	①	②	③	④	⑤	⑥
	16	Je suis nul(le) en physique.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	17	Lors des activités au cours de physique des derniers mois, j'ai essayé de relier ce que j'étais en train d'apprendre à mes connaissances antérieures en physique.	①	②	③	④	⑤	⑥
	18	Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	19	Pendant les derniers mois, j'ai expliqué mes idées sur les sujets du cours de physique à mes camarades.	①	②	③	④	⑤	⑥
	20	J'ai participé activement aux cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	21	J'aimerais approfondir les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	22	Lors du cours de physique des derniers mois, j'ai eu de la peine à comprendre les notions de physique des expériences.	①	②	③	④	⑤	⑥
	23	Lors des expériences de physique des derniers mois, j'ai essayé de différencier les choses importantes de celles moins importantes.	①	②	③	④	⑤	⑥
	24	Pendant les derniers mois, j'ai souvent discuté avec des camarades sur la résolution des problèmes de physique.	①	②	③	④	⑤	⑥
	25	Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	26	En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	27	Je trouve fascinants les sujets traités au cours de physique des derniers mois .	①	②	③	④	⑤	⑥
	28	Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec le matériel ou sa mise en place.	①	②	③	④	⑤	⑥
	29	Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	30	J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois.	①	②	③	④	⑤	⑥
	31	Lors du cours de physique des derniers mois, j'ai pu démarrer les activités rapidement.	①	②	③	④	⑤	⑥
	32	Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique.	①	②	③	④	⑤	⑥
	33	Je ne vois pas de liens entre les sujets traités dans le cours de physique et la vie de tous les jours.	①	②	③	④	⑤	⑥
	34	Lors des expériences du cours de physique des derniers mois, j'ai eu des problèmes à utiliser les instruments de mesure.	①	②	③	④	⑤	⑥
	35	Pendant les cours de physique des derniers mois, j'ai posé souvent des questions.	①	②	③	④	⑤	⑥

Combien d'heures par semaine, en moyenne, as-tu travaillé avec un répétiteur de physique pendant les derniers mois?

▢ 0 ▢1-2 ▢3-4 ▢ 5 ou plus

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Nom et prénom :	Groupe: Date :

COMMENT AVEZ-VOUS TROUVE LES DERNIERS MOIS DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner votre avis, concernant le cours de physique notamment **dans les six derniers mois**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	1	Pendant les derniers mois, j'ai débattu sur les sujets traités en classe.	①	②	③	④	⑤	⑥
	2	Pendant les derniers mois, j'ai bien aimé le cours de physique.	①	②	③	④	⑤	⑥
	3	Lors du cours de physique des derniers mois, j'ai pu démarrer les activités rapidement.	①	②	③	④	⑤	⑥
	4	Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec l'utilisation des applications pour tablettes.	①	②	③	④	⑤	⑥
	5	Il m'arrive de relier les contenus traités dans le cours de physique à des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	6	Lors du cours de physique des derniers mois, j'ai pu me concentrer sur les activités, sans avoir à me battre avec le matériel ou sa mise en place.	①	②	③	④	⑤	⑥
	7	Lors des expériences du cours de physique des derniers mois, j'ai eu des problèmes à utiliser les instruments de mesure.	①	②	③	④	⑤	⑥
	8	Lors des activités au cours de physique des derniers mois, j'ai essayé de relier ce que j'étais en train d'apprendre à mes connaissances antérieures de physique.	①	②	③	④	⑤	⑥
	9	Je suis nul(le) en physique.	①	②	③	④	⑤	⑥
	10	Je trouve pratique d'utiliser des tablettes pour les activités de physique.	①	②	③	④	⑤	⑥
	11	J'ai bien compris les sujets traités au cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	12	Je voudrais en savoir davantage sur les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	13	Pendant les derniers mois, je me suis investi(e) davantage pour le cours de physique que pour les autres matières.	①	②	③	④	⑤	⑥
	14	Les problèmes traités au cours de physique des derniers mois sont utiles pour réfléchir à des situations vécues en dehors de l'école.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	pas d'accord du tout	pas d'accord	plutôt pas d'accord	plutôt d'accord	d'accord	tout à fait d'accord
	15	Pendant les derniers mois, j'ai trouvé ennuyeux de résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	16	En plus des devoirs, j'ai consacré du temps libre aux sujets abordés dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	17	Je ne vois pas de liens entre les sujets traités dans le cours de physique et la vie de tous les jours.	①	②	③	④	⑤	⑥
	18	Lors des activités de physique des derniers mois, j'ai eu des problèmes en effectuant les mesures avec les tablettes.	①	②	③	④	⑤	⑥
	19	Je pense que, pendant les derniers mois, mes camarades ont trouvé que j'étais bon(ne) en physique.	①	②	③	④	⑤	⑥
	20	J'aimerais approfondir les sujets traités dans le cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	21	J'aime passer du temps à réfléchir sur les sujets traités en physique les derniers mois.	①	②	③	④	⑤	⑥
	22	Pendant les cours de physique des derniers mois, j'ai posé souvent des questions.	①	②	③	④	⑤	⑥
	23	Je me suis engagé(e) activement lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	24	Lors les activités de physique des derniers mois, j'ai trouvé difficile de comprendre les instructions pour utiliser les applications pour tablettes.	①	②	③	④	⑤	⑥
	25	J'ai participé activement aux cours de physique des derniers mois.	①	②	③	④	⑤	⑥
	26	Pendant les derniers mois, j'ai expliqué mes idées sur les sujets du cours de physique à mes camarades.	①	②	③	④	⑤	⑥
	27	Pendant les derniers mois, j'ai eu des difficultés à comprendre les sujets traités en physique.	①	②	③	④	⑤	⑥
	28	Pendant les derniers mois, j'ai souvent discuté avec des camarades sur la résolution des problèmes de physique.	①	②	③	④	⑤	⑥
	29	Le cours de physique des derniers mois a éveillé ma curiosité à propos des sujets traités.	①	②	③	④	⑤	⑥
	30	Lors du cours de physique des derniers mois, j'ai eu de la peine à comprendre les notions de physique des expériences.	①	②	③	④	⑤	⑥
	31	Les sujets traités dans le cours de physique des derniers mois sont utiles pour des situations de la vie quotidienne.	①	②	③	④	⑤	⑥
	32	Pendant les derniers mois, j'ai bien aimé résoudre des problèmes de physique.	①	②	③	④	⑤	⑥
	33	J'ai pu résoudre les problèmes de physique pendant les cours des derniers mois.	①	②	③	④	⑤	⑥
	34	Lors des expériences de physique des derniers mois, j'ai essayé de différencier les choses importantes de celles moins importantes.	①	②	③	④	⑤	⑥
	35	Les activités expérimentales du cours de physique des derniers mois étaient simples à effectuer.	①	②	③	④	⑤	⑥
	36	J'étais concentré(e) lors des expériences de physique des derniers mois.	①	②	③	④	⑤	⑥
	37	Les sujets traités dans le cours de physique des derniers mois sont utiles pour réfléchir à des situations en dehors de l'école.	①	②	③	④	⑤	⑥

		Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
	38	Lors des activités de physique des derniers mois, les applications pour tablettes étaient difficiles à utiliser.	①	②	③	④	⑤	⑥
	39	Je trouve fascinants les sujets traités au cours de physique des derniers mois .	①	②	③	④	⑤	⑥
	40	Lors des expériences de physique des derniers mois, j'ai eu un regard critique sur les idées testées.	①	②	③	④	⑤	⑥

Combien d'heures par semaine, en moyenne, as-tu travaillé avec un répétiteur de physique pendant les derniers mois?

▢ 0 ▢1-2 ▢3-4 ▢ 5 ou plus

ÉVALUATION DE LA MOTIVATION ACTUELLE DANS LES COURS DE PHYSIQUE

Réponses Anonymes	Date :

COMMENT AVEZ-VOUS TROUVE LES DERNIERS MOIS DU COURS DE PHYSIQUE ?

Avec ce questionnaire vous pouvez donner votre avis, concernant le cours de physique notamment **dans les six derniers mois**. Veuillez mettre une croix sur la colonne qui correspond le mieux à votre opinion.

	Avec cette affirmation, je suis…	**pas d'accord du tout**	**pas d'accord**	**plutôt pas d'accord**	**plutôt d'accord**	**d'accord**	**tout à fait d'accord**
1	Pendant le cours de physique des derniers mois, l'enseignant(e) a pris du temps pour nous aider quand nous avions des problèmes avec les tâches assignées.	①	②	③	④	⑤	⑥
2	Pendant le cours de physique des derniers mois, les explications de l'enseignant(e) nous ont aidés à mieux comprendre les sujets traités.	①	②	③	④	⑤	⑥
3	Pendant le cours de physique des derniers mois, l'enseignant semblait particulièrement engagé.	①	②	③	④	⑤	⑥
4	Pendant le cours de physique des derniers mois, l'enseignant(e) nous encourageait.	①	②	③	④	⑤	⑥
5	Pendant le cours de physique des derniers mois, l'enseignant(e) s'est déplacé(e) dans la classe pour répondre à nos questions.	①	②	③	④	⑤	⑥

AVIS IMPORTANT

Ce questionnaire a été créé en tant qu'évaluation de vos connaissances conceptuelles sur le programme de physique couvert pendant cet hiver. Suite aux conditions exceptionnelles survenues à cause de la pandémie de coronavirus, vous n'avez pas pu effectuer ce test en classe et une note sur ce travail ne pourra pas vous être attribuée.

Toutefois ce questionnaire complète le travail que vous avez effectué tout au long des six derniers mois. Ainsi, son passage est maintenu et se fera à distance par vidéoconférence sous la forme d'un exercice, avec le but de vous faire prendre connaissance de l'évolution de votre apprentissage depuis le début de l'année : un retour ciblé sera fait et l'enseignement sera adapté en fonction des vos réponses, qui doivent être les plus authentiques possible.

Il est ainsi important que, pendant le passage du test, vous puissiez respecter les mêmes consignes qu'en classe, soit

- lire attentivement toutes les questions et y répondre de manière réfléchie, suivant vos connaissances personnelles,

- travailler individuellement dans un lieu calme, sans interactions avec d'autres personnes ou avec votre matériel du cours (pas de messages personnels ou échanges pendant 45'),

- si vous avez des questions de compréhension de l'énoncé vous pouvez demander de l'aide à l'enseignant qui vous suit en vidéoconférence. On pourra reprendre et/ou répondre à toutes les questions de contenu en physique après la reddition du questionnaire.

Merci pour votre collaboration ☺

1. LEVENE'S TEST ok for all variables (p > 0.05) => equal variances.

RELATION TO REALITY

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)
Using summary.lm(model) we get the r-squared, which we just need to square-root to get r :
values: 0.1 < small r < 0.3 < medium r < 0.5 < large r
⇔ $0.01 < \text{small } r^2 < 0.09 < \text{medium } r^2 < 0.25 < \text{large } r^2$
Condition to be retained as covariate: p-value > 0.05

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_RR	TREATMENT	0.01722	2.77	0.09917	-
PRE_RR	TREATMENT	0.05911	7.346	0.007913	S
POST_RR	GENDER	0.01229	2.257	0.1361	-
POST_RR	USE_APP	0.005088	1.517	0.221	-
POST_RR	OS	0.05877	1.901	0.07792	-
POST_RR	MA_GRADE_POST	0.007807	1.795	0.1834	-
POST_RR	PY_GRADE_POST	-0.002536	0.7445	0.3903	-
POST_RR	FR_GRADE_POST	-0.0001638	0.9835	0.3237	-
POST_RR	MA_GRADE_PRE	0.00653	7.718	0.00653	-
POST_RR	PY_GRADE_PRE	0.007349	1.748	0.1892	-
POST_RR	FR_GRADE_PRE	-0.009087	0.09045	0.7642	-
POST_RR	SPATIAL_ABILITIES	-0.001483	0.8504	0.3586	-
POST_RR	PRE_RR+	0.2635	37.13	2.075e-08	L
POST_RR	PRE_IN	0.02363	3.444	0.06642	-
POST_RR	PRE_SC	-0.0021	0.7884	0.3767	-
POST_RR	PRE_CS+	0.03756	4.941	0.02848	S
POST_RR	PRE_CT	0.02366	3.448	0.06628	-
POST_RR	PRE_SCS	0.02616	3.713	0.05682	-
POST_RR	POST_CLS*	-0.001103	0.9361	0.3374	-
POST_RR	POST_CLE	0.002242	1.227	0.2706	-
POST_RR	POST_CAE+	0.06944	8.537	0.004303	S
POST_RR	POST_INV+	0.05957	7.398	0.007702	S
POST_RR	POST_TA**	-0.00999	0.001023	0.9745	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive r (increasing DV for increasing IV)

3. ANOVA WITH COVARIATE AND PREDICTOR: when adding a covariate we must be sure it is independent from the main predictor. For that we can do a one-way ANOVA with covariate~predictor

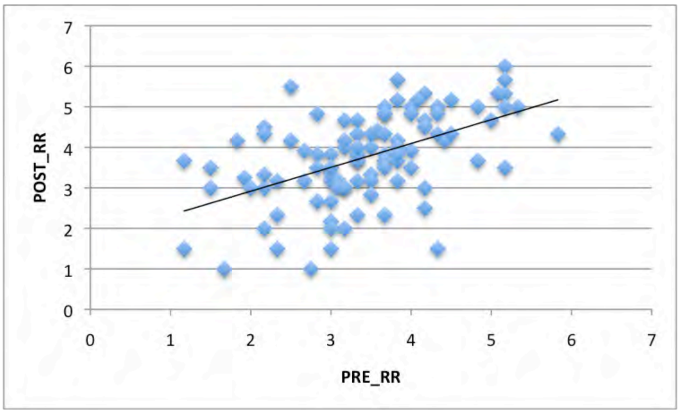
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_RR	TREATMENT (CG>TG)	0.05911	7.346	0.007913	S
PRE_CS	TREATMENT	0.02197	3.269	0.07362	-
POST_CAE	TREATMENT	0.005582	1.567	0.2136	-
POST_INV	TREATMENT	-0.006215	0.3762	0.541	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_RR

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.032	1	0.0389	0.8442
PRE_RR	25.881	1	31.2082	2.16e-07 ***
PRE_CS	0.614	1	0.7406	0.3916
POST_CAE	1.785	1	2.1526	0.1456
POST_INV	2.180	1	2.6292	0.1082
Residuals	79.613	96		

Only PRE_RR has an effect on POST_RR and tanking into account of this (subtracting the effect of PRE_RR) there is no effect of TREATMENT on POST_RR.



INTEREST

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_IN	TREATMENT	0.01579	2.62	0.1086	S
PRE_IN	TREATMENT	0.01203	2.23	0.1385	-
POST_IN	GENDER	-0.009962	0.003788	0.951	-
POST_IN	USE_APP	-0.009458	0.05372	0.8172	-
POST_IN	OS	-0.02227	0.6857	0.6838	-
POST_IN	MA_GRADE_POST	-0.006646	0.3332	0.5651	-
POST_IN	PY_GRADE_POST	-0.009225	0.07677	0.7823	-
POST_IN	FR_GRADE_POST	-0.009857	0.01421	0.9054	-
POST_IN	MA_GRADE_PRE	-0.00271	0.7271	0.3959	-
POST_IN	PY_GRADE_PRE	-0.009391	0.0603	0.8065	-
POST_IN	FR_GRADE_PRE	-0.00986	0.01385	0.9065	-
POST_IN	SPATIAL_ABILITIES	0.02031	3.093	0.08167	-
POST_IN	PRE_RR	-0.001973	0.8011	0.3729	-
POST_IN	PRE_IN+	0.08955	10.93	0.001312	S/M
POST_IN	PRE_SC	0.001841	1.186	0.2787	-
POST_IN	PRE_CS+	0.1951	25.47	2.014e-06	M
POST_IN	PRE_CT+	0.1267	15.66	0.0001421	M
POST_IN	PRE_SCS	-0.002481	0.75	0.3885	-
POST_IN	POST_CLS*	0.04487	3.725	0.05859	S
POST_IN	POST_CLE	0.02522	3.613	0.06021	S
POST_IN	POST_CAE+	0.2368	32.34	1.289e-07	M
POST_IN	POST_INV+	0.1585	20.02	2.03e-05	M
POST_IN	POST_TA**	0.0008477	1.086	0.2999	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

3. ANOVA WITH COVARIATE AND PREDICTOR

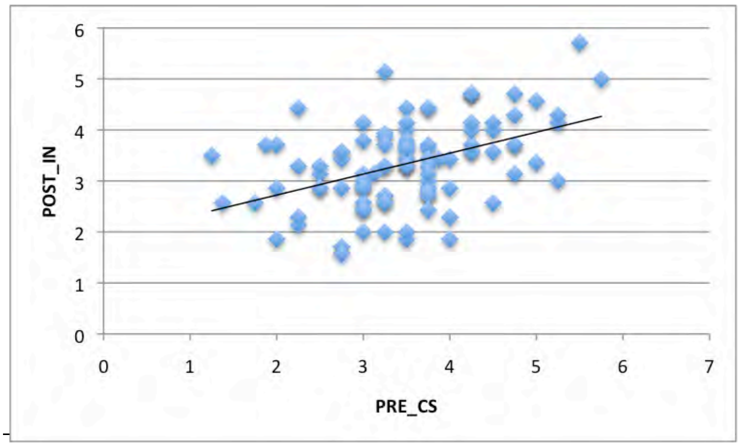
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_IN	TREATMENT	0.01203	2.23	0.1385	-
PRE_CS	TREATMENT	0.02197	3.269	0.07362	-
PRE_CT	TREATMENT	0.02819	3.93	0.05017	-
POST_CAE	TREATMENT	0.005582	1.567	0.2136	-
POST_INV	TREATMENT	-0.006215	0.3762	0.541	-

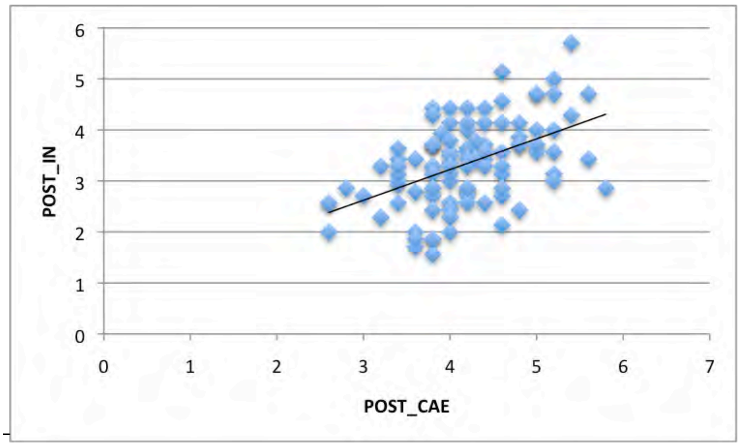
4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_IN

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.282	1	0.6092	0.437042
PRE_IN	0.135	1	0.2906	0.591070
PRE_CS	2.166	1	4.6798	0.033028 *
PRE_CT	0.008	1	0.0174	0.895386
POST_CAE	4.142	1	8.9505	0.003534 **
POST_INV	0.824	1	1.7804	0.185295
Residuals	43.967	95		

Conclusion: no effect of TREATMENT on POST_IN.





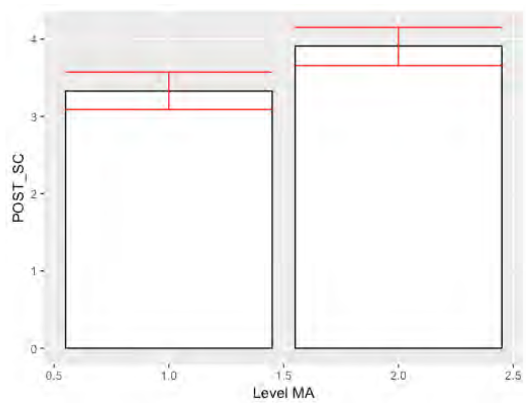
SELF CONCEPT

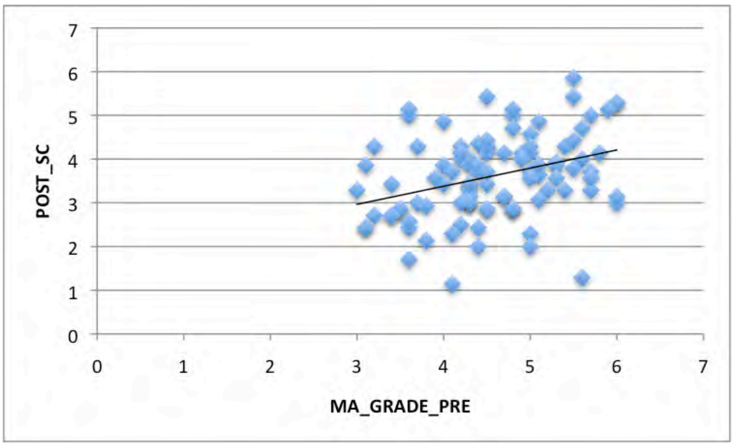
2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_SC	TREATMENT	0.01688	2.734	0.1014	-
PRE_SC	TREATMENT	-0.004289	0.5686	0.4526	-
POST_SC	GENDER°	0.06482	8.001	0.005649	S
POST_SC	USE_APP	-0.007639	0.2343	0.6294	-
POST_SC	OS	0.008777	1.128	0.3525	-
POST_SC	MA_GRADE_POST	0.08185	10	0.002069	S
POST_SC	PY_GRADE_POST	-0.009225	0.0767	0.7823	-
POST_SC	FR_GRADE_POST	-0.009857	0.01421	0.9054	-
POST_SC	MA_GRADE_PRE° +	0.1057	12.94	0.0005021	M
POST_SC	PY_GRADE_PRE	-0.009391	0.0603	0.8065	-
POST_SC	FR_GRADE_PRE	-0.00986	0.01385	0.9065	-
POST_SC	SPATIAL_ABILITIES	0.0006038	1.061	0.3055	-
POST_SC	PRE_RR	0.01545	2.585	0.111	-
POST_SC	PRE_IN	0.02398	3.482	0.06498	-
POST_SC	PRE_SC+	0.1301	16.1	0.0001161	M
POST_SC	PRE_CS+	0.1268	15.66	0.0001417	M
POST_SC	PRE_CT+	0.09596	11.72	0.0008973	M
POST_SC	PRE_SCS	0.002456	1.249	0.2665	-
POST_SC	POST_CLS*	-0.01611	0.08059	0.7775	-
POST_SC	POST_CLE+	0.2661	37.62	1.727e-08	L
POST_SC	POST_CAE+	0.07918	9.685	0.002422	S
POST_SC	POST_INV+	0.1547	19.49	2.566e-05	M
POST_SC	POST_TA**	-0.001822	0.8163	0.3684	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

° GENDER has an effect on SC (girls have a lower level of SC than boys). Same for MA_GRADE_PRE (better prior knowledge in math means higher SC in physics).





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
GENDER	TREATMENT	0.006438	1.654	0.2013	-
MA_GRADE_PRE	TREATMENT	0.07831	9.581	0.00255	S
PRE_SC	TREATMENT	0.01203	2.23	0.1385	-
PRE_CS	TREATMENT	0.02197	3.269	0.07362	-
PRE_CT	TREATMENT	0.02819	3.93	0.05017	-
POST_CLE	TREATMENT	0.08287	10.13	0.001948	S
POST_CAE	TREATMENT	0.005582	1.567	0.2136	-
POST_INV	TREATMENT	-0.006215	0.3762	0.541	-

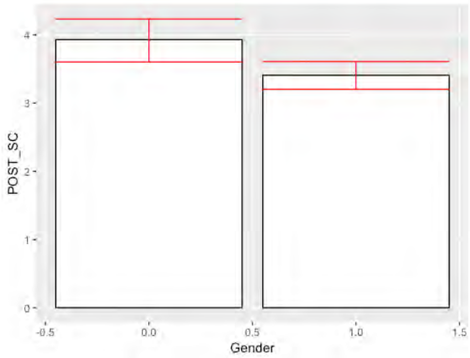
4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

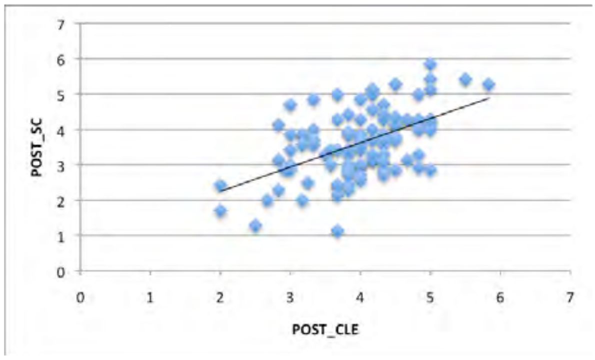
From what seen at point 2. (ONE WAY ANOVA), TREATMENT has not an impact on POST_SC.

Response: POST_SC

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.649	1	1.2571	0.26514
GENDER	3.016	1	5.8426	0.01764 *
LEVEL_MA	0.016	1	0.0319	0.85867
MA_GRADE_PRE	1.963	1	3.8029	0.05424 .
PRE_SC	0.264	1	0.5110	0.47656
PRE_CS	0.108	1	0.2091	0.64853
PRE_CT	0.982	1	1.9019	0.17124
POST_CLE	10.578	1	20.4921	1.808e-05 ***
POST_CAE	0.020	1	0.0383	0.84525
POST_INV	1.112	1	2.1539	0.14566
Residuals	46.974	91		

Conclusion: no effect of TREATMENT on SC_POST.





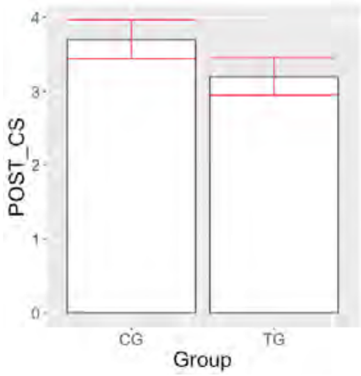
CURIOSITY STATE

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_CS	TREATMENT CG>TG	0.0585	7.275	0.008206	S
PRE_CS	TREATMENT	0.02197	3.269	0.07362	-
POST_CS	GENDER	-0.006416	0.3561	0.552	-
POST_CS	USE_APP	0.005282	1.536	0.2181	-
POST_CS	OS	-0.0336	0.5309	0.8091	-
POST_CS	MA_GRADE_POST	-0.00997	0.002984	0.9565	-
POST_CS	PY_GRADE_POST	0.007705	1.784	0.1847	-
POST_CS	FR_GRADE_POST	-0.007421	0.256	0.614	-
POST_CS	MA_GRADE_PRE	0.01334	2.366	0.1272	-
POST_CS	PY_GRADE_PRE	0.0004843	1.049	0.3082	-
POST_CS	FR_GRADE_PRE	-0.007956	0.2027	0.6535	-
POST_CS	SPATIAL_ABILITIES	0.02437	3.523	0.06344	-
POST_CS	PRE_RR+	0.05932	7.37	0.007815	S
POST_CS	PRE_IN+	0.154	19.39	2.68e-05	M
POST_CS	PRE_SC	0.02709	3.813	0.05366	-
POST_CS	PRE_CS+	0.3707	60.5	6.806e-12	L
POST_CS	PRE_CT+	0.2547	35.51	3.813e-08	L
POST_CS	PRE_SCS	0.02258	3.333	0.07088	-
POST_CS	POST_CLS*	-0.01751	0.00196	0.9648	-
POST_CS	POST_CLE	0.0245	3.537	0.06293	S
POST_CS	POST_CAE+	0.1182	14.54	0.0002377	M
POST_CS	POST_INV+	0.1325	16.43	0.0001002	M
POST_CS	POST_TA**	-0.001351	0.8637	0.3549	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

There is a possible effect of TREATMENT on POST_CS. Let's see if this effect remains after taking into account of covariates.



3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_RR	TREATMENT	0.05911	7.346	0.007913	S
PRE_IN	TREATMENT	0.01203	2.23	0.1385	-
PRE_CS	TREATMENT	0.02197	3.269	0.07362	-
PRE_CT	TREATMENT	0.02819	3.93	0.05017	-
POST_CAE	TREATMENT	0.005582	1.567	0.2136	-
POST_INV	TREATMENT	-0.006215	0.3762	0.541	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_CS

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.668	1	3.0711	0.0829549 .
PRE_RR	0.101	1	0.1850	0.6680582
PRE_IN	1.117	1	2.0567	0.1548522
PRE_CS	7.777	1	14.3186	0.0002715 ***
PRE_CT	0.553	1	1.0188	0.3154020
POST_CAE	0.115	1	0.2113	0.6468054
POST_INV	1.391	1	2.5604	0.1129263
Residuals	51.055	94		

Conclusion: there is no effect of TREATMENT on CS_POST.

LEARNING POST

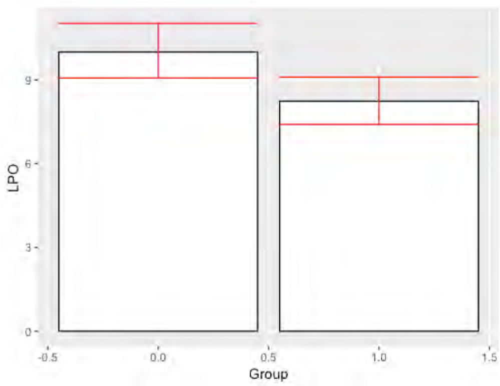
DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO	TREATMENT CG>TG	0.05336	6.693	0.01112	S
LPO	LPR+	0.2313	31.39	1.867e-07	M
LPO	GENDER M>F	0.0638	7.883	0.006	S
LPR	GENDER	0.04257	5.491	0.0211	S
LPO	USE_APP	-0.00736		> 0.05	-
LPR	USE_APP	-0.003368		> 0.05	-
LPO	MA_GRADE_PRE+	0.09918	12.12	0.0007408	M
LPO	PY_GRADE_PRE+	0.1367	16.99	7.762e-05	M
LPO	FR_GRADE_PRE+	0.07857	9.613	0.002511	S
LPO	SPATIAL_ABILITIES+	0.07145	8.772	0.003822	S
LPO	PRE_RR	0.003964		> 0.05	-
LPO	OS	0.02214	1.327	0.2464	-
LPO	PRE_IN	-0.009373		> 0.05	-
LPO	PRE_SC+	0.06812	8.383	0.004651	S
LPO	PRE_CS	0.004602		> 0.05	-
LPO	PRE_CT	0.01695	2.742	0.1009	-
LPO	PRE_SCS	-0.009965		> 0.05	-
LPO	POST_CLS*	0.003284		> 0.05	-
LPO	POST_CLE+	0.05646	7.043	0.009257	S
LPO	POST_CAE+	0.03056	4.184	0.04343	S
LPO	POST_INV+	0.1006	12.3	0.0006798	M
LPO	POST_TA**+	0.03087	4.217	0.04262	S

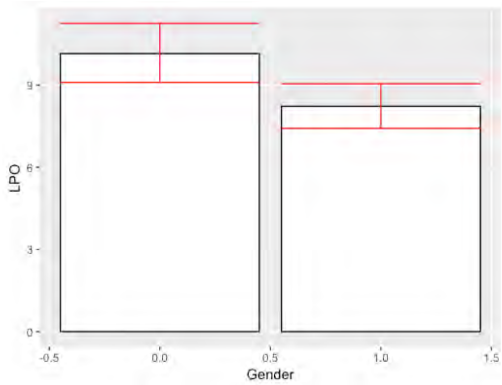
*1 to 57 DF (only TG); ** Average on all PY group used as individual valu;e
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

1) LPO is correlated with GENDER: boys have better results than girls.

2) LPO depends on variables that are correlated: LEVEL_MA, MA_GRADE and PY_GRADE, then we take as covariate only the one with the largest effect: LEVEL_MA.

3) LPO is correlated with PRE_SC (a better PRE_SC means better LPO)





3. ANOVA WITH COVARIATE AND PREDICTOR

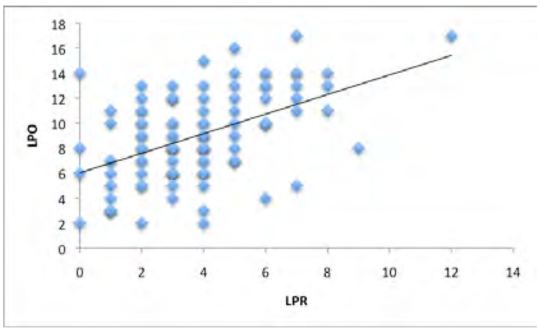
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR	TREATMENT	0.0183	2.882	0.09267	-
GENDER	TREATMENT	0.006438	1.654	0.2013	-
(MA_GRADE_PRE)	TREATMENT	0.07831	9.581	0.00255	S
(PY_GRADE_PRE)	TREATMENT	0.03672	4.851	0.02993	S
FR_GRADE_PRE	TREATMENT	-0.008298	0.1688	0.682	-
SPATIAL_ABILITIES	TREATMENT	-0.008205	0.1781	0.6739	-
PRE_SC	TREATMENT	0.01203	2.23	0.1385	-
POST_CLE	TREATMENT	0.08287	10.13	0.001948	S
POST_CAE	TREATMENT	0.005582	1.567	0.2136	-
POST_INV	TREATMENT	-0.006215	0.3762	0.541	-

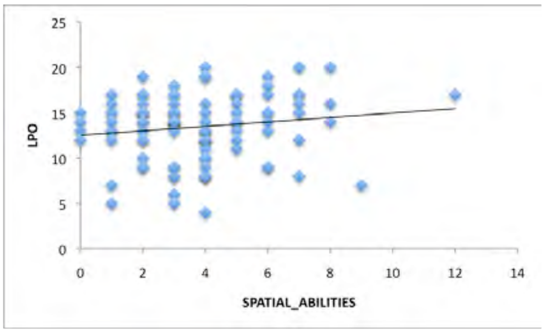
4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	19.79	1	2.8221	0.0964048 .
LPR	114.76	1	16.3649	0.0001094 ***
GENDER	28.41	1	4.0508	0.0471074 *
LEVEL_MA	38.22	1	5.4505	0.0217625 *
FR_GRADE_PRE	12.98	1	1.8512	0.1770078
SPATIAL_ABILITIES	32.31	1	4.6074	0.0344950 *
PRE_SC	5.72	1	0.8150	0.3690257
POST_CLE	0.42	1	0.0594	0.8079350
POST_CAE	9.18	1	1.3096	0.2554688
POST_INV	21.44	1	3.0577	0.0837293 .
Residuals	638.15	91		

Conclusion: no effect of TREATMENT on LPO.

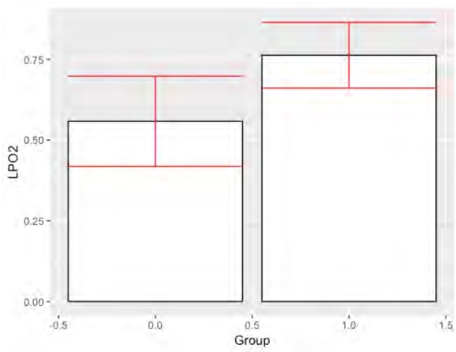


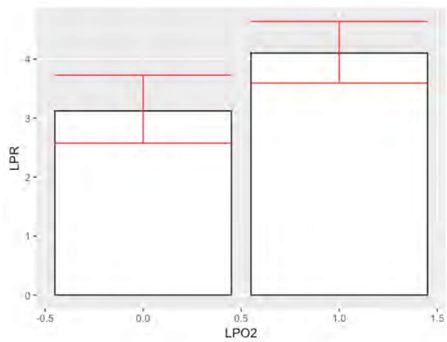


LEARNING POST 2

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO2	TREATMENT CG<TG	0.03709	4.891	0.02928	S
LPO2	LPR2+	0.1293	15.99	0.0001218	M
LPO2	LPR+	0.0352	4.685	0.0328	S
LPO2	GENDER	0.0189	2.946	0.08918	-
LPO2	USE_APP	0.01018	2.038	0.1565	-
LPO2	MA_GRADE_PRE	-0.005893		> 0.05	-
LPO2	PY_GRADE_PRE	-0.01		> 0.05	-
LPO2	FR_GRADE_PRE	-0.003263		> 0.05	-
LPO2	SPATIAL_ABILITIES	0.02424	3.51	0.06394	-
LPO2	PRE_RR	-0.0008835		> 0.05	-
LPO2	OS	-0.04729		> 0.05	-
LPO2	PRE_IN	-0.003677		> 0.05	-
LPO2	PRE_SC	0.0006674		> 0.05	-
LPO2	PRE_CS	-0.009069		> 0.05	-
LPO2	PRE_CT	-0.00979		> 0.05	-
LPO2	PRE_SCS	0.003725		> 0.05	-
LPO2	POST_CLS*	-0.006707		> 0.05	-
LPO2	POST_CLE	-0.002441		> 0.05	-
LPO2	POST_CAE+	0.03056	4.184	0.04343	S
LPO2	POST_INV	-0.009087		> 0.05	-
LPO2	POST_TA**	-0.0009357		> 0.05	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR	TREATMENT	0.0183	2.882	0.09267	-
LPR2	TREATMENT	-0.001244	0.8746	0.352	-
POST_CAE	TREATMENT	0.005582	1.567	0.2136	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO2

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.4874	1	8.2634	0.004982 **
LPR2	1.8885	1	10.4920	0.001647 **
LPR	0.0468	1	0.2598	0.611459
POST_CAE	0.0120	1	0.0665	0.796997
Residuals	17.2799	96		

There is an effect of TREATMENT on LPO2 in favor of the TG with $\eta_t^2 = 0.07$.

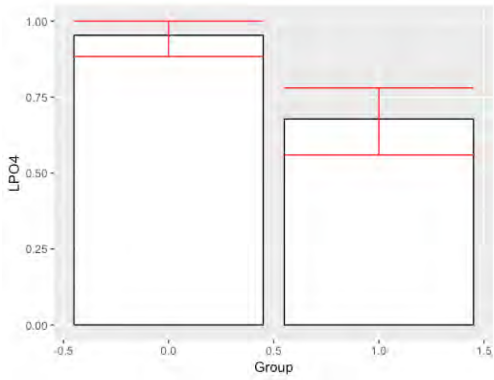
LEARNING POST 4

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO4	TREATMENT CG>TG	0.1044	12.77	0.0005445	M
LPO4	LPR	0.001335		> 0.05	-
LPO4	GENDER	-0.006199		> 0.05	-
LPO4	USE_APP	-0.009761		> 0.05	-
LPO4	MA_GRADE_PRE	0.01351	2.384	0.1258	-
LPO4	PY_GRADE_PRE+	0.03557	4.725	0.03209	S
LPO4	FR_GRADE_PRE	4.683e-05		> 0.05	-
LPO4	SPATIAL_ABILITIES	0.0006547		> 0.05	-
LPO4	PRE_RR	0.004644		> 0.05	-
LPO4	OS	-0.004181		> 0.05	-
LPO4	PRE_IN	-0.004988		> 0.05	-
LPO4	PRE_SC	-0.008356		> 0.05	-
LPO4	PRE_CS	-0.004401		> 0.05	-
LPO4	PRE_CT	-0.005367		> 0.05	-
LPO4	PRE_SCS	-0.009588		> 0.05	-
LPO4	POST_CLS*	-0.005174		> 0.05	-
LPO4	POST_CLE	-0.005074		> 0.05	-
LPO4	POST_CAE	0.007119		> 0.05	-
LPO4	POST_INV	-0.008363		> 0.05	-
LPO4	POST_TA**	0.01132	2.157	0.1451	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PY_GRADE_PRE	TREATMENT	0.03672	4.851	0.02993	S



4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO4

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.4786	1	10.1335	0.001946 **
PY_GRADE_PRE	0.3429	1	2.3501	0.128467
Residuals	14.4454	99		

There is an effect of TREATMENT on LPO4 in favor of GC, with $\eta_t^2 = 0.09$.

The effect remains when putting LPR as covariate (even if it has not an effect as IV in the one way ANOVA):

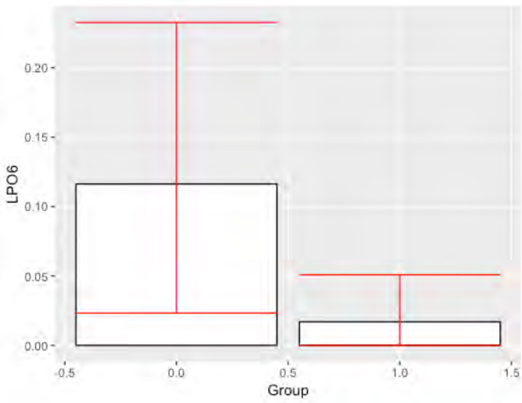
Response: LPO4

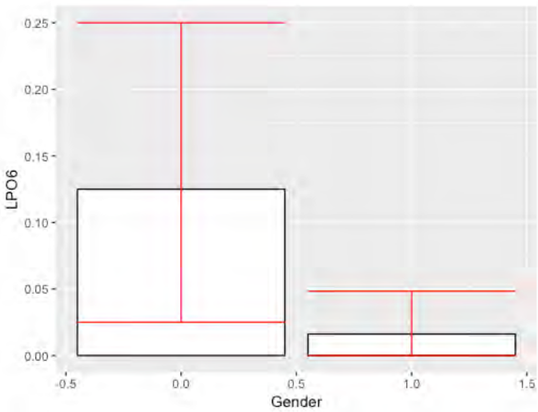
	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.4578	1	9.8902	0.0022 **
LPR	0.0005	1	0.0031	0.9558
PY_GRADE_PRE	0.3011	1	2.0430	0.1561
Residuals	14.4450	98		

LEARNING POST 6

DV (outcome)	DV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO6	TREATMENT	0.03389	4.543	0.0355	S
LPO6	LPR+	0.01567	2.608	0.01567	S
LPO6	GENDER	0.04154	5.378	0.02243	S
LPO6	USE_APP	-0.005037		> 0.05	-
LPO6	MA_GRADE_PRE	-5.098e-05		> 0.05	-
LPO6	PY_GRADE_PRE	0.02497	3.587	0.06113	-
LPO6	FR_GRADE_PRE	-0.0002837		> 0.05	-
LPO6	SPATIAL_ABILITIES+	0.04228	5.459	0.02146	S
LPO6	PRE_RR	0.01094	2.117	0.1488	-
LPO6	OS	0.00697		> 0.05	-
LPO6	PRE_IN	-0.009995		> 0.05	-
LPO6	PRE_SC	0.01467	2.504	0.1167	-
LPO6	PRE_CS	-0.009827		> 0.05	-
LPO6	PRE_CT	-0.008724		> 0.05	-
LPO6	PRE_SCS	-0.00738		> 0.05	-
LPO6	POST_CLS*	-0.006957		> 0.05	-
LPO6	POST_CLE	0.02439	3.525	0.06335	-
LPO6	POST_CAE	-0.00704		> 0.05	-
LPO6	POST_INV	0.007153		> 0.05	-
LPO6	POST_TA**	-0.009589		> 0.05	-

*1 to 57 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR	TREATMENT	0.0183	2.882	0.09267	-
GENDER	TREATMENT	0.006438	1.654	0.2013	-
SPATIAL_ABILITIES	TREATMENT	-0.008205	0.1781	0.6739	-

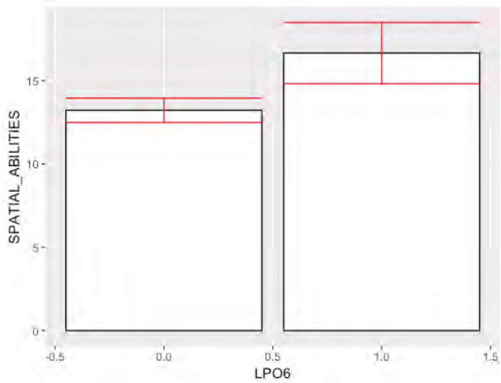
4. MAIN ANALYSIS

Response: LPO6

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.1753	1	3.5540	0.06242 .
LPR	0.0027	1	0.0542	0.81633
GENDER	0.1495	1	3.0311	0.08489 .
SPATIAL_ABILITIES	0.1968	1	3.9888	0.04863 *
Residuals	4.7356	96		

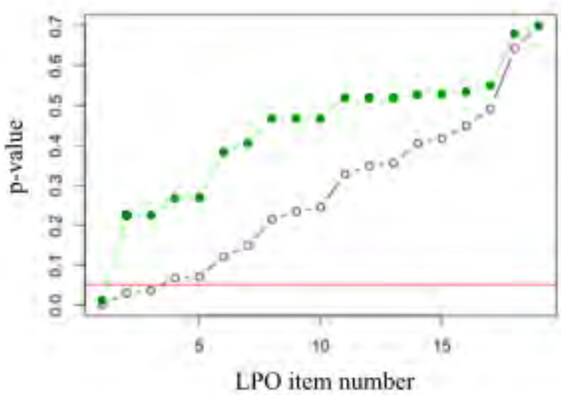
There is no effect of TREATMENT on LPO6.

Only spatial abilities has an effect on LPO6, the item testing the vector average acceleration in 2 dimensions.



ESTIMATION OF THE FALSE DISCOVERY RATE FOR INDIVIDUAL ITEMS RESULTS

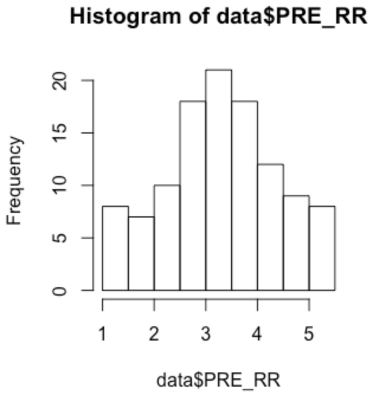
We carry out a *multiple significance testing* analysis, based on a step-down procedure on the set of the p-values obtained for each item of the post-test, in order to obtain a new set of adjusted p-values, which take into account the estimation of the false discovery rate (FDR) [Benjamini and Hochberg, 1995].

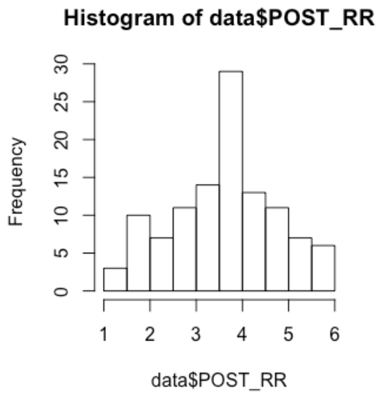


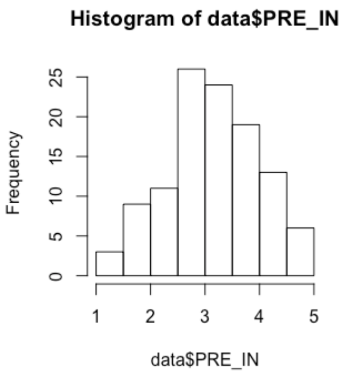
Outcome	IV/predictor	p-value	Effect	Adjusted p-value
LPO1	TREATMENT	0.45	-	> 0.05
LPO2	TREATMENT	0.030	✔	0.22
LPO3	TREATMENT	0.071	-	> 0.05
LPO4	TREATMENT	0.00054	✔	0.010
LPO5	TREATMENT	0.068	-	> 0.05
LPO6	TREATMENT	0.035	✔	0.22
LPO7	TREATMENT	0.70	-	> 0.05
LPO8	TREATMENT	0.23	-	> 0.05
LPO9	TREATMENT	0.15	-	> 0.05
LPO10	TREATMENT	0.25	-	> 0.05
LPO11	TREATMENT	0.21	-	> 0.05
LPO12	TREATMENT	0.40	-	> 0.05
LPO13	TREATMENT	0.36	-	> 0.05
LPO14	TREATMENT	0.64	-	> 0.05
LPO16	TREATMENT	0.49	-	> 0.05
LPO17	TREATMENT	0.35	-	> 0.05
LPO18	TREATMENT	0.12	-	> 0.05
LPR19	TREATMENT	0.33	-	> 0.05
LPO20	TREATMENT	0.42	-	> 0.05

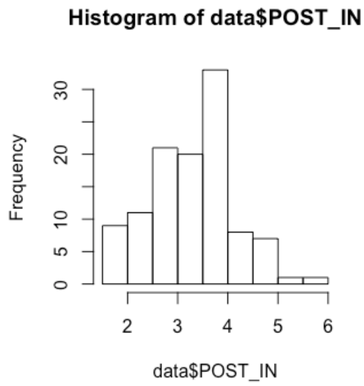
The only surviving effect is the one on LPO4.

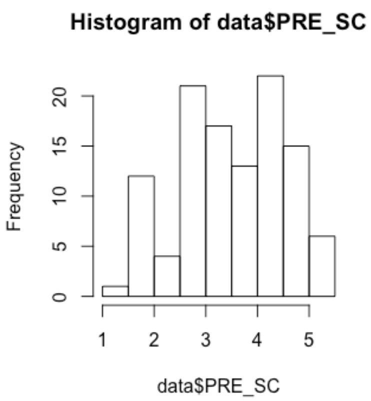
SOME HISTOGRAMS

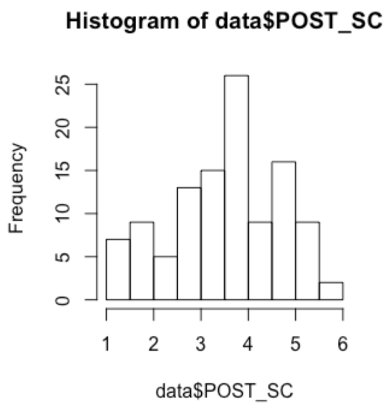


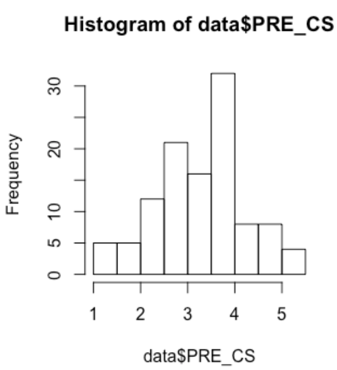


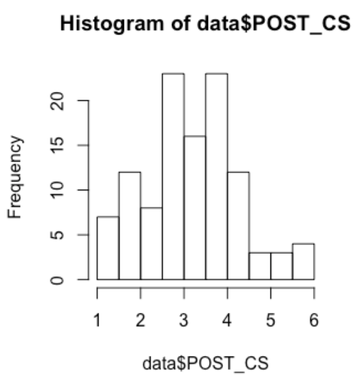


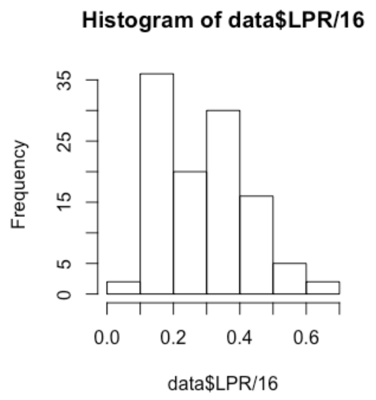


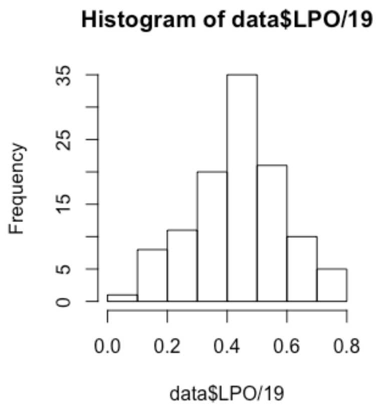












N.B. LPR has 16 items, LPO has 19 items.

Density histograms with normal curves of the same variables follow Gaussians

QQ plots roughly follow the diagonal

Descriptive statistics:

- Skewness is ok (|skew2SE| < 1) for all variables except for PRE_SCS where skew2SE = -1.54
- Kurtosis is ok (|kurt2SE| < 1) for all variables except for PRE_SCS where skew2SE = -1.54
- Shapiro-Wilk test is ok (normtest.p > 0.05) for all variables except for PRE_SC (p = 0.00898) PRE_SCS (p = 0.00044), POST_CLS (p = 0.042) and POST_CAE (p = 0.031); this means the distribution significantly deviates from normal.

1 .LEVENE'S TEST ok for all variables (Pr. > 0.05) => equal variances.

RELATION TO REALITY

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV). Using summary.lm(model) we get the r-squared, which we just need to square-root to get r : values: 0.1 < small r < 0.3 < medium r < 0.5 < large r
⇔ 0.01 < small r^2 < 0.09 < medium r^2 < 0.25 < large r^2
Condition to be retained as covariate: p-value < 0.05

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_RR	TREATMENT	-0.006713		0.6068	-
PRE_RR	TREATMENT	-0.001165		0.3525	-
POST_RR	GENDER	-0.007466		0.6681	-
POST_RR	USE_APP	-0.009134		0.221	-
POST_RR	OS	-0.03884		0.9705	-
POST_RR	MA_GRADE_POST	0.000504		0.3065	-
POST_RR	PY_GRADE_POST	0.02931	4.321	0.03999	S
POST_RR	FR_GRADE_POST	-0.009146		0.9562	-
POST_RR	MA_GRADE_PRE	-0.007573		0.6781	-
POST_RR	PY_GRADE_PRE	-0.002566		0.3985	-
POST_RR	FR_GRADE_PRE	-0.008768		0.8345	-
POST_RR	SPATIAL_ABILITIES	-0.0009705		0.3464	-
POST_RR	PRE_RR+	0.2038	29.15	3.954e-07	M
POST_RR	PRE_IN+	0.1278	17.11	6.959e-05	M
POST_RR	PRE_SC+	0.1037	13.72	0.0003343	M
POST_RR	PRE_CS+	0.1835	25.73	1.624e-06	M
POST_RR	PRE_CT+	0.04753	6.489	0.01225	S
POST_RR	PRE_SCS	-0.005513		0.53	-
POST_RR	POST_CLS*	-0.01194		0.5494	-
POST_RR	POST_CLE+	0.1389	18.74	3.332e-05	M
POST_RR	POST_CAE+	0.1259	16.84	7.859e-05	M
POST_RR	POST_INV+	0.06881	9.129	0.003136	S
POST_RR	POST_TA**	0.008555		0.1655	-
POST_RR	GROUP	0.03502	2.331	0.07841	-

*1 to 53 DF (only TG); ** Average on all PY group used as individual value;
+: The correlation refers to a positive r (increasing DV for increasing IV)

Conclusion: there is no effect of TREATMENT on relation to reality.

INTEREST

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_IN	TREATMENT	-0.0007246		0.3395	-
PRE_IN	TREATMENT	-0.001984		0.3784	-
POST_IN	GENDER	-0.008444		0.7792	-
POST_IN	USE_APP	0.01226	2.365	0.1269	-
POST_IN	OS	-0.01523		0.6471	-
POST_IN	MA_GRADE_POST	0.01564		0.1002	-
POST_IN	PY_GRADE_POST	-0.004367		0.4716	-
POST_IN	FR_GRADE_POST	0.008928		0.1611	-
POST_IN	MA_GRADE_PRE	0.009107		0.159	-
POST_IN	PY_GRADE_PRE	0.001994		0.2718	-
POST_IN	FR_GRADE_PRE	-0.008896		0.8626	-
POST_IN	SPATIAL_ABILITIES	-0.008606		0.7919	-
POST_IN	PRE_RR+	0.03161	4.591	0.03437	S
POST_IN	PRE_IN+	0.2439	36.48	2.182e-08	M/L
POST_IN	PRE_SC	0.02476	3.793	0.05403	-
POST_IN	PRE_CS+	0.1623	22.31	6.951e-06	M
POST_IN	PRE_CT+	0.07445	9.848	0.002187	S
POST_IN	PRE_SCS	-0.007722		0.6926	-
POST_IN	POST_CLS*	0.0517	3.944	0.05222	-
POST_IN	POST_CLE+	0.1449	19.64	2.24e-05	M
POST_IN	POST_CAE+	0.3514	60.59	4.325e-12	L
POST_IN	POST_INV+	0.3005	48.25	2.857e-10	L
POST_IN	POST_TA**+	0.09856	13.03	0.0004653	M
POST_IN	GROUP	0.118	15.72	0.0001315	M

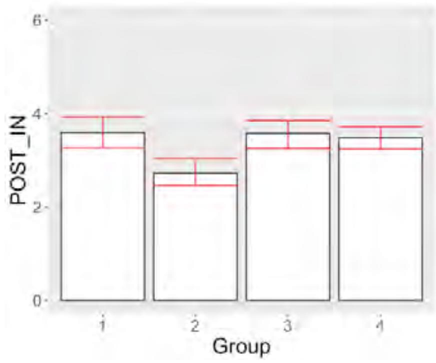
*1 to 53 DF (only TG); ** Average on all PY group used as individual value;
+: The correlation refers to a positive slope (increasing DV for increasing IV)

Conclusion: there is no effect of TREATMENT on interest; however there can be an effect of GROUP (of teacher, 1, 2, 3, 4).

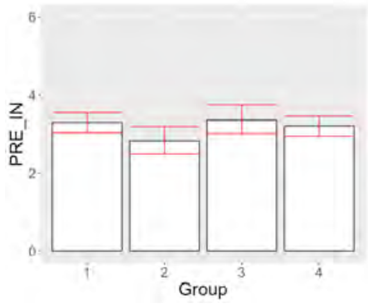
3. ANOVA WITH COVARIATE AND PREDICTOR: when adding a covariate we must be sure it is independent from the main predictor. For that we can do a one-way ANOVA with covariate ~ predictor.

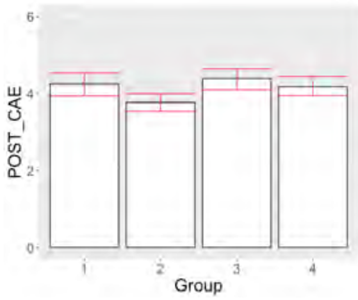
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_IN	GROUP	0.03186	2.207	0.09152	-
PRE_CS	GROUP	0.003882	1.143	0.3352	-
PRE_CT	GROUP	-0.01309	0.5264	0.6651	-
POST_CLE	GROUP	0.1295	6.454	0.0004663	M
POST_CAE	GROUP	0.06889	3.713	0.01381	S
(POST_TA)	GROUP	0.7691	123.1	2.2e-16	L
POST_INV	GROUP	-0.001	0.9634	0.4129	-

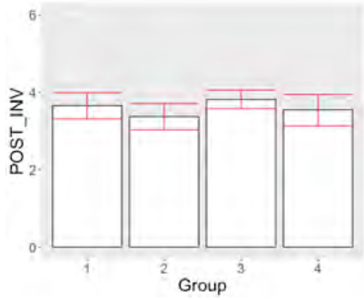
We do not consider POST_TA as a covariate because it can be considered as a variable too close to GROUP.



Group	Post interest (SD)
Tot	3,35(,86)
1	3,59(,94)
2	2,72(,77)
3	3,57(,83)
4	3,48(,66)







4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_IN

	Sum Sq	Df	F value	Pr(>F)
GROUP	3.496	3	3.304	0.02314*
PRE_IN	1.030	1	2.9244	0.0903192
PRE_CS	0.162	1	0.4588	0.4997312
PRE_CT	0.589	1	1.6708	0.1990998
POST_CLE	0.185	1	0.5252	0.4703151
POST_CAE	2.132	1	6.0517	0.0155908 *
POST_INV	5.054	1	14.3470	0.0002585 ***
Residuals	35.578	101		

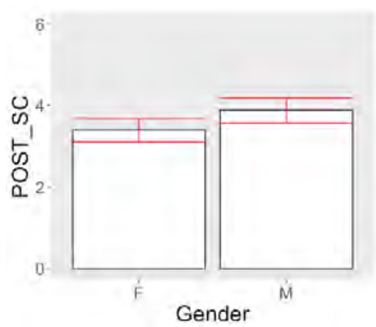
Conclusion: there is an effect of GROUP on POST_IN, with $\eta_t^2 = 0.04$.

SELF CONCEPT

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_SC	TREATMENT	-0.009085		0.9217	-
PRE_SC	TREATMENT	-0.007994		0.7216	-
POST_SC	GENDER°	0.03507	4.998	0.02742	S
POST_SC	USE_APP	-0.00734		0.6568	-
POST_SC	OS	0.03427	1.781	0.1231	-
POST_SC	MA_GRADE_POST +	0.04295	5.937	0.01645	S
POST_SC	PY_GRADE_POST+	0.293	46.58	5.168e-10	L
POST_SC	FR_GRADE_POST	-0.007903		0.7115	-
POST_SC	MA_GRADE_PRE	0.009701		0.1523	-
POST_SC	PY_GRADE_PRE+	0.04312	5.958	0.01627	S
POST_SC	FR_GRADE_PRE	-0.00857		0.7987	-
POST_SC	SPATIAL_ABILITIES+	0.03746	5.242	0.024	S
POST_SC	PRE_RR	-0.005229		0.5144	S
POST_SC	PRE_IN+	0.05144	6.965	0.00953	S
POST_SC	PRE_SC+	0.3875	70.58	1.826e-13	L
POST_SC	PRE_CS+	0.05501	7.403	0.007581	S
POST_SC	PRE_CT	0.01666	2.864	0.09347	-
POST_SC	PRE_SCS+	0.03151	4.579	0.03459	S
POST_SC	POST_CLS* +	0.0898	6.328	0.01495	S/M
POST_SC	POST_CLE+	0.5252	122.7	2.2e-16	XL
POST_SC	POST_CAE+	0.1801	25.17	2.058e-06	M
POST_SC	POST_INV+	0.09809	12.96	0.0004798	M
POST_SC	POST_TA**	0.09964	13.17	0.0004341	M
POST_SC	GROUP	0.0778	4.093	0.00857	S
PRE_SC	GROUP	0.04958	2.913	0.03776	S

*1 to 53 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV);
° GENDER has an effect on SC (girls have a lower level of SC than boys), which confirms a known result.



Conclusion: there is no effect of TREATMENT on self-concept; however there can be an effect of GROUP, as GROUP.

3. ANOVA WITH COVARIATE AND PREDICTOR with covariate ~ predictor

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
GENDER	GROUP	0.005115		0.3177	-
MA_GRADE_POST	GROUP	-0.021		0.8641	-
PY_GRADE_POST	GROUP	0.08871	4.569	0.00473	S
SPATIAL_ABILITIES	GROUP	0.006871		0.295	-
PRE_IN	GROUP	0.03186	2.207	0.09152	-
PRE_SC	GROUP	0.04958	2.913	0.03776	S
PRE_CS	GROUP	0.003882	1.143	0.3352	-
PRE_SCS	GROUP	-0.01515		0.7159	-
POST_CLS	GROUP	0.113		0.02776	M
POST_CLE	GROUP	0.1295	6.454	0.0004663	M
POST_CAE	GROUP	0.06889	3.713	0.01381	S
(TA)	GROUP	0.7691	123.1	2.2e-16	L
POST_INV	GROUP	-0.001	0.9634	0.4129	-

We do not consider POST_TA as a covariate, as previously.

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_SC

	Sum Sq	Df	F value	Pr(>F)
GROUP	2.0690	3	1.9253	0.141428
PRE_SC	3.3422	1	9.3301	0.004051 **
GENDER	2.4254	1	6.7709	0.013031 *
MA_GRADE_POST	1.3920	1	3.8858	0.055820 .
PY_GRADE_POST	3.0950	1	8.6401	0.005502 **
SPATIAL_ABILITIES	0.0621	1	0.1734	0.679396
PRE_IN	0.0386	1	0.1078	0.744363
PRE_CS	0.0269	1	0.0750	0.785656
PRE_SCS	0.1079	1	0.3013	0.586179
POST_CLS	0.0885	1	0.2470	0.621991
POST_CLE	1.9080	1	5.3265	0.026396 *
POST_CAE	0.9146	1	2.5532	0.118143
POST_INV	0.1864	1	0.5204	0.474957
Residuals	13.9703	39		

Conclusion: there is no effect of the GROUP on POST_SC, and there is an effect of GENDER on POST_SC, with a total η_t^2 = 0.03.

CURIOSITY STATE

2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_CS	TREATMENT	0.4232		0.4232	-
PRE_CS	TREATMENT	-0.005254		0.5158	-
POST_CS	GENDER	-0.004252		0.4664	-
POST_CS	USE_APP	0.003975		0.2329	-
POST_CS	OS	0.01573	0.6593	0.6551	-
POST_CS	MA_GRADE_POST	0.006529	1.723	0.1921	-
POST_CS	PY_GRADE_POST	-0.003586	0.6069	0.4376	-
POST_CS	FR_GRADE_POST	0.0009374		0.2959	-
POST_CS	MA_GRADE_PRE	0.0149	2.663	0.1056	-
POST_CS	PY_GRADE_PRE	-0.004719	0.4834	0.4884	-
POST_CS	FR_GRADE_PRE	-0.00375		0.4444	-
POST_CS	SPATIAL_ABILITIES	-0.009023		0.8739	-
POST_CS	PRE_RR+	0.06284	8.376	0.004593	S
POST_CS	PRE_IN+	0.2116	30.53	2.266e-07	M
POST_CS	PRE_SC+	0.0519	7.022	0.009249	S
POST_CS	PRE_CS+	0.3135	51.23	1.009e-10	L
POST_CS	PRE_CT+	0.09724	12.85	0.0005068	M
POST_CS	PRE_SCS	-0.00885		0.8518	-
POST_CS	POST_CLS*	0.03665	3.054	0.08632	-
POST_CS	POST_CLE	0.09249	12.21	0.0006879	M
POST_CS	POST_CAE+	0.2288	33.64	6.58e-08	M
POST_CS	POST_INV+	0.1777	24.78	2.425e-06	M
POST_CS	POST_TA**	0.007762	1.86	0.1754	-
POST_CS	GROUP	0.04865	2.875	0.03959	S
PRE_CS	GROUP	0.003882	1.143	0.3352	-
POST_CS	LPR	0.001934		0.2731	-
POST_CS	LPO	0.007484		0.179	-

*1 to 53 DF (only TG) ; ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

Conclusion: no effect of on POST_SC on curiosity as state, however there can be an effect of GROUP.

3. ANOVA WITH COVARIATE AND PREDICTOR with covariate ~ predictor

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_IN	GROUP	0.03186	2.207	0.09152	-
PRE_RR	GROUP	0.04494	2.725	0.0478	-
PRE_SC	GROUP	0.04958	2.913	0.03776	S
PRE_CS	GROUP	0.003882	1.143	0.3352	-
PRE_CT	GROUP	-0.01309	0.5264	0.6651	-
POST_CLE	GROUP	0.1295	6.454	0.0004663	M
POST_CAE	GROUP	0.06889	3.713	0.01381	S
POST_INV	GROUP	-0.001	0.9634	0.4129	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_CS

	Sum Sq	Df	F value	Pr(>F)
GROUP	1.400	3	0.7010	0.55365
PRE_IN	0.426	1	0.6402	0.42556
PRE_CS	12.383	1	18.6065	3.806e-05 ***
PRE_RR	0.033	1	0.0493	0.82467
PRE_SC	0.304	1	0.4571	0.50054
PRE_CT	0.886	1	1.3311	0.25138
POST_CLE	0.426	1	0.6402	0.42554
POST_CAE	3.046	1	4.5769	0.03486 *
POST_INV	2.766	1	4.1556	0.04416 *
Residuals	65.885	99		

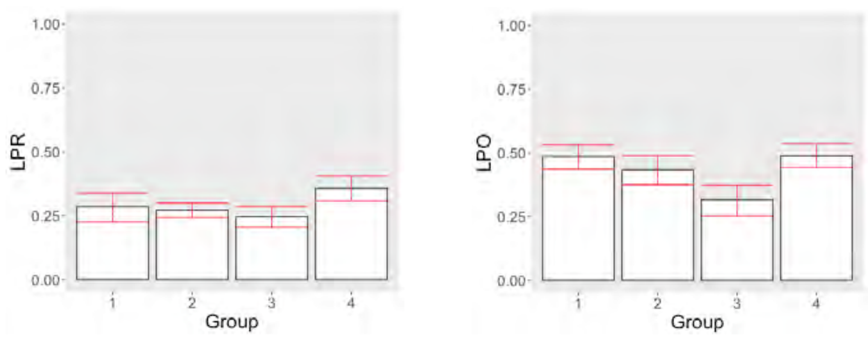
Conclusion: there is no effect of the GROUP on POST_CS.

LEARNING POST

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO	TREATMENT	-0.008934		0.8722	-
LPR	TREATMENT	0.01266	2.41	0.1235	-
MA_GRADE_POST	TREATMENT	0.03098	4.516	0.03583	S
PY_GRADE_POST	TREATMENT	0.01296	2.445	0.1208	-
MA_GRADE_PRE	TREATMENT	-0.003139	0.6558	0.4198	-
PY_GRADE_PRE	TREATMENT	-0.000396	0.9565	0.3302	-
LPO	LPR+	0.1465	19.88	2.013e-05	M
LPO	GENDER	-0.008964		0.8804	-
LPR	GENDER	-0.005038		0.5044	-
LPO	USE_APP	-0.0056		0.5349	-
LPR	USE_APP	-0.003304		0.4263	-
LPO	MA_GRADE_PRE+	0.03932	5.502	0.0208	S
LPO	PY_GRADE_PRE	0.00618		0.1971	-
LPO	FR_GRADE_PRE	-0.007464		0.6679	-
LPO	SPATIAL_ABILITIES+	0.06441	8.503	0.004311	S
LPO	PRE_RR	-0.009169		0.9811	-
LPO	OS	0.08331	2.999	0.0143	S/M
LPO	PRE_IN	-0.009052		0.9086	-
LPO	PRE_SC+	0.04668	6.386	0.01294	S
LPO	PRE_CS	0.008557		0.1655	-
LPO	PRE_CT	0.01166	2.298	0.1324	-
LPO	PRE_SCS	-0.003669		0.4411	-
LPO	POST_CLS*	0.01097		0.2116	-
LPO	POST_CLE+	0.04666	6.383	0.01295	S
LPO	POST_CAE+	-0.006085		0.5641	-
LPO	POST_INV+	0.0008373		0.2983	-
LPO	POST_TA**+	0.01564	2.747	0.1003	-
LPO	GROUP	0.167	8.353	4.853e-05	M
LPR	GROUP	0.08413	4.368	0.006078	S

*1 to 53 DF (only TG) ; ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

Conclusion: no effect of TREATMENT on LPO, however there can be an effect of TREATMENT on MA_GRADE_POST, and there can be an effect of GROUP on LPO.



3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR	GROUP	0.08413	4.368	0.006078	S
MA_GRADE_PRE	GROUP	0.02054	1.769	0.1575	-
SPATIAL_ABILITIES	GROUP	0.006871		0.295	-
OS	GROUP	-	-	> 0.05	-
PRE_SC	GROUP	0.04958	2.913	0.03776	S
POST_CLE	GROUP	0.1295	6.454	0.0004663	M

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO

	Sum Sq	Df	F value	Pr(>F)
GROUP	98.84	3	5.2066	0.002249 **
LPR	54.70	1	8.6444	0.004110 **
MA_GRADE_PRE	4.42	1	0.6978	0.405591
OS	76.45	5	2.4163	0.041431 *
SPATIAL_ABILITIES	17.69	1	2.7953	0.097798 .
PRE_SC	0.00	1	0.0000	0.997092
POST_CLE	2.79	1	0.4403	0.508577
Residuals	607.47	96		

Conclusion: there is an effect of the GROUP (teacher) on LPO, with $\eta_t^2 = 0.10$.

MA_GRADE

There is no effect of treatment on LPO, but the effect of TREATMENT could be on MA_GRADE_POST.

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
MA_GRADE_POST	TREATMENT	0.03098	4.516	0.03583	S
MA_GRADE_PRE	TREATMENT	-0.003139	0.6558	0.4198	-
MA_GRADE_POST	LPR	0.01243	2.385	0.1254	-
MA_GRADE_POST	GENDER	0.004231		0.2284	-
MA_GRADE_POST	USE_APP	-0.00452		0.4788	-
MA_GRADE_POST	MA_GRADE_PRE+	21.7	0.1584	9.064e-06	M
MA_GRADE_POST	PY_GRADE_PRE	0.1307	17.54	5.73e-05	M
MA_GRADE_POST	FR_GRADE_PRE	0.02904	4.29	0.04071	S
MA_GRADE_POST	SPATIAL_ABILITIES+	0.04974	6.705	0.01094	S
MA_GRADE_POST	PRE_RR	-0.002203		0.3858	-
MA_GRADE_POST	OS	-0.005549		0.4982	-
MA_GRADE_POST	PRE_IN	-0.003482		0.4334	-
MA_GRADE_POST	PRE_SC+	0.008529		0.1658	-
MA_GRADE_POST	PRE_CS	-0.008983		0.886	-
MA_GRADE_POST	PRE_CT	-0.008688		0.819	-
MA_GRADE_POST	PRE_SCS	-0.00914		0.9514	-
MA_GRADE_POST	POST_CLS*	-0.005037		0.3969	-
MA_GRADE_POST	POST_CLE	0.002731		0.2565	-
MA_GRADE_POST	POST_CAE	-0.001002		0.3476	-
MA_GRADE_POST	POST_INV+	0.07533	9.962	002067	S
MA_GRADE_POST	POST_TA**+	-0.005951		0.5557	-
MA_GRADE_POST	GROUP	-0.021		0.8641	-

*1 to 53 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

3. ANOVA WITH COVARIATE AND PREDICTOR: when adding a covariate we must be sure it is independent from the main predictor. For that we can do a one-way ANOVA with covariate ~ predictor

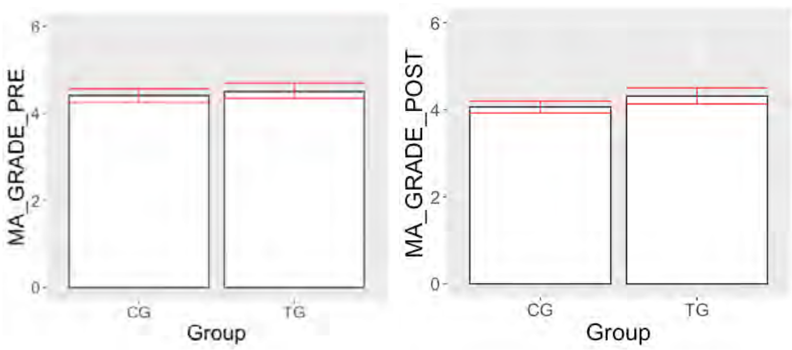
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
MA_GRADE_PRE	TREATMENT	-0.003139		0.4198	-
PY_GRADE_PRE	TREATMENT	-0.0003958		0.3302	-
FR_GRADE_PRE	TREATMENT	-0.008317		0.7613	-
SPATIAL_ABILITIES	TREATMENT	0.0009647		0.2955	-
LPR	TREATMENT	0.01266		0.1235	-
POST_INV	TREATMENT	-0.007859		0.7068	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: MA_GRADE_POST

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.8468	1	2.9367	0.08962 .
LPR	0.1635	1	0.5671	0.45316
FR_GRADE_PRE	0.0264	1	0.0916	0.76280
MA_GRADE_PRE	1.8315	1	6.3517	0.01328 *
PY_GRADE_PRE	0.6938	1	2.4060	0.12397
SPATIAL_ABILITIES	0.5641	1	1.9563	0.16495
POST_INV	3.0472	1	10.5680	0.00156 **
Residuals	29.4112	102		

Conclusion: there is the possibility (p above the threshold) of a small effect of TREATMENT on MA_GRADE_POST in favor of the TG with $\eta_t^2 = 0.020$.

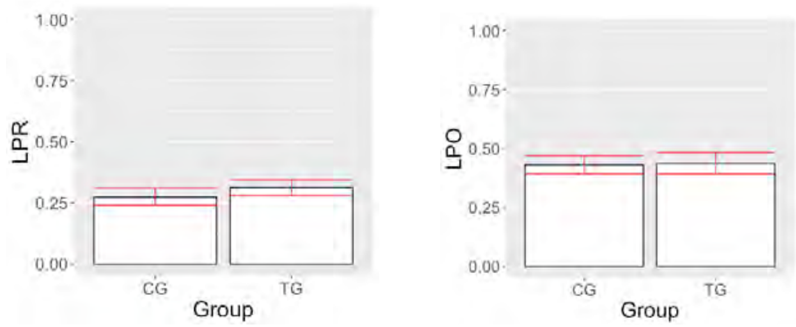


INDIVIDUALS ITEMS LPO

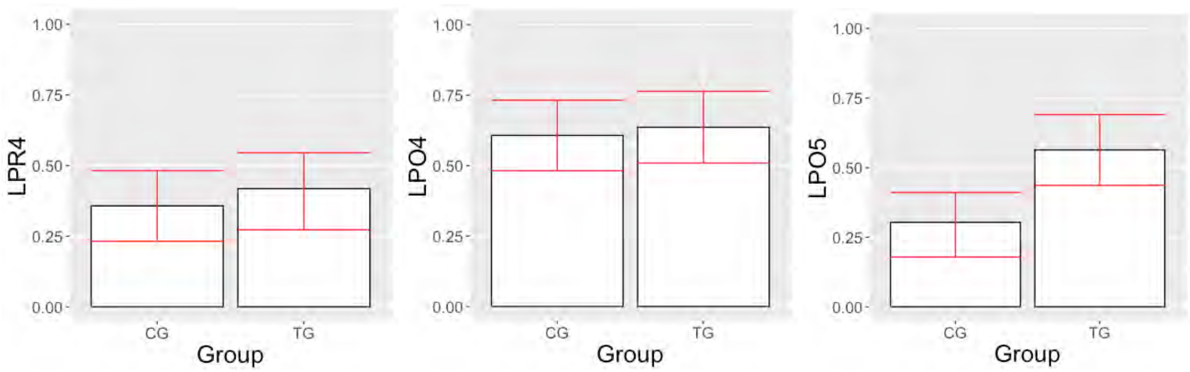
DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO1 (LPR1)	TREATMENT	-0.009091		0.9246	-
LPO2 (LPR2)	TREATMENT	-0.009132		0.946	-
LPO3 (LPR3)	TREATMENT	-0.006356		0.5817	-
LPO4 (LPR4)	TREATMENT	-0.008259		0.7536	-
LPO5	TREATMENT	0.06034	8.064	0.005388	S
LPO6 (LPR5)	TREATMENT	-0.006162		0.569	-
LPO7 (LPR6)	TREATMENT	-0.005204		0.5131	-
LPO8 (LPR7)	TREATMENT	-0.002606		0.3999	-
LPO9	TREATMENT	0.002574		0.2597	-
LPO10	TREATMENT	-0.009063		0.9128	-
LPO11 (LPR8)	TREATMENT	-0.008919		0.8685	-
LPO12 (LPR9)	TREATMENT	-0.007046		0.6322	-
LPO13 (LPR10)	TREATMENT	-0.001724		0.3699	-
LPO14 (LPR11)	TREATMENT	-0.00717		0.6423	-
LPO15 (LPR12)	TREATMENT	-0.008893		0.8618	-
LPO16 (LPR13)	TREATMENT	-0.007034		0.6312	-
LPO17 (LPR14)	TREATMENT	0.04322	5.969	0.01616	S
LPR14	TREATMENT	-0.009102		0.9298	-
LPO18 (LPR15)	TREATMENT	-0.005137		0.5096	-
LPO19 (LPR16)	TREATMENT	-0.007338		0.6566	-

There can be an effect of TREATMENT on LPO5 and on LPO17.

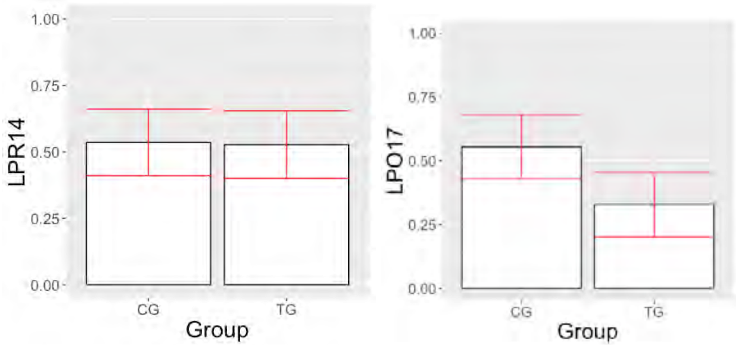
Whole test: PRE and POST



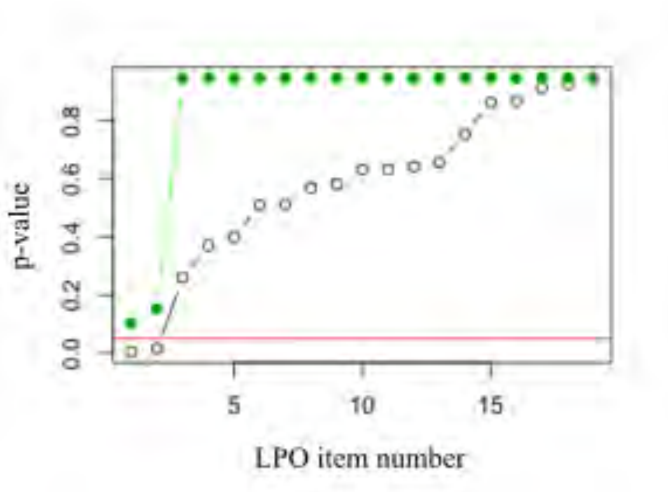
LPO5 is related and complementary to LPO4, and LPO4 was also in the pretest (LPR4):



Item 17 of learning post-test: PRE (LPR14) and POST (LPO17)



For the individual items effect, we perform a multiple testing analysis in order to control the false positive effect [Benjamini and Hochberg, 1995]. In the graph below we can observe, for each of the 19 items (Index = LPO1, LPO2, …, LPO19), the standard previously calculated p-values (p_standard, black circles) and the corrected p-values (p_BH, green circles). The p values are in ascending order and the red line is the threshold of significance of an effect ($p < 0.05$).



LPO5 and LPO17 standard p-values are respectively 0.005 and 0,016. However their corrected values are 0,11 and 0,16 so they cannot be considered as significant. We perform the ANCOVA analysis for those two items, although we know that with the more stringent conditions there is not a significant effect. However, we carry out the following steps of the ANCOVA, with the aim to see if the effect would be significant.

LEARNING POST 5

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO5	TREATMENT: CG<TG	0.06034	8.064	0.005388	S
LPO5	LPR4+	0.03191	4.626	0.0337	S
LPO5	LPR+	0.05939	7.945	0.005727	S
LPO5	GROUP	0.05691	3.212	0.0259	S
LPO5	GENDER	0.03486	4.973	0.02779	S
LPO5	USE_APP	-0.0007307		0.3397	-
LPO5	MA_GRADE_PRE+	0.03401	4.873	0.02938	S
LPO5	PY_GRADE_PRE	-0.006222		0.5729	-
LPO5	FR_GRADE_PRE	0.01057		0.1431	-
LPO5	SPATIAL_ABILITIES	0.000464		0.3077	-
LPO5	PRE_RR	-0.003211		0.4226	
LPO5	OS	0.06472	2.522	0.03374	S
LPO5	PRE_IN	-0.003227		0.4232	
LPO5	PRE_SC	0.01824	3.044	0.08385	-
LPO5	PRE_CS	0.003957		0.2332	-
LPO5	PRE_CT	-0.006739		0.6087	-
LPO5	PRE_SCS	-0.006053		0.5621	-
LPO5	POST_CLS*	0.02997		0.1083	-
LPO5	POST_CLE	-0.003972		0.454	-
LPO5	POST_CAE+	0.02666	4.013	0.04764	S
LPO5	POST_INV	-0.006909		0.6215	-
LPO5	POST_TA**	-0.008956		0.8784	-

*1 to 53 DF (only TG); ** Average on all PY group used as individual value;
+ : The correlation refers to a positive slope (increasing DV for increasing IV)

3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR	TREATMENT	0.01266	2.41	0.1235	-
LPR4	TREATMENT	-0.005214		0.5136	-
GENDER	TREATMENT	-0.006947		0.6244	-
POST_CAE	TREATMENT	0.004188		0.2291	-
MA_GRADE_PRE	TREATMENT	-0.003139		0.4198	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME
Response: LPO5

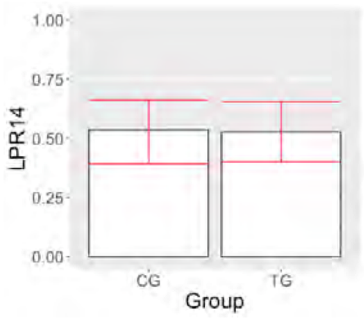
	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.5637	1	3.0362	0.08466 .
LPR4	0.1933	1	1.0413	0.31011
LPR	0.3288	1	1.7709	0.18646
POST_CAE	0.1060	1	0.5711	0.45169
MA_GRADE_PRE	0.0721	1	0.3881	0.53477
OS	1.9339	5	2.0831	0.07419 .
GENDER	1.2289	1	6.6189	0.01164 *
GROUP	1.5193	3	2.7277	0.04833 *
Residuals	17.6384	95		

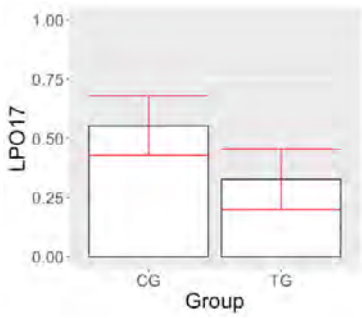
There is no effect of TREATMENT on LPO5.

LEARNING POST 17

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO17	TREATMENT - CG>TG	0.04322	5.969	0.01616	S
LPO17	LPR	-0.00523		0.5145	-
LPO17	LPR14+	0.02358	3.656	0.05848	S
LPO17	GROUP	-0.004986		0.4866	-
LPO17	GENDER	0.001099		0.292	-
LPO17	USE_APP	0.008997		0.8901	-
LPO17	MA_GRADE_PRE	0.001625		0.2799	-
LPO17	PY_GRADE_PRE	0.01821		0.08406	-
LPO17	FR_GRADE_PRE	-0.006264		0.5756	-
LPO17	SPATIAL_ABILITIES	-0.00745		0.6605	-
LPO17	PRE_RR	-0.006772		0.6111	-
LPO17	OS	0.03249		0.1321	-
LPO17	PRE_IN	0.001764		0.2769	-
LPO17	PRE_SC	0.004024		0.232	-
LPO17	PRE_CS	-0.003486		0.4336	-
LPO17	PRE_CT	-0.009167		0.978	-
LPO17	PRE_SCS	-0.0008316		0.3426	-
LPO17	POST_CLS*	0.02118		0.1468	-
LPO17	POST_CLE	-0.003319		0.4269	-
LPO17	POST_CAE	0.02267	3.551	0.06216	-
LPO17	POST_INV	-0.003916		0.4515	-
LPO17	POST_TA**	-0.008746		0.83	-

*1 to 53 DF (only TG); ** Average on all PY group used as individual value;
+: The correlation refers to a positive slope (increasing DV for increasing IV)





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PY_GRADE_PRE	TREATMENT	-0.0003958		0.3302	-
LPR14	TREATMENT	-0.009102		0.9298	-
POST_CAE	TREATMENT	0.004188		0.2291	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO17

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.0625	1	4.6739	0.03287 *
LPR14	0.6834	1	3.0062	0.08585 .
POST_CAE	0.3766	1	1.6567	0.20085
PY_GRADE_PRE	0.5697	1	2.5062	0.11638
Residuals	24.0974	106		

The effect would be small ($\eta_t^2 = 0.04$), and is not significant if we take into account the previous multiple testing analysis [Benjamini and Hochberg, 1995].

GROUP 1

Descriptive statistics:

- Skewness is ok (|skew2SE| < 1) for all variables except for PRE_CAE where skew2SE = -1.05
- Kurtosis is ok (|kurt2SE| < 1) for all variables.
- Shapiro-Wilk test is ok (normtest.p > 0.05) for all variables except for PRE_SCS (p = 0.0020) and for POST_CAE (p = 0.0387); this means the distribution significantly deviates from normal.

1. LEVENE'S TEST ok for all variables (Pr. > 0.05) => equal variances.

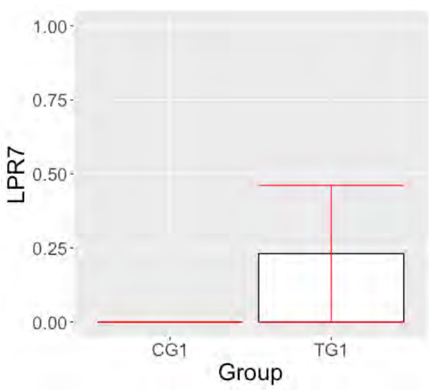
2. ONE-WAY ANOVA: one categorical predictor (IV) and one numerical outcome (DV)
Using summary.lm(model) we get the r-squared, which we just need to square-root to get r :
⇔ $0.01 < \text{small } r^2 < 0.09 < \text{medium } r^2 < 0.25 < \text{large } r^2$
Condition to be retained as covariate: p-value < 0.05

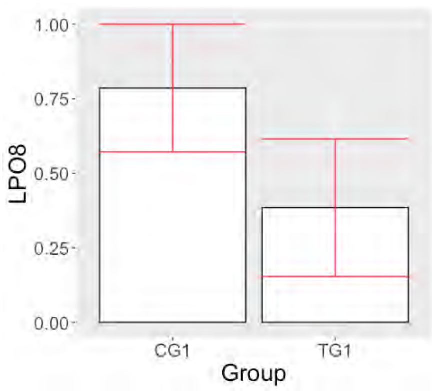
DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_RR	TREATMENT	-0.002582		0.3433	-
POST_IN	TREATMENT	0.0358		0.1732	-
POST_CS	TREATMENT	0.01792		0.236	-
POST_SC	TREATMENT	-0.01298		0.4218	-
MA_GRADE_POST	TREATMENT	-0.0335		0.6952	-
PY_GRADE_POST	TREATMENT	-0.03149		0.6536	-
FR_GRADE_POST	TREATMENT	-0.03754		0.8095	-
LPO	TREATMENT	-0.02003		0.4906	-
LPO1 (LPR1)	TREATMENT	-0.03916		0.8881	-
LPO2 (LPR2)	TREATMENT	0.01224		0.2611	-
LPO3 (LPR3)	TREATMENT	-0.0394		0.9052	-
LPO4 (LPR4)	TREATMENT	-0.01388		0.4298	-
LPO5	TREATMENT	-0.02744		0.5853	-
LPO6 (LPR5)	TREATMENT	0.01588		0.2447	-
LPO7 (LPR6)	TREATMENT	0.08481	3.409	0.0767	-
LPO8 (LPR7)	TREATMENT TG1<CG1	0.133	4.989	0.03469	M
LPO9	TREATMENT	0.05605	2.544	0.1233	-
LPO10	TREATMENT	0.0287	1.768	0.1956	-
LPO11 (LPR8)	TREATMENT	0.01224		0.2611	-
LPO12 (LPR9)	TREATMENT	-0.026		0.5644	-
LPO13 (LPR10)	TREATMENT	-0.03371		0.6999	-
LPO14 (LPR11)	TREATMENT	-0.003705		0.3508	-
LPO15 (LPR12)	TREATMENT	0.08071	3.283	0.08204	-
LPO16 (LPR13)	TREATMENT	0.07701	3.169	0.08719	-
LPO17 (LPR14)	TREATMENT	-0.02744		0.5853	-
LPO18 (LPR15)	TREATMENT TG1<CG1	0.1	3.889	0.05977	-
LPO19 (LPR16)	TREATMENT	-0.03975		0.939	-

LEARNING POST 8 – Group 1

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO8	TREATMENT TG1<CG1	0.133	4.989	0.03469	M
LPO8	LPR7	-0.03705		0.7918	-
LPO8	LPR	-0.0354		0.7418	-
LPO8	GENDER	-0.0381		0.8321	-
LPO8	USE_APP	-0.02696		0.5782	-
LPO8	MA_GRADE_PRE	-0.0278		0.5907	-
LPO8	PY_GRADE_PRE+	0.08421	3.391	0.07746	-
LPO8	FR_GRADE_PRE	-0.03327		0.6899	-
LPO8	SPATIAL_ABILITIES+	0.3442	14.65	0.0007709	L
LPO8	PRE_RR	-0.01736		0.4627	-
LPO8	OS	-0.006656		0.461	-
LPO8	PRE_IN	0.01941		0.2299	-
LPO8	PRE_SC+	0.1017	3.944	0.0581	-
LPO8	PRE_CS	-0.03949		0.9123	-
LPO8	PRE_CT	0.05976	2.652	0.1159	-
LPO8	PRE_SCS	-0.03069		0.6387	-
LPO8	POST_CLS*	-0.06518		0.6164	-
LPO8	POST_CLE	0.04062		0.1597	-
LPO8	POST_CAE	-0.03129		0.6498	-
LPO8	POST_INV	0.02867		0.1957	-

*1 to 11 DF (only TG); +: The correlation refer to a positive slope (increasing DV for increasing IV)





3. ANOVA WITH COVARIATE AND PREDICTOR: when adding a covariate we must be sure it is independent from the main predictor. For that we can do a one-way ANOVA with covariate ~ predictor

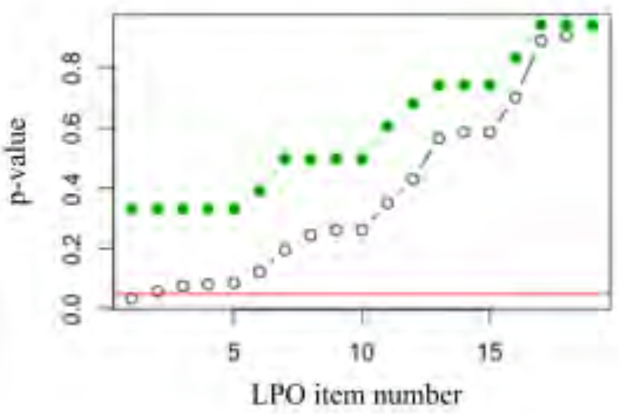
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_SC	TREATMENT	-0.03989		0.9592	-
SPATIAL_ABILITIES	TREATMENT	-0.03968		0.931	-
PY_GRADE_PRE	TREATMENT	-0.01344		0.4259	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO8

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.04214	1	8.0575	0.009559 **
PY_GRADE_PRE	0.00733	1	0.0566	0.814077
SPATIAL_ABILITIES	1.53808	1	11.8920	0.002290 **
PRE_SC	0.23196	1	1.7934	0.194182
Residuals	2.84543	22		

There can be an effect of TREATMENT on LPO8 (= LPR7) in favor of CG1 with $\eta_t^2 = 0.16$. However for the individual item effect, we performed a multiple testing analysis in order to control the false positive effect [Benjamini and Hochberg, 1995].



We observe that LPO8 standard p-value is 0.03, then below the threshold 0,05 is the only one that could be significant. However its corrected value is 0.33 (the corresponding green circle) so it cannot be considered as significant. Conclusion: here is a large "false" positive effect of GROUP on LPO8 in favor of CG1. This effect is not present up to the multiple testing analysis.

GROUP 2

Descriptive statistics:

- Skewness is ok (|skew2SE| < 1) for all variables except POST_IN (skew2SE = -1.17)
- Kurtosis is ok (|kurt2SE| < 1) for all variables.
- Shapiro-Wilk test is ok (normtest.p > 0.05) for all variables except for POST_IN (p = 0.016) and for PRE_SCS (p = 0.023). The distribution deviates from normal.

1. LEVENE'S TEST ok for all variables (Pr. > 0.05) => equal variances.

2. ONE-WAY ANOVA

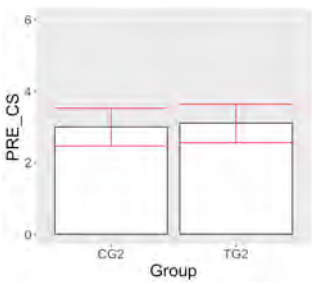
DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_RR	TREATMENT	-0.03642		0.7304	-
POST_IN	TREATMENT	-0.001831		0.3384	-
POST_CS	TREATMENT TG2>CG2	0.1	3.778	0.06375	-
POST_SC	TREATMENT	0.001186		0.3204	-
MA_GRADE_POST	TREATMENT	0.02334		0.2184	-
PY_GRADE_POST	TREATMENT	-0.02823		0.5807	-
FR_GRADE_POST	TREATMENT	-0.01439		0.4297	-
LPO	TREATMENT	-0.03803		0.7743	-
LPO1 (LPR1)	TREATMENT	-0.01687		0.4517	-
LPO2 (LPR2)	TREATMENT	-0.02772		0.5735	-
LPO3 (LPR3)	TREATMENT	-0.03268		0.6518	-
LPO4 (LPR4)	TREATMENT	0.008109		0.2833	-
LPO5	TREATMENT	0.05754		0.125	-
LPO6 (LPR5)	TREATMENT	0.02175		0.2243	-
LPO7 (LPR6)	TREATMENT	-0.01687		0.4517	-
LPO8 (LPR7)	TREATMENT	-0.03779		0.7672	-
LPO9	TREATMENT	-0.03999		0.8456	-
LPO10	TREATMENT	0.1095	4.074	0.05485	-
LPO11 (LPR8)	TREATMENT	0.08542	3.335	0.08029	-
LPO12 (LPR9)	TREATMENT	-0.03443		0.6857	-
LPO13 (LPR10)	TREATMENT	-0.04115		0.914	-
LPO14 (LPR11)	TREATMENT	-0.01221		0.4115	-
LPO15 (LPR12)	TREATMENT	-0.007564		0.3764	-
LPO16 (LPR13)	TREATMENT	-0.03779		0.7672	-
LPO17 (LPR14)	TREATMENT TG2<CG2	0.3552	14.77	0.000783	L
LPO18 (LPR15)	TREATMENT	0.05754		0.125	-
LPO19 (LPR16)	TREATMENT	-0.03999		0.8456	-

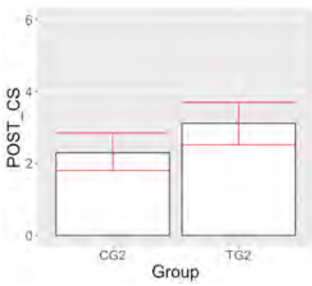
There is possible effect of TREATMENT on POST_CS and on LPO17 (= LPR14).

POST_CS – Group 2

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_CS	TREATMENT TG2>CG2	0.1	3.778	0.06375	-
POST_CS	LPR	-0.03648		0.732	-
POST_CS	GENDER	0.06535		0.1104	-
POST_CS	USE_APP	-0.00462		0.3562	-
POST_CS	MA_GRADE_PRE	-0.04089		0.8945	-
POST_CS	PY_GRADE_PRE	0.0234		0.2182	-
POST_CS	FR_GRADE_PRE	-0.04088		0.8939	-
POST_CS	SPATIAL_ABILITIES	-0.03303		0.6582	-
POST_CS	PRE_RR	-0.03613		0.7234	-
POST_CS	OS	0.05887		0.2369	-
POST_CS	PRE_IN	0.07203	2.94	0.09928	-
POST_CS	PRE_SC	-0.04103		0.9045	-
POST_CS	PRE_CS+	0.2234	8.193	0.008586	M
POST_CS	PRE_CT	-0.00789		0.3787	-
POST_CS	PRE_SCS	-0.03151		0.6313	-
POST_CS	POST_CLS*	-0.06842		0.6896	-
POST_CS	POST_CLE	-0.01523		0.437	-
POST_CS	POST_CAE	-0.00138		0.3356	-
POST_CS	POST_INV	0.1038		0.06001	-

*1 to 12 DF (only TG); +: The correlation refers to a positive slope





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_CS	TREATMENT	-0.03799		0.7731	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: POST_CS

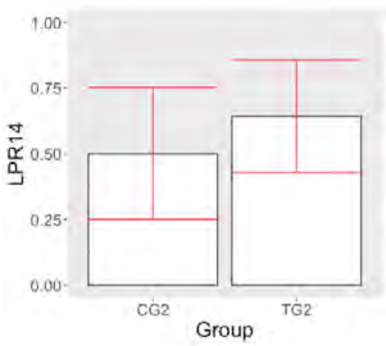
	Sum Sq	Df	F value	Pr(>F)
TREATMENT	3.6503	1	4.2037	0.051902 .
PRE_CS	7.4047	1	8.5273	0.007702 **
Residuals	19.9720	23		

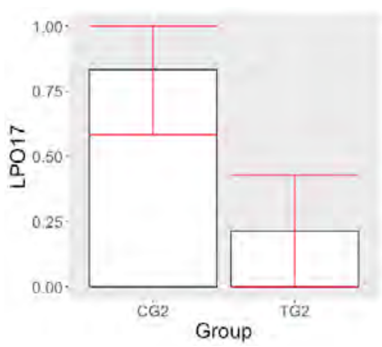
There is no effect of TREATMENT on POST_CS.

LEARNING POST 17 – Group 2

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO17	TREATMENT CG2>TG2	0.3552	14.77	0.0007826	L
LPO17	LPR	0.0397		0.1667	-
LPO17	LPR15	-0.03535		0.7054	-
LPO17	GENDER	0.2604	9.8	0.004542	L
LPO17	USE_APP	-0.04052		0.8722	-
LPO17	MA_GRADE_PRE	-0.03298		0.6574	-
LPO17	PY_GRADE_PRE+	0.1506	5.434	0.02848	M
LPO17	FR_GRADE_PRE	-0.02792		0.5763	-
LPO17	SPATIAL_ABILITIES	-0.02696		0.5632	-
LPO17	PRE_RR	-0.0387		0.7958	-
LPO17	OS	0.2053	3.153	0.04521	S
LPO17	PRE_IN	-0.02062		0.4885	-
LPO17	PRE_SC	0.01581		0.2481	-
LPO17	PRE_CS	-0.0414		0.938	-
LPO17	PRE_CT	-0.02982		0.6041	-
LPO17	PRE_SCS+	0.1927	6.968	0.01435	M
LPO17	POST_CLS*	0.1305	2.951	0.1115	-
LPO17	POST_CLE	0.01912		0.2345	-
LPO17	POST_CAE+	0.1271	4.639	0.0415	M
LPO17	POST_INV	-0.01431		0.429	-

*1 to 12 DF (only TG); +: The correlation refers to a positive slope





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
GENDER	TREATMENT	0.05754		0.125	-
PY_GRADE_PRE	TREATMENT	-0.03166		0.6339	-
OS	TREATMENT	-	-	-	-
PRE_SCS	TREATMENT	-0.002671		0.3436	-
POST_CAE	TREATMENT	0.08642	3.365	0.07903	-

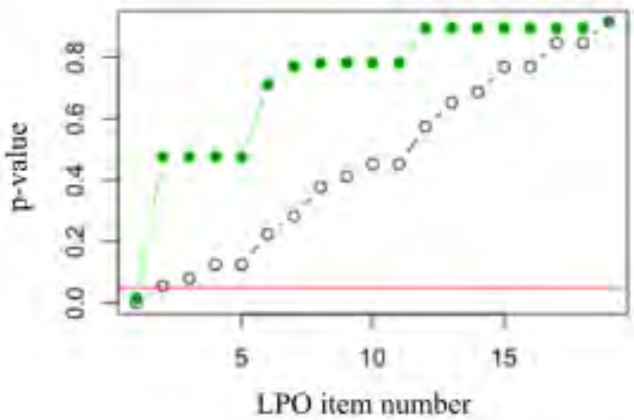
4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO17

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.65749	1	6.2503	0.022305 *
PY_GRADE_PRE	0.91121	1	8.6622	0.008695 **
OS	0.12483	3	0.3955	0.757761
PRE_SCS	0.51797	1	4.9240	0.039578 *
POST_CAE	0.30578	1	2.9068	0.105403
Residuals	1.89348	18		

There can be an effect of TREATMENT on LPO17 in favor of CG2, with $\eta_t^2 = 0.10$.

For the individual item effect, we perform a multiple testing analysis in order to control the false positive effect [Benjamini and Hochberg, 1995]. We can see that the effect on LPO17 remains significant.



GROUP 3

Descriptive statistics:

- Skewness is |skew2SE| < 1 for all variables except for PRE_CAE where skew is 2SE = -1.35
- Kurtosis is |kurt2SE| < 1 for all variables except for PRE_CAE where kurt2SE = 1.17
- Shapiro-Wilk test is ok (normtest.p > 0.05) for all variables except for POST_CAE (p = 0.0096); this means the distribution significantly deviates from normal.

1. LEVENE'S TEST ok for all variables (Pr. > 0.05) => equal variances.

2. ONE-WAY ANOVA

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_RR	TREATMENT	-	-	> 0.05	-
POST_IN	TREATMENT (TG3<CG3)	0.1866	6.963	0.01412	M
POST_CS	TREATMENT	-	-	> 0.05	-
POST_SC	TREATMENT	-	-	> 0.05	-
MA_GRADE_POST	TREATMENT	-	-	> 0.05	-
PY_GRADE_POST	TREATMENT (TG3>CG3)	0.2025	7.603	0.01073	M
FR_GRADE_POST	TREATMENT	-	-	> 0.05	-
LPO	TREATMENT	-	-	0.9012	-
LPO1 (LPR1)	TREATMENT	-	-	0.5342	-
LPO2 (LPR2)	TREATMENT	-	-	0.09119	-
LPO3 (LPR3)	TREATMENT	-	-	0.9586	-
LPO4 (LPR4)	TREATMENT	-	-	0.3508	-
LPO5	TREATMENT	-	-	0.1233	-
LPO6 (LPR5)	TREATMENT	-	-	0.4298	-
LPO7 (LPR6)	TREATMENT	-	-	0.9219	-
LPO8 (LPR7)	TREATMENT	-	-	0.9052	-
LPO9	TREATMENT	-	-	0.2447	-
LPO10	TREATMENT	0.02936	1.786	0.02936	S
LPO11 (LPR8)	TREATMENT (TG3>CG3)	0.2172	8.213	0.008314	M
LPO12 (LPR9)	TREATMENT	-	-	0.8696	-
LPO13* (LPR10)	TREATMENT	NaN	NaN	NA	-
LPO14 (LPR11)	TREATMENT	-	-	0.8881	-
LPO15 (LPR12)	TREATMENT	-	-	0.6999	-
LPO16 (LPR13)	TREATMENT	-	-	0.4298	-
LPO17 (LPR14)	TREATMENT	-	-	0.3508	-
LPO18 (LPR15)	TREATMENT	-	-	0.5342	-
LPO19 (LPR16)	TREATMENT	-	-	0.6999	-

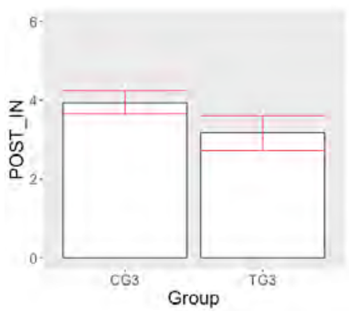
*All the pupils of group 3 gave the wrong answer for LPO13

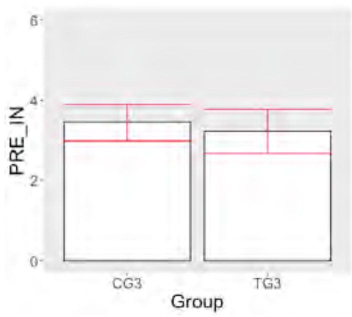
Conclusion: possible effect of TREATMENT on POST_IN, PY_GRADE_POST and LPO11 (= LPR8)

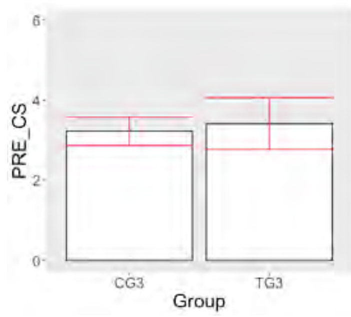
POST_IN – Group 3

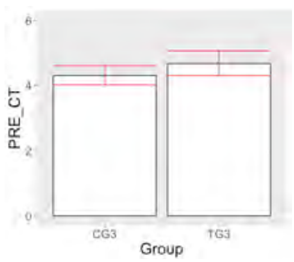
DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_IN	TREATMENT CG3>TG3	0.1866	6.963	0.01412	M
POST_IN	LPR	-	-	> 0.05	-
POST_IN	GENDER	-	-	> 0.05	-
POST_IN	USE_APP	-	-	> 0.05	-
POST_IN	LEVEL_MA	-	-	> 0.05	-
POST_IN	MA_GRADE_PRE	-	-	> 0.05	-
POST_IN	PY_GRADE_PRE	-	-	> 0.05	-
POST_IN	FR_GRADE_PRE	-	-	> 0.05	-
POST_IN	SPATIAL_ABILITIES	-	-	> 0.05	-
POST_IN	PRE_RR	-	-	> 0.05	-
POST_IN	OS	-	-	> 0.05	-
POST_IN	PRE_IN+	0.2851	11.37	0.002431	M
POST_IN	PRE_SC	-	-	> 0.05	-
POST_IN	PRE_CS-	0.1169	4.443	0.04524	M
POST_IN	PRE_CT-	0.191	7.137	0.01309	M
POST_IN	PRE_SCS	-	-	> 0.05	-
POST_IN	POST_CLS*	-	-	> 0.05	-
POST_IN	POST_CLE-	0.1114	4.258	0.04958	M
POST_IN	POST_CAE+	0.2141	8.083	0.008774	M
POST_IN	POST_INV+	0.4756	24.58	4.161e-05	L

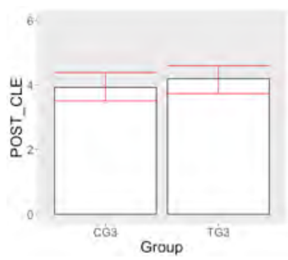
*1 to 11 DF (only TG); +: The correlation refers to a positive slope

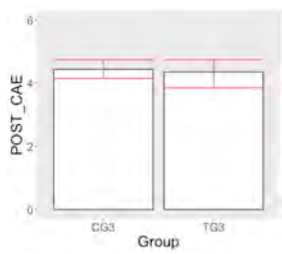


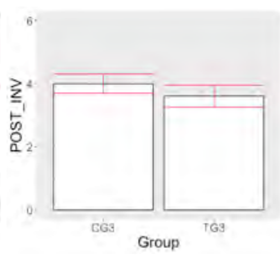












3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_CS	TREATMENT	-	-	> 0.05	-
PRE_IN	TREATMENT	-	-	> 0.05	-
PRE_CT	TREATMENT	-	-	> 0.05	-
POST_CLE	TREATMENT	-	-	> 0.05	-
POST_CAE	TREATMENT	-	-	> 0.05	-
POST_INV	TREATMENT	-	-	> 0.05	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR + COVARIATE AND OUTCOME

Response: POST_IN

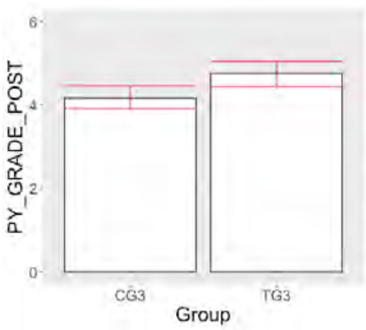
	Sum Sq	Df	F value	Pr(>F)
TREATMENT	2.0931	1	9.5396	0.006046 **
PRE_IN	0.4025	1	1.8344	0.191499
PRE_CS	0.1391	1	0.6341	0.435683
PRE_CT	1.5703	1	7.1570	0.014966 *
POST_CLE	0.0007	1	0.0031	0.956276
POST_CAE	0.3446	1	1.5708	0.225300
POST_INV	0.4112	1	1.8741	0.186975
Residuals	4.1688	19		

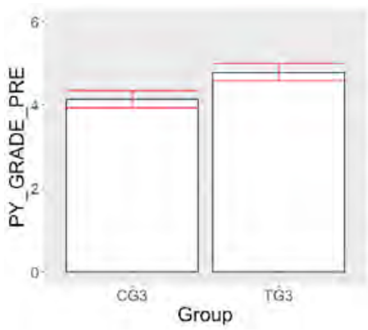
There is an effect of TREATMENT on POST_IN, and it is in favor of CG3 with $\eta_t^2 = 0.12$.

PY_GRADE_POST – Group 3

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
PY_GRADE_POST	TREATMENT CG3<TG3	0.2025	7.603	0.01073	M
PY_GRADE_POST	LPR	-	-	> 0.05	-
PY_GRADE_POST	GENDER	-	-	> 0.05	-
PY_GRADE_POST	USE_APP	0.1507	5.612	0.02587	M
PY_GRADE_POST	LEVEL_MA	0.2819	11.2	0.002584	L
PY_GRADE_POST	MA_GRADE_PRE	0.2799	11.11	0.00268	L
PY_GRADE_POST	PY_GRADE_PRE	0.2598	10.12	0.003884	L
PY_GRADE_POST	FR_GRADE_PRE	-	-	> 0.05	-
PY_GRADE_POST	SPATIAL_ABILITIES	-	-	> 0.05	-
PY_GRADE_POST	PRE_RR	0.266	10.42	0.003469	L
PY_GRADE_POST	OS	0.3277	4.168	0.0116	L
PY_GRADE_POST	PRE_IN-	0.2289	8.718	0.006763	M
PY_GRADE_POST	PRE_SC	0.2045	7.683	0.01037	M
PY_GRADE_POST	PRE_CS	0.15	4.377	0.04674	M
PY_GRADE_POST	PRE_CT	0.15	5.588	0.02617	M
PY_GRADE_POST	PRE_SCS	-	-	> 0.05	-
PY_GRADE_POST	POST_CLS*	-	-	> 0.05	-
PY_GRADE_POST	POST_CLE	0.1796	6.691	0.0159	M
PY_GRADE_POST	POST_CAE	-	-	> 0.05	-
PY_GRADE_POST	POST_INV	-	-	> 0.05	-

*1 to 11 DF (only TG)





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_IN	TREATMENT	-	-	> 0.05	-
PRE_SC	TREATMENT	-	-	> 0.05	-
PRE_CS	TREATMENT	-	-	> 0.05	-
PRE_CT	TREATMENT	-	-	> 0.05	-
PRE_RR	TREATMENT	-	-	> 0.05	-
USE_APP	TREATMENT	0.1604	5.969	0.02196	M
MA_GRADE_PRE	TREATMENT	0.1538	5.725	0.02456	M
PY_GRADE_PRE	TREATMENT	0.3473	14.83	0.0007251	L
LEVEL_MA	TREATMENT	0.2145	8.102	0.008706	M
POST_CLE	TREATMENT	-	-	> 0.05	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: PY_GRADE_POST

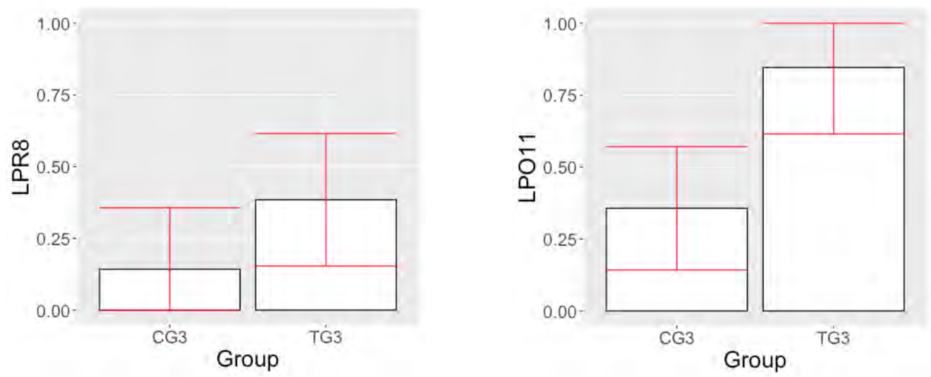
	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.46024	1	2.6859	0.12204
PY_GRADE_PRE	0.02220	1	0.1295	0.72392
MA_GRADE_PRE	0.32938	1	1.9222	0.18588
LEVEL_MA	0.10033	1	0.5855	0.45604
USE_APP	0.02914	1	0.1701	0.68589
POST_CLE	0.52429	1	3.0597	0.10068
PRE_IN	0.82288	1	4.8023	0.04462 *
PRE_SC	0.04293	1	0.2505	0.62398
PRE_CS	0.09587	1	0.5595	0.46602
PRE_CT	0.00000	1	0.0000	0.99802
PRE_RR	0.00508	1	0.0296	0.86566
Residuals	2.57031	15		

There is no effect of TREATMENT on PY_GRADE_POST for the group 3.

LEARNING POST 11 - group 3

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO11 (LPR8)	TREATMENT	0.2172	8.213	0.008314	M
LPO11	LPR7	-	-	> 0.05	-
LPO11	LPR8	-	-	> 0.05	-
LPO11	LPR	-	-	> 0.05	-
LPO11	GENDER	-	-	> 0.05	-
LPO11	USE_APP	-	-	> 0.05	-
LPO11	LEVEL_MA	-	-	> 0.05	-
LPO11	MA_GRADE_PRE	-	-	> 0.05	-
LPO11	PY_GRADE_PRE	-	-	> 0.05	-
LPO11	FR_GRADE_PRE	-	-	> 0.05	-
LPO11	SPATIAL_ABILITIES	-	-	> 0.05	-
LPO11	PRE_RR	-	-	> 0.05	-
LPO11	OS	-	-	> 0.05	-
LPO11	PRE_IN	0.1201	4.548	0.04296	M
LPO11	PRE_SC	-	-	> 0.05	-
LPO11	PRE_CS	-	-	> 0.05	-
LPO11	PRE_CT	-	-	> 0.05	-
LPO11	PRE_SCS	-	-	> 0.05	-
LPO11	POST_CLS*	-	-	> 0.05	-
LPO11	POST_CLE	-	-	> 0.05	-
LPO11	POST_CAE	-	-	> 0.05	-
LPO11	POST_INV	-	-	> 0.05	-

*1 to 11 DF (only TG)



3. ANOVA WITH COVARIATE AND PREDICTOR

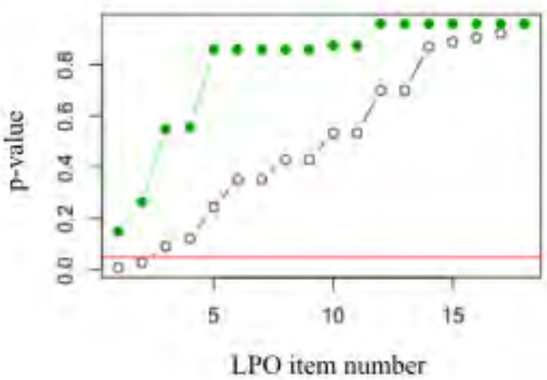
COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
PRE_IN	TREATMENT	-	-	-	-

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO11

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.3451	1	7.7411	0.01035 *
PRE_IN	0.7365	1	4.2384	0.05053 .
Residuals	4.1701	24		

There can be an effect of TREATMENT on LPO11 in favor of TG3, with $\eta_t^2 = 0.21$. However, this effect is not present up to the multiple testing analysis [Benjamini and Hochberg, 1995]. Indeed, LPO10 and LPO11 standard p-values are below the threshold 0,05 and could be considered as significant. However, the corrected values for those two items are respectively above 0.05, and then they cannot be considered as significant, as shown in the figure below.



GROUP 4

Descriptive statistics:

- Skewness is ok (|skew2SE| < 1) for all variables.
- Kurtosis is ok (|kurt2SE| < 1) for all variables.
- Shapiro-Wilk test is ok (normtest.p > 0.05) for all variables.

1. LEVENE'S TEST ok for all variables (Pr. > 0.05) => equal variances.

2. ONE-WAY ANOVA

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
POST_RR	TREATMENT	-	-	> 0.05	-
POST_IN	TREATMENT	-	-	> 0.05	-
POST_CS	TREATMENT	-	-	> 0.05	-
POST_SC	TREATMENT	-	-	> 0.05	-
MA_GRADE_POST	TREATMENT	-	-	> 0.05	-
PY_GRADE_POST	TREATMENT	-	-	> 0.05	-
FR_GRADE_POST	TREATMENT	-	-	> 0.05	-
LPO	TREATMENT	-	-	0.2282	-
LPO1 (LPR1)	TREATMENT	-	-	0.2236	-
LPO2 (LPR2)	TREATMENT	-	-	0.6249	-
LPO3 (LPR3)	TREATMENT	-	-	0.5854	-
LPO4 (LPR4)	TREATMENT	-	-	0.8757	-
LPO5	TREATMENT TG4>CG4	0.09946	4.313	0.04678	M
LPO6 (LPR5)	TREATMENT	-	-	0.1152	-
LPO7 (LPR6)	TREATMENT	-	-	0.8393	-
LPO8 (LPR7)	TREATMENT	-	-	0.8911	-
LPO9	TREATMENT	-	-	0.1029	-
LPO10	TREATMENT	-	-	0.1029	-
LPO11 (LPR8)	TREATMENT	-	-	0.5977	-
LPO12 (LPR9)	TREATMENT TG4>CG4	0.1086	4.655	0.03938	M
LPO13* (LPR10)	TREATMENT			0.3824	
LPO14 (LPR11)	TREATMENT TG4>CG4	0.1466	6.154	0.01915	M
LPO15 (LPR12)	TREATMENT	-	-	0.6194	-
LPO16 (LPR13)	TREATMENT	-	-	0.9471	-
LPO17 (LPR14)	TREATMENT	-	-	0.1681	-
LPO18 (LPR15)	TREATMENT	-	-	0.3348	-
LPO19 (LPR16)	TREATMENT	-	-	0.3322	-

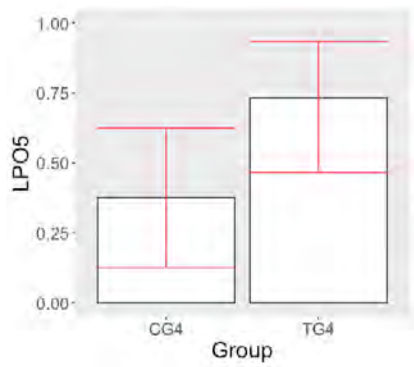
There is a possible effect of TREATMENT on LPO5, LPO12 (= LPR9) and LPO14 (=LPR11).

LEARNING POST 5 – Group 4

2. ANOVA WITH COVARIATE AND PREDICTOR

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO5	TREATMENT TG4>CG4	0.09946	4.313	0.04678	M
LPO5	LPR	-	-	> 0.05	-
LPO5	LPR4**	-	-	> 0.05	-
LPO5	GENDER	-	-	> 0.05	-
LPO5	USE_APP	-	-	> 0.05	-
LPO5	LEVEL_MA	-	-	> 0.05	-
LPO5	MA_GRADE_PRE	-	-	> 0.05	-
LPO5	PY_GRADE_PRE	-	-	> 0.05	-
LPO5	FR_GRADE_PRE	-	-	> 0.05	-
LPO5	SPATIAL_ABILITIES	-	-	> 0.05	-
LPO5	PRE_RR	-	-	> 0.05	-
LPO5	OS	-	-	> 0.05	-
LPO5	PRE_IN	-	-	> 0.05	-
LPO5	PRE_SC	-	-	> 0.05	-
LPO5	PRE_CS	-	-	> 0.05	-
LPO5	PRE_CT	-	-	> 0.05	-
LPO5	PRE_SCS	-	-	> 0.05	-
LPO5	POST_CLS*	-	-	> 0.05	-
LPO5	POST_CLE	-	-	> 0.05	-
LPO5	POST_CAE	-	-	> 0.05	-
LPO5	POST_INV	-	-	> 0.05	-

*1 to 13 DF (only TG) ** LPO5 is related and complementary to LPO4, and LPO4 was also in the pretest (LPR4).



3. ANOVA WITH COVARIATE AND PREDICTOR

For this variable, the covariates did not have any significant influence.

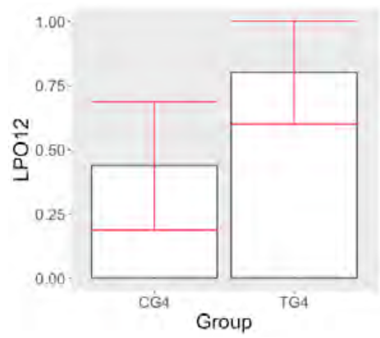
There is the possibility of an effect of TREATMENT on LPO5 in favor of TG4, with $\eta_t^2 =$ 0.13.

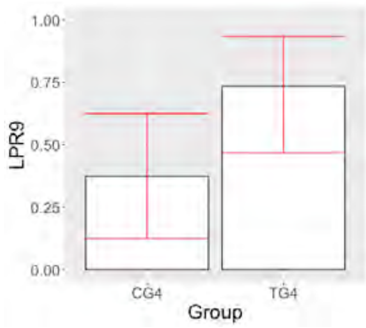
LEARNING POST 12 – Group 4

2. ANOVA WITH COVARIATE AND PREDICTOR

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO12 (LPR9)	TREATMENT TG4>CG4	0.1086	4.655	0.03938	M
LPO12	LPR9	0.08753	3.878	0.05855	S
LPO12	LPR	-	-	> 0.05	-
LPO12	GENDER	-	-	> 0.05	-
LPO12	USE_APP	-	-	> 0.05	-
LPO12	LEVEL_MA	-	-	> 0.05	-
LPO12	MA_GRADE_PRE	-	-	> 0.05	-
LPO12	PY_GRADE_PRE	-	-	> 0.05	-
LPO12	FR_GRADE_PRE	-	-	> 0.05	-
LPO12	SPATIAL_ABILITIES	-	-	> 0.05	-
LPO12	PRE_RR	-	-	> 0.05	-
LPO12	OS	-	-	> 0.05	-
LPO12	PRE_IN	-	-	> 0.05	-
LPO12	PRE_SC	-	-	> 0.05	-
LPO12	PRE_CS	-	-	> 0.05	-
LPO12	PRE_CT	-	-	> 0.05	-
LPO12	PRE_SCS	-	-	> 0.05	-
LPO12	POST_CLS*	-	-	> 0.05	-
LPO12	POST_CLE	-	-	> 0.05	-
LPO12	POST_CAE	-	-	> 0.05	-
LPO12	POST_INV	-	-	> 0.05	-

*1 to 13 DF (only TG)





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR9	TREATMENT	0.09946	4.313	0.04678	M

4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO12

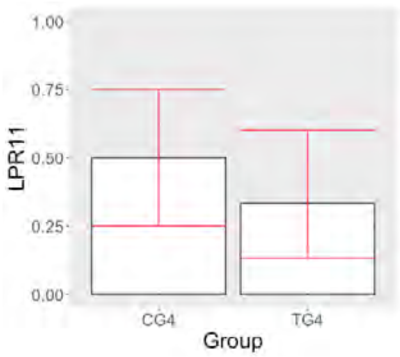
	Sum Sq	Df	F value	Pr(>F)
TREATMENT	0.5211	1	2.4453	0.1291
LPR9	0.3712	1	1.7419	0.1976
Residuals	5.9663	28		

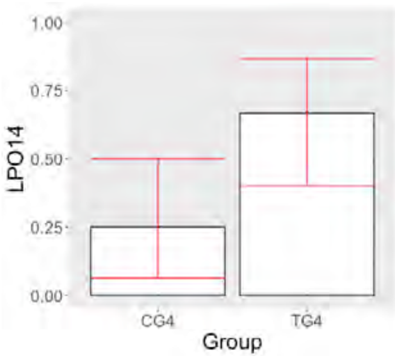
There is no effect of TREATMENT on LPO12 for teacher 4.

LEARNING POST 14 – group 4

DV (outcome)	IV (predictor)	Adj. r^2	F-stat	p-value	Effect
LPO14 (LPR11)	TREATMENT TG4>CG4	0.1466	6.154	0.01915	M
LPO14	LPR11	-	-	-	-
LPO14	LPR	0.1404	5.901	0.02156	M
LPO14	GENDER	-	-	> 0.05	-
LPO14	USE_APP	-	-	> 0.05	-
LPO14	MA_GRADE_PRE	-	-	> 0.05	-
LPO14	PY_GRADE_PRE	-	-	> 0.05	-
LPO14	FR_GRADE_PRE	-	-	> 0.05	-
LPO14	SPATIAL_ABILITIES	-	-	> 0.05	-
LPO14	PRE_RR	-	-	> 0.05	-
LPO14	OS	-	-	> 0.05	-
LPO14	PRE_IN	-	-	> 0.05	-
LPO14	PRE_SC	-	-	> 0.05	-
LPO14	PRE_CS	-	-	> 0.05	-
LPO14	PRE_CT	-	-	> 0.05	-
LPO14	PRE_SCS	-	-	> 0.05	-
LPO14	POST_CLS*	-	-	> 0.05	-
LPO14	POST_CLE	-	-	> 0.05	-
LPO14	POST_CAE	-	-	> 0.05	-
LPO14	POST_INV	-	-	> 0.05	-

*1 to 13 DF (only TG)





3. ANOVA WITH COVARIATE AND PREDICTOR

COVARIATE	PREDICTOR	Adj. r^2	F-stat	p-value	Effect
LPR	TREATMENT	-	-	> 0.05	-

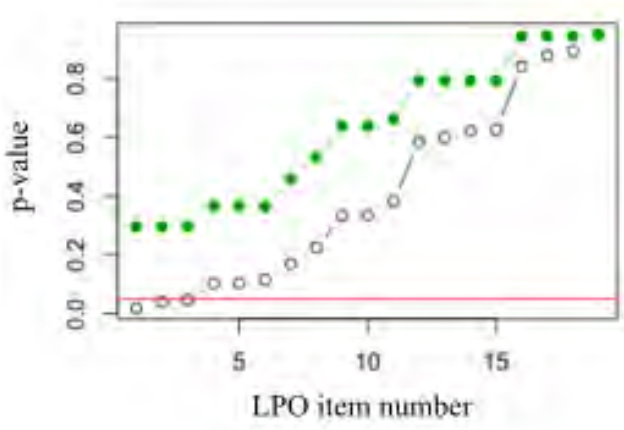
4. MAIN ANALYSIS: ANOVA WITH PREDICTOR+COVARIATE AND OUTCOME

Response: LPO14

	Sum Sq	Df	F value	Pr(>F)
TREATMENT	1.5645	1	9.0982	0.005395 **
LPR	1.5185	1	8.8306	0.006025 **
Residuals	4.8148	28		

There is the possibility of an effect of TREATMENT on LPO14 in favor of TG4, with $\eta_t^2 = 0.20$.

Conclusion: possible effect of TREATMENT on LPO5, LPO12 (= LPR9) and LPO14 (=LPR11). However, performing a multiple testing analysis in order to control the false positive effect [Benjamini and Hochberg, 1995], we see that they cannot be considered as significant.



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