Using Mobile Devices as Experimental Tools in Physics Lessons

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

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Use of Mobile Devices as Experimental Tools (MDETs) in physics lessons at high school

- Background in PER & motivation of this study
- Research questions & design
- Results of the pilot study (PS)
- Results of the main study (MS)
- Conclusions

The Context Based Lerning and Transfert Project (CoBaLT)

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Prof. Dr. Andreas Müller
Dr. Alice Gasparini

- 3 qualification posts at PhD level
- Related to each other
- Complementary expertise at 3 different locations
- Focus on « Context-Based Science Education & Transfer » (CBSE)

PH LUZERN
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Prof. Dr. Dorothee Brovelli
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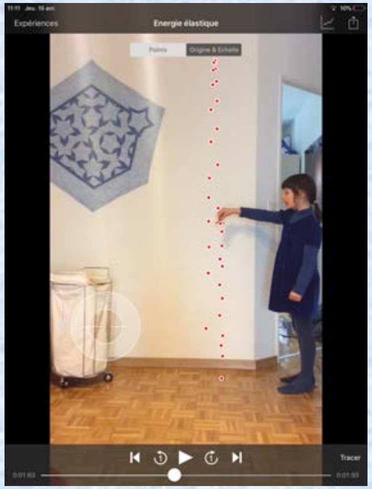
Prof. Dr. Nicolas Robin
Mrs. Daniela Schriebl

Advantages of MDETs for teaching

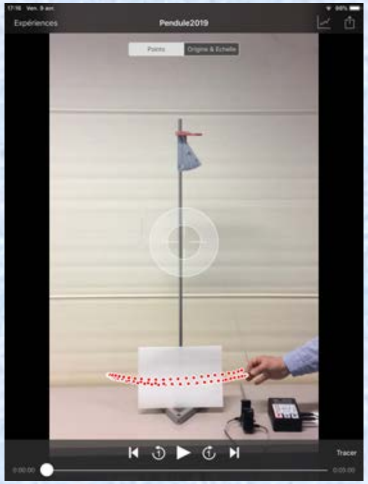


a) Simple apparatus replacing complex laboratory sets

→ *quicker laboratory* sessions
→ *real time* data analysis devices
→ in many cases *more economic* than "traditional" lab systems

b) Mobile and ubiquitous

→ *real life exercises* (data ownership)
→ possibility as *homework* tasks
→ *interdisciplinary* (data from gym lessons)
→ contextualisation, authenticity
=> "topic context"



c) Wide-spread

→ pupils are *familiar* with the device as such (BYOD) => "material context"
→ *informal learning*: show how to use devices for *science*

→ **Unify** experiments / classroom exercises / homework task

Background in PER & motivations

- Context Based Science Education (CoBaSE): authentic contexts can have a positive impact on <u>motivation</u> (large SE) and <u>learning</u> (medium SE)

  (see e.g. Bennett *et al*. 2007, Gilbert *et al*. 2011, Kuhn & Müller, 2014)

- Effects on <u>learning</u> achievement:

  - Weak (positive) correlation between motivation and learning : r ≈ 0,3
    (Uguroglu and Walberg 1979, Wild *et al*. 2001)
  - Reducing extraneous cognitive load (CL)
    (Thornton and Sokoloff 1990, for new technologies)
  - Simultaneous, real-time representations of the data
    (Brasell 1987, Beichner 1996)

  } + effect

  - The coordination of multiple representations increases CL
    (Van Bruggen et al. 2002)
  - Distracting effect by the ownership of the instrument
    (Tossel et al. 2014, Beland and Murphy 2015)

  } − effect

Background in PER & motivations

- Many concepts for use of MDETs in sciences education have been introduced for about ten of years (see e.g. *The Physics Teacher Series*, Khun & Vogt, 2012)

- However, few specifics studies exist on the educational effects of MDETs

STUDY 1 (Hochberg *et al., Journal of Science Education and Technology*, 2018)

1) Secondary school classes non specialized in physics, N_{TG}= 87 N_{CG}= 67
2) Topics: harmonic mechanical oscillations
3) *Short* intervention (3h)
4) CG : traditional experiment
5) TG : same experiment using smartphones (no topic context)
6) Smartphones supplied

- Positive effects on:
  - Interest (high)
  - Curiosity state (small)
- No effects on learning achievement
- No distracting effect (no ownership of the instrument)

Background in PER & motivations

STUDY 2 (Hochberg et al., Journal of Science Education and Technology, 2020)

- N_{TG}= 23 N_{CG}= 28
- Secondary school specialized physics classes
- Topics: harmonic mechanical oscillations
- *Short* intervention (3h, same as in 2018)
- CG : traditional experiment
- TG : same experiment using smartphones (no topic context)
- smartphones supplied (no distracting effect expected)

• Positive effects on learning achievement (medium)
• No effects on affective variables (interest, curiosity)
• No distracting effect (no ownership of the instrument)

STUDY 3 (Klein, Kuhn & Müller, 2017)

1) Physics undergraduate level, N_{TG}= 40 N_{CG}= 36
2) Topics: Mechanics
3) Long intervention (few months)
4) CG: no experiments, only traditional exercises
5) TG: same exercises, *enriched* by mobile video analysis tasks (30%)
6) Tablets were supplied

Medium to large + effects on:

- kinematic representations
- conceptual understanding
- relation to reality
- curiosity
- disciplinary authenticity
- self-concept
- interest
- autonomy

=> Need for more empirical evidence of the effects of MDETs on physics education with

- Non-specialized secondary II level pupils
- Full teaching sequence

Research Questions

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 related mathematics** among high school pupils ?

3. Does the long-term use of MDETs **improve levels of interest, relation to reality, self-concept and curiosity related to the studied** topics in high school pupils?

Study features

- **Sample** : 2nd year high-school students

PS: N_{TG}= 59 N_{CG}= 43; 3 teachers **MS**: N_{TG}= 56 N_{CG}= 60, 4 teachers

- **Duration**: 36 double-lessons (one semester)

- **Topics** : kinematics & dynamics

Position, displacement vectors, average & instant velocity, speed, acceleration, uniform linear motion, uniformly accelerated linear motion, Newton's laws, free fall

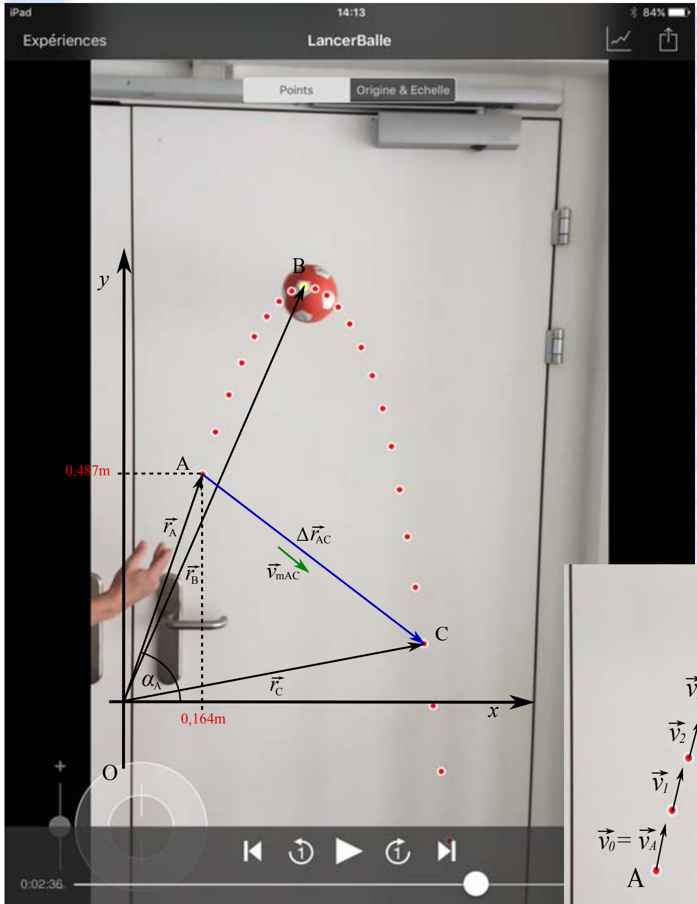
- **Treatment**: MDETs activities *replacing* standard exercises and/or laboratory sessions

  - Tablets were supplied to TG
  - For TG and CG
    - ✓ same amount of time for data collection, manipulations and problem solving sessions
    - ✓ same authentic topic context overall the duration of the investigation

- **Test** : **affective** and **concept** QCM based standard tests items (FCI, TUV, TUG, MCT) and "standard" assessment by teachers

MDET activity n. 1 & 4: ball throw

Curriculum: position & displacement vectors, duration, average velocity, speed, instant velocity, average acceleration vector

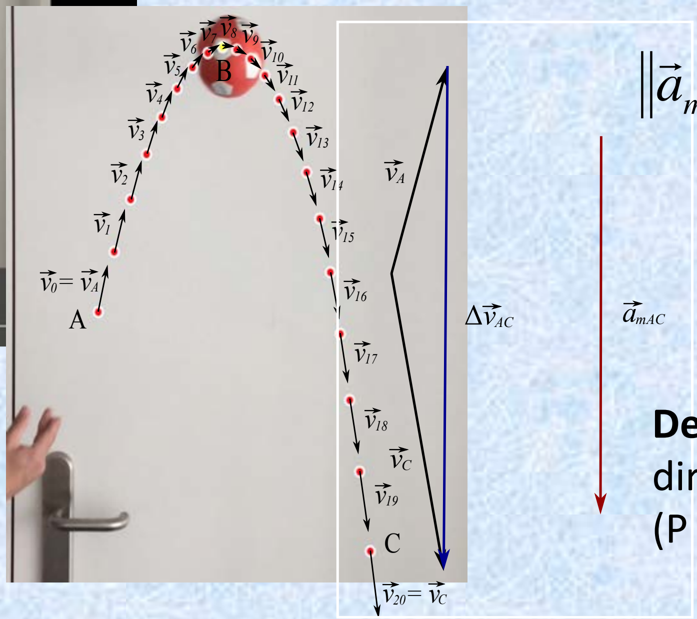


Act. 1: distinction between speed (scalar) and velocity vector (instant and average)

$$\left\|\Delta\vec{r}_{AC}\right\| = 0{,}59\ \text{m} \qquad \Delta t_{AC} = t_C - t_A = 0{,}66\ \text{s}$$

$$\left\|\vec{v}_{mAC}\right\| = \frac{\left\|\Delta\vec{r}_{AC}\right\|}{\Delta t_{AC}} = 0{,}9\ \text{m/s} \qquad v_{mAC} = \frac{\Delta s_{AC}}{\Delta t_{AC}} = 2{,}0\ \text{m/s}$$

Act. 4: distinction between acceleration and velocity vector



$$\left\|\vec{a}_{m12}\right\| = \frac{\left\|\Delta\vec{v}_{AC}\right\|}{\Delta t_{AC}} = \frac{6{,}4\ \text{m/s}}{0{,}66\ \text{s}} = 9{,}7\ \text{m/s}^2$$

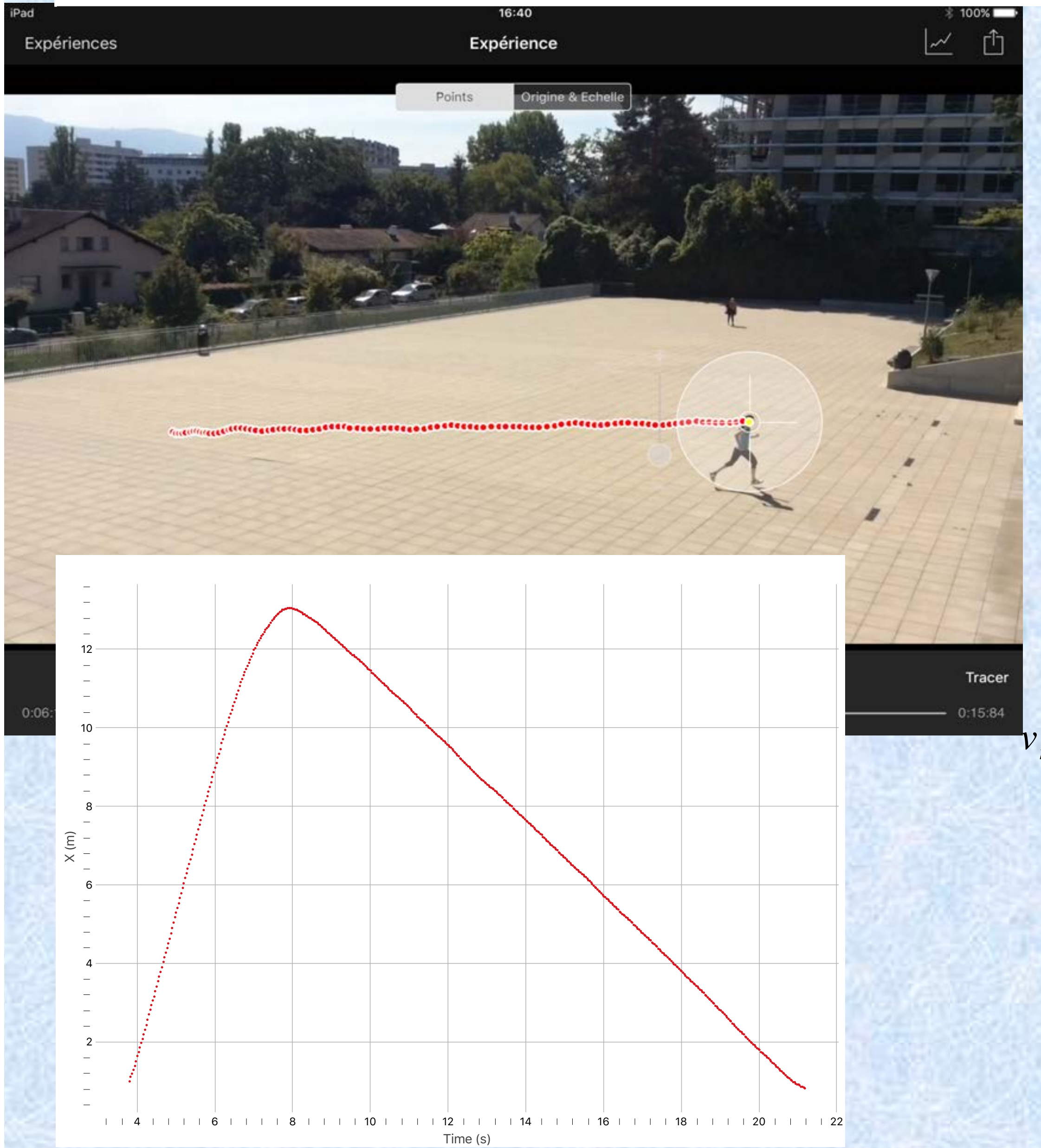
Average acceleration
= constant instant acceleration
= *g* (free fall)

Deeply rooted misconception: change of direction does not imply acceleration (P ≈ 0,10 - 0,15 after instruction)

RQs & design

MDET activity n. 2: return trip

Curriculum : Average velocity/speed and mathematical average of 2 speeds



Strong misconception (Reed, 1984)

$v_m = (v_{go} + v_{back}): 2$ ➔ 84% of the students

Correct answer ➔ 5% of the sudents

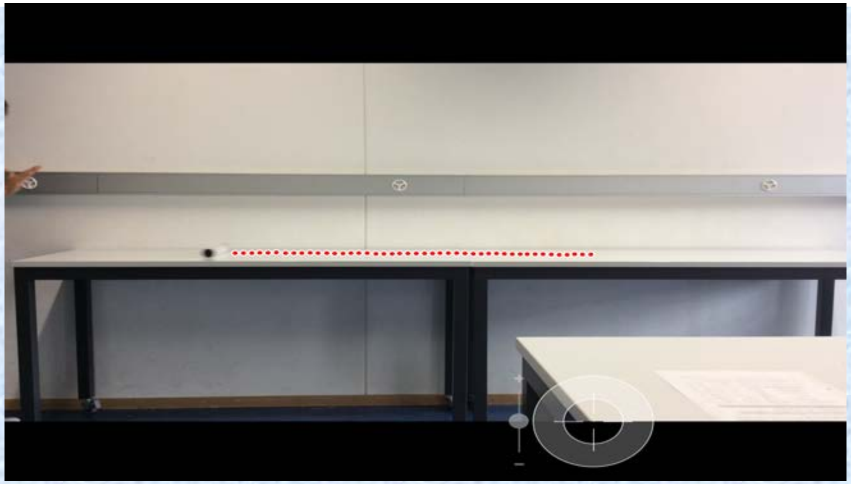
$$\vec{v}_{m\,tot} = \frac{\Delta x_{tot}}{\Delta t_{tot}} = \frac{0{,}01}{4{,}1 + 13{,}3} = 0{,}0 \text{ m/s}$$

$$v_{m\,tot} = \frac{\Delta s_{tot}}{\Delta t_{tot}} = \frac{\Delta s_{go} + \Delta s_{back}}{\Delta t_{go} + \Delta t_{back}} = \frac{12{,}4 + 12{,}4}{4{,}1 + 13{,}3} = 1{,}4 \text{ m/s}$$

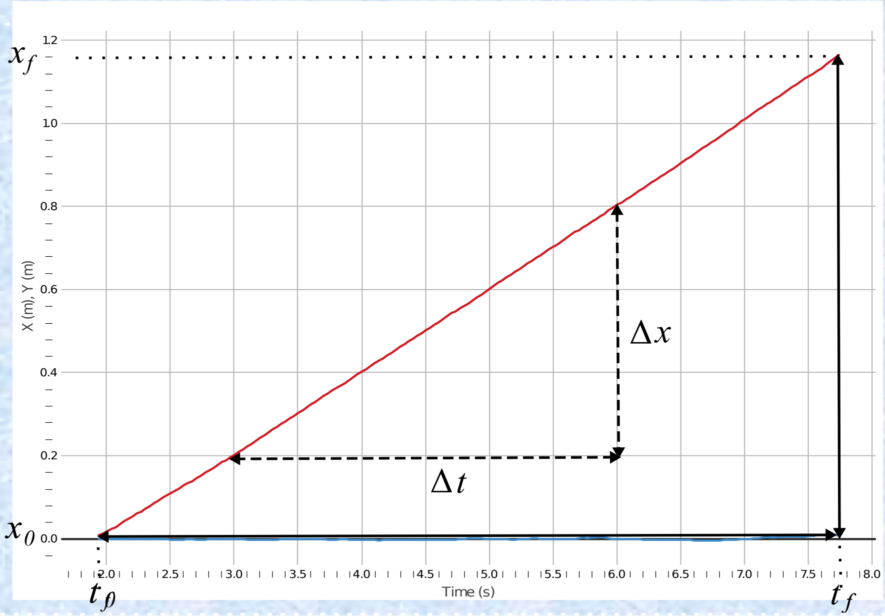
$$\frac{v_{m\,go} + v_{m\,back}}{2} = \frac{3{,}0 + 0{,}93}{2} = 2{,}0 \text{ m/s} \neq v_{m\,tot}$$

Example of activity 3: toy train

Curriculum: uniform linear motion ULM (proportionality, velocity, intercept, slope, time equation, time diagram)



$$x(t) = x_0 + v(t - t_0)$$



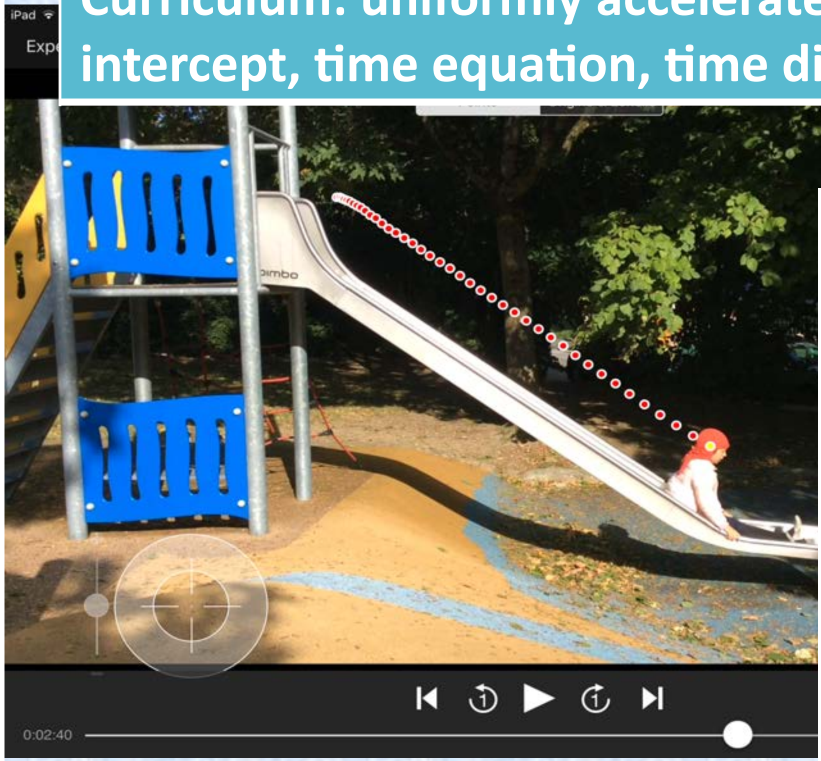
$$v = v_x = \frac{1{,}1 - 0}{7{,}7 - 1{,}9} = \frac{1{,}1 \text{ m}}{5{,}8 \text{ s}} = 0{,}19 \text{ m/s}$$

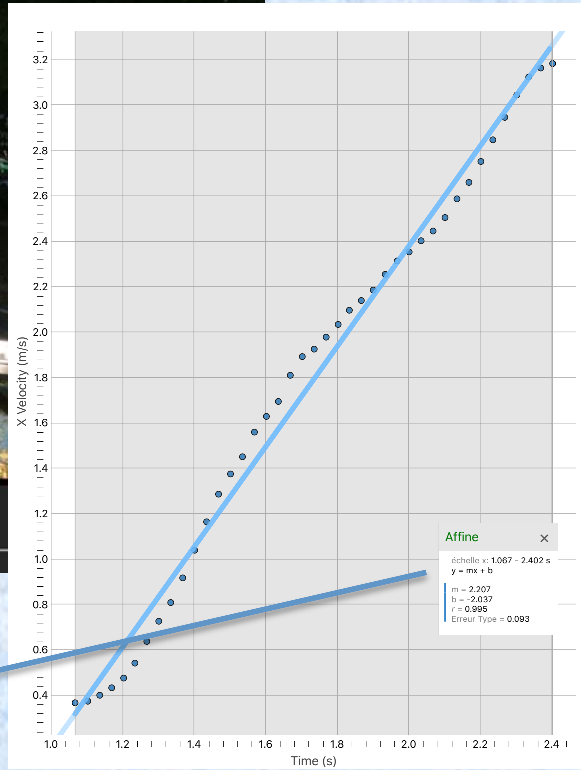
$$x_0 = 0{,}01 \text{ m}$$

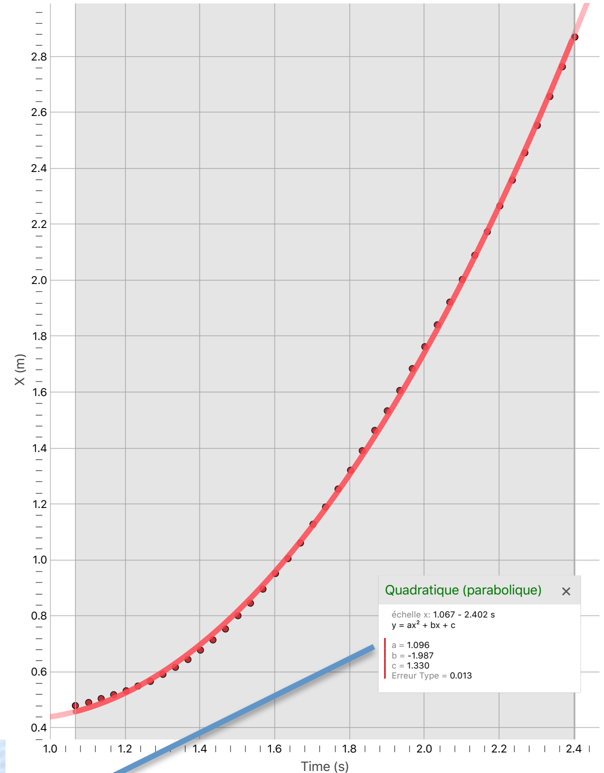
RQs & design

MDET activity n. 5 : slide at playground

Curriculum: uniformly accelerated linear motion (UALM), inclined plane (slope, intercept, time equation, time diagram)







- $v(t) = v_0 + a(t - t_0)$

$$a = a_x = \frac{v_{xf} - v_{x0}}{t_f - t_0} = \frac{1{,}98\ \text{m/s}}{0{,}9\ \text{s}} = 2{,}2\ \text{m/s}^2 \quad = g\sin(\alpha)$$

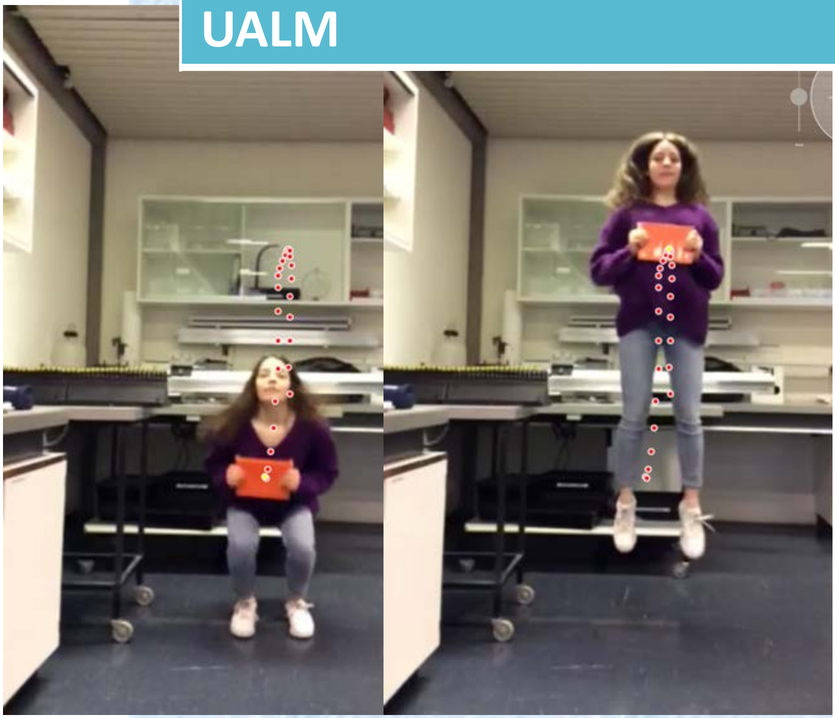
$$v_0 = 0{,}37\ \text{m/s}$$

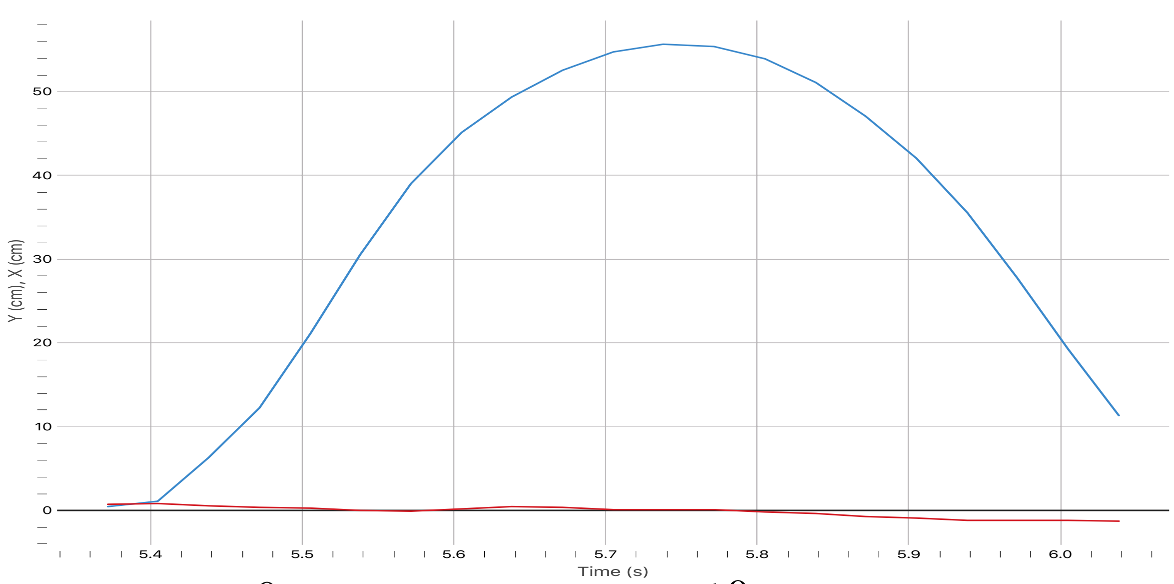
- $x(t) = x_0 + v_0(t - t_0) + 0{,}5a(t - t_0)$

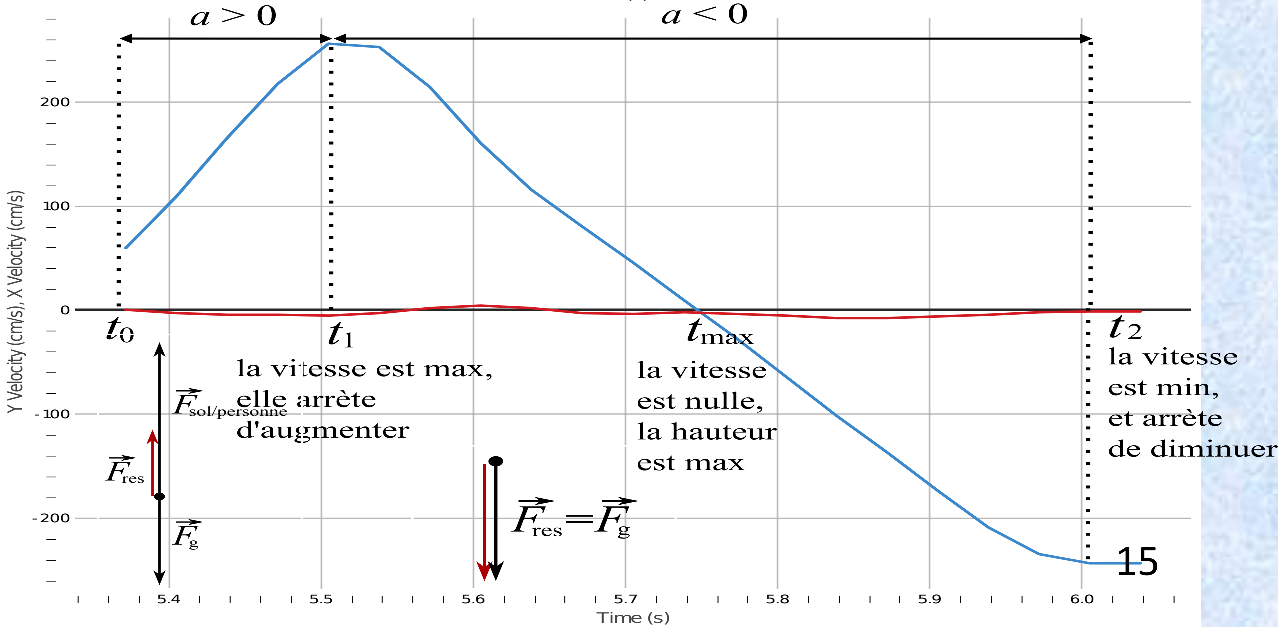
$$a = \tfrac{1}{2}a_x = 1{,}1\ \text{m/s}^2 \quad \Rightarrow \quad a_x = 2 * 1{,}1 = 2{,}2\ \text{m/s}^2$$

MDET activity n. 6: vertical jump

2nd year curriculum : Newton's laws (1D), free fall with velocity's change of sign, UALM







1) Forces' balance to predict $F_{ground/person}$
2) Kinematic prediction (h_{max}, t_2)
3) Verification with data check

Design of the Study (PS & MS)

3 teachers participating in the PS, 4 teachers in the MS
each one having at least one TG and one CG

Week	4 Test class-groups (PS) 4 Test class-groups (MS)	3 Control class-groups (PS) 4 Control class-groups (MS)
1	Pre-tests: prior motivation and conceptual understanding	
2 to 5	MDETs activities session + exercises	Conventional lab sessions + exercises
6	Standard test	
7 to 10	MDETs activities session + exercises	Conventional lab sessions + exercises
11	Standard test	
12	MDETs activities session + exercises	Conventional lab sessions + exercises
13 and 14	Exam session	
15 to 18	MDETs activities session + exercises	Conventional lab sessions + exercises
19	Post-test: prior motivation and conceptual understanding	

Variables (overview)

Selection of variables	Pre test	Post test
Control/test group	IV	
Self-concept **SC**	CV	DV
Interest **IN**	CV	DV
Relation to reality **RR**	CV	DV
Curiosity as a state **CS**	CV	DV
Learning achievement **LPR/LPO**	CV (QCM)	DV (QCM)
Physics grade pre/post	CV	DV
Math grade pre/post	CV	DV
Curiosity as a trait/ Intrinsic motivation **CT**	CV	
Self concept reg. Smartphone **SCS**	CV	

+ 10 other relevant control variables (gender, cognitive load, involvement, teacher assessment, spatial abilities, …)

Affective Variables

Main instrument properties and results

Dependent variables

- self concept (SC, α_C = 0,86), interest (IN, α_C = 0,77),
  relation to reality (RR, α_C = 0,90), curiosity state, (CS, α_C = 0,84),
  cognitive load experiments/apps (CLE, α_C = 0,68; CLA, α_C = 0,87)

- temporal changes of the dependent variables
  - all slightly negative except RR
  - similar for the two groups

- no significant differences by the intervention (ANCOVA)

- **no increased *perceived* cognitive load for TG**

Control variables

Many effects on dependant variables, in line with the previous results in literature, e.g.

- The effect of **gender** on self-concept (S)
- The effect of **spatial abilities** on learning achievement (S)
- The effect of **previous knowledge** (maths & physics) on self concept (S)

Affective Variables

Main instrument properties and results

<u>control variables</u>

gender (*SC),
spatial abilities(*SC, *LPO),
math level (**SC),
physics grade(*SC),
involvement (*RR, **IN, **SC, **CS),
curiosity-trait (**IN, **SC, ***CS),
self concept regarding apps(**SC),
cognitive load (**RR, **IN,***SC,**CS,*LPO),
cognitive activation (*RR, **IN, *SC, **CS)

(*) small, (**) medium or (***) large effect on dependent variables

Results of the PS

Affective variables

Standard items from existing literature (or adapted) + few “new” items (negative or typical French expressions)

Dim.	Example	k	α_{pre}	$r_{it\,pre}$ between		α_{post}	$r_{it\,post}$ between	
IN	I invested more effort during the physics lessons than in the other subjects.	7	**0,78**	0,53	0,76	**0,75**	0,59	0,76
SC	I could always solve the phsics exercises	7	**0,86**	0,49	0,85	**0,86**	0,56	0,81
CT	I find fascinating to learn new things	6	**0,86**	0,73	0,85	**0,85**	0,69	0,82
CS	I want to inquire further about this subject	4*	**0,82**	0,77	0,83	**0,86**	0,75	0,85
RR	Topics are useful for thinking about situations outside of school	6	**0,88**	0,72	0,83	**0,92**	0,77	0,91
SCS	I'm comfortable with using apps	6	**0,67**	0,43	0,76	-	-	-
CLE	I could well concentrate on experiments, without “struggling” with the equipment	6	-	-	-	**0,68**	0,45	0,73
CLS (TG)	I could well concentrate on experiments, without “struggling” with the apps	7	-	-	-	**0,87**	0,69	0,85
CAE	I was actively involved in doing the experiments	5	-	-	-	**0,58**	0,60	0,63
INV	During the lessons I asked questions	5	-	-	-	**0,73**	0,55	0,79
AT	The teacher helped me when I had trouble with the work	5	-	-	-	**0,74**	0,59	0,79

Learning achievement

<u>Validation</u> of the conceptual test (January-March 2018)

- Testing 31 items : 14 from standard tests (FCI, TUV, TUG, MBT, MCT)
  + 7 modified from standard tests (FCI, TUV, TUG, MBT)
  + 10 newly created
- on
  - 145 pupils of the first year as a pre-test
  - 111 pupils of the second year after the kinematics & dynamics course, as a post-test

Selected items for the pilot study

According to

1) The coherence with the learning objectives of the planned activities
2) The psychometric results of the validation

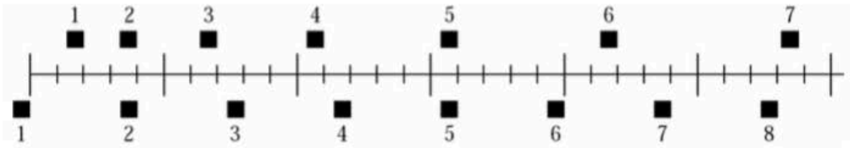
- 20 post-test items
  (9 from std. tests, 3 modified from std. tests, 8 created), whose
- 14 pre-test items
  (only concept items: 7 from std. tests, 3 modified from std. tests, 4 created)

Results of the PS

Learning achievement

Examples of items of the conceptual test

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.

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.

Results of the PS

Learning achievement

Examples of items of the conceptual test

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.

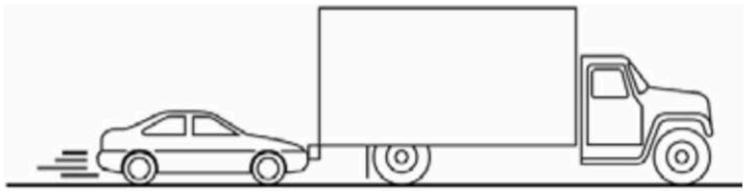
(B) moins que 45km/h.

(C) plus que 45km/h.

(D) nulle.

(E) les informations fournies ne sont pas suffisantes pour répondre à la question.

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.

Results of the PS

Learning achievement

❖ Psychometric standard properties of the conceptual tests (according to & Beichner, 2009)

Post-test: k = 19; N = 103 (N_{CG}= 44 N_{TG}= 59)	
α*	0,72
$\langle r\rangle_{it}$	0,40 [0,25 ; 0,59]
<P>	0,47 [0,06 ; 0,79]
$\langle P_{TG}\rangle$	0,43 [0,02 ; 0,76]
$\langle P_{CG}\rangle$	0,52 [0,09 ; 0,93]

The pre-test presented similar general acceptable results, however with a lower internal consistency

❖ Pre/post gain for conceptual tests

	TG	CG	Tot
Gain G = $(\langle P_{post}\rangle - \langle P_{pre}\rangle)/(1- \langle P_{pre}\rangle)$	25%	32%	28%

- no significant differences by the intervention for the whole test
- impact of many **control variables** (e.g. previous math & physics grade**, self-concept*, spatial abilities*, teacher assessment*)

(*) small or (**) medium effect

Results of the PS

Learning achievement

- CG had slightly (at most few %) better learning scores (pre, post) and gains than TG
  - for the whole conceptual test
  - for almost all individual items of the conceptual test

- Medium sized effect ($\eta_t^2 = 0.09$; $P < .05$) in favour of the CG for item 4 involving instant velocity vector and related to the MDETs activity n. 1 ("ball throw" on introduction to 2D kinematics)

4) La vitesse instantanée de la balle au point P, $\vec{v}_P$, peut se représenter

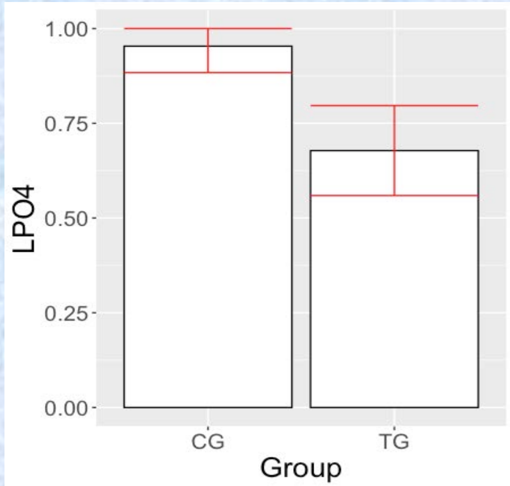
(A) par une flèche qui part du point P et se termine nécessairement au point R.

(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.



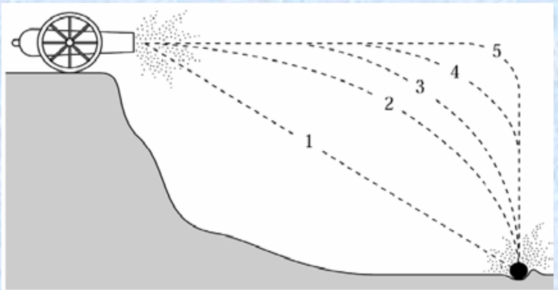
$P_{CG} = 0.95\ (0.21)$ $P_{TG} = 0.68(0.47)$

Learning achievement

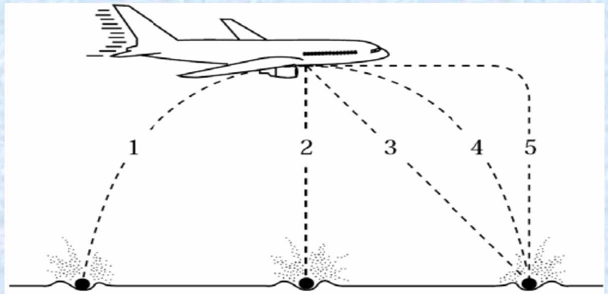
Explantation of the observed effect: the information about the motion given by the applications was beyond the skills of the pupils at this time of the year: they acceded the data of the two components of the motion (*x* and *y*) and they could see the relative graphs, before studying the simpler one-dimensional motions (ULM and UALM) => possible cognitive overload for the 1st activity

Changes for the main study:

- replace MDETs act. n. 1 with an exercise with real data for TG
- introduce one new MDETs activity (n. 7) on projectile motion
- introduce 2 items in the conceptual test on projectile motion :



FCI12



FCI14

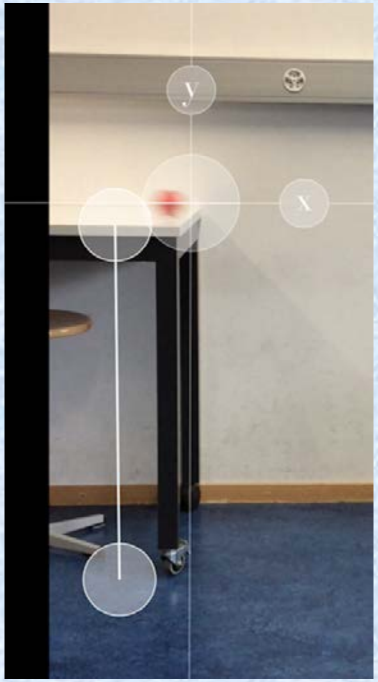
- + few minor changes

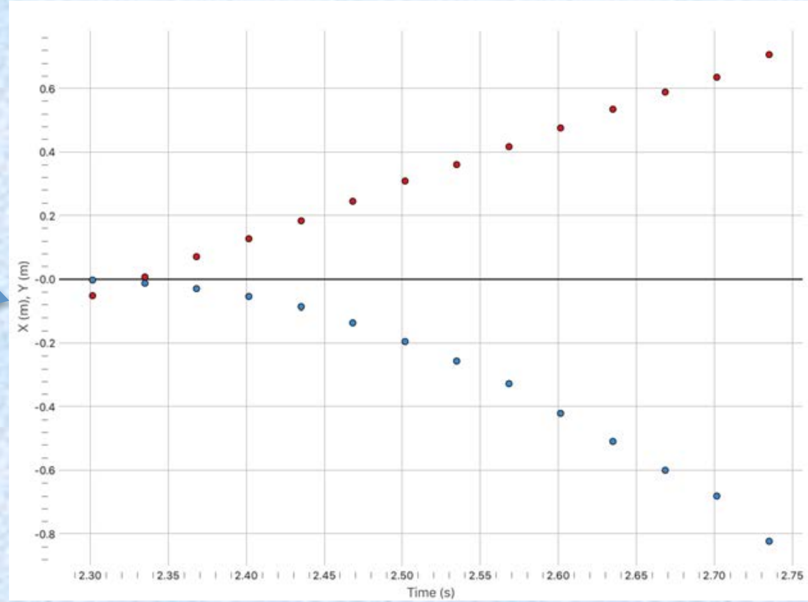
Results of the PS

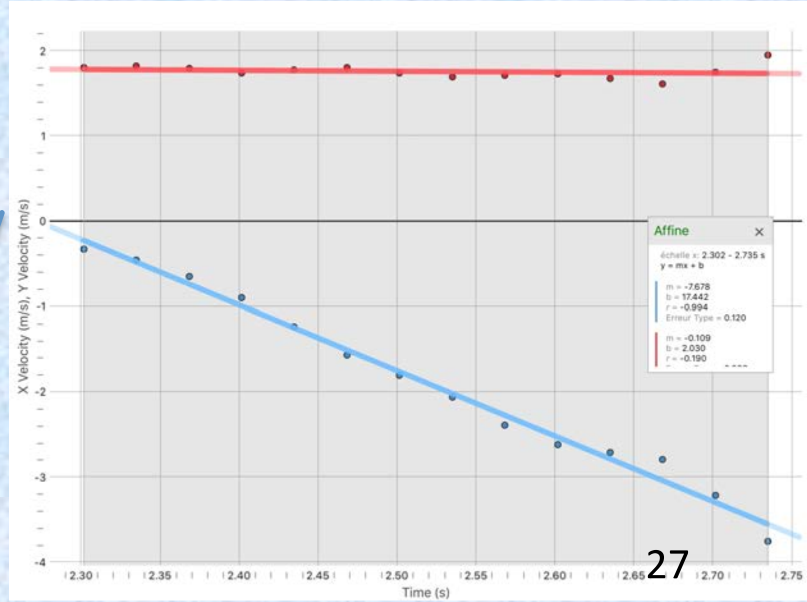
MDET activity n. 7: projectile motion

Curriculum : free fall, 2D kinematics as composition of two linear motions

1) Application of the laws of UALM and ULM
2) *x* and *y* time diagrams (position and velocity)
3) *Range* of the projectile as a function of the initial horizontal velocity
4) Flight time of the projectile as a function of the initial horizontal velocity







Affective Variables

Main instrument properties and results

Dependent variables

- self concept (SC, α_C = 0,87), interest (IN, α_C = 0,72), relation to reality (RR, α_C = 0,89), curiosity state, (CS, α_C = 0,88), cognitive load experiment/use apps (CLE, α_C = 0,66; CLA, α_C = 0,88)

- temporal changes of the dependent variables
  - all slightly positive except CS
  - pre/post small positive effect for IN (d = 0.2) and RR (d = 0.3)
  - similar results for TG and CG

- no significant differences by the intervention (ANCOVA)

- **no increased perceived cognitive load for TG**

control variables

Many effects on dependant variables, in line with the previous results in literature, and with those found in the PS. Moreover

- The effect of **previous knowledge in maths** on self concept and on physics learning (S)
- The effect of **teacher assessment** on interest (M)

Results of the MS

Affective Variables

Main instrument properties and results

Control variables

gender (*SC),

spatial abilities(*SC, *LPO),

physics grade(*SC),

math grade(*LPO),

teacher assessment(**IN,**SC),

involvement (*RR,***IN,**SC,**CS),

curiosity-trait (*RR,*IN,**CS),

self concept regarding apps(**SC),

cognitive load (**RR, **IN,**SC,**CS,*LPO),

cognitive activation (*RR,***IN,***SC,**CS)

(*) small, (**) medium or (***) large effect on dependent variables

Results of the MS

Affective variables

- Same standard items from existing literature (or adapted) + few “new” items from the PS
- Reduced to 5 items for each scale, to optimize the time available without overloading the test

Dim.	Example	k	α_{pre}	$r_{it\ pre}$ between		α_{post}	$r_{it\ post}$ between	
IN	I invested more effort during the physics lessons than in the other subjects.	5	**0,72**	0,60	0,80	**0,71**	0,56	0,76
SC	I could always solve the phsics exercises	5	**0,85**	0,71	0,83	**0,89**	0,75	0,89
CT	I find fascinating to learn new things	5	**0,77**	0,66	0,76	**-**	-	-
CS	I want to inquire further about this subject	5	**0,79**	0,77	0,83	**0,89**	0,81	0,86
RR	Topics are useful for thinking about situations outside of school	5	**0,87**	0,78	0,84	**0,90**	0,79	0,90
SCS	I'm comfortable with using apps	5	**0,69**	0,43	0,78	-	-	-
CLE	I could well concentrate on experiments, without “struggling” with the equipment	5	-	-	-	**0,66**	0,51	0,75
CLS (TG)	I could well concentrate on experiments, without “struggling” with the apps	5	-	-	-	**0,88**	0,73	0,92
CAE	I was actively involved in doing the experiments	5	-	-	-	**0,59**	0,51	0,75
INV	During the lessons I asked questions	5	-	-	-	**0,73**	0,55	0,79
AT	The teacher helped me when I had trouble with the work	5	-	-	-	**0,75**	0,66	0,75

Results of the MS

Learning achievement

❖ Psychometric standard properties of the conceptual tests (according to & Beichner, 2009)

Post-test: k = 19; N = 103 (N_{CG}= 44 N_{TG}= 59)	
α*	0,6
$\langle r \rangle_{it}$	0,34 [0,05 ; 0,54]
$\langle P \rangle$	0,44 [0,16 ; 0,76]
$\langle P_{TG} \rangle$	0,43 [0,16 ; 0,76]
$\langle P_{CG} \rangle$	0,44 [0,14 ; 0,75]

The pre-test presented similar general acceptable results, however with a lower internal consistency

❖ Pre/post gain for conceptual tests

	TG	CG	Tot
Gain = $(\langle P_{post} \rangle - \langle P_{pre} \rangle)/(1- \langle P_{pre} \rangle)$	17% (d = 1,0)	21% (d = 1,1)	20% (d = 0,9)

- no significant differences by the intervention for the whole test
- impact of many **control variables** (e.g. previous math & physics grade**, teacher**, spatial abilities*, self-concept*)

(*) small or (**) medium effect

Learning achievement

The ANCOVA analysis indicates **no effects of the treatment** on the results of the conceptual post-test or the physics grade, nevertheless

- some effects were found within the groups of teacher taken individually
- an indication of a possible effect of the treatment on the average grade of mathematics in favour of the TG was found (P = .09)

Interpretation: the representations provided by the apps of video analysis are based on the mastery of the mathematics content treated in parallel math classes

➢ learning to use and coordinate the multiple representations provided by the video analysis apps requires a **cognitive effort** (more easily for higher-level students which would explain the positive learning results observed on undergraduates or specialized physics classes)

➢ 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

Limitations of the intervention

- There is a phase of appropriation of the used mobile device *and* of the apps (to make a video of sufficiently good quality for the tracing by the app to be possible, the tracing circle has to be chosen with an appropriate width, ...). This takes time to be learned and mastered, which is not evident for pupils and frequently for the teachers too
- Beyond the practical mastery of the technological object MDETs can cause cognitive overload if pupils do not master the mathematics underlying the representations provided by the apps used during the experiments
- MDETs require maintenance and the technical assistance
- Planned obsolescence (cost in environmental and durability terms)

Conclusions for research

❖ This research indicates, for non specialized physics classes at secondary II:

- No significant effect of a regular use of MDETs on affective variables
- No global effect on mechanics learning
- No increased perceived cognitive load
- No distracting effects
- Hypothetical positive effect on the learning of mathematics underlying studied contents

=> Need to deepen this aspect for the future research in Physics Education

❖ Teachers perceptions:

- Teachers want to keep on using MDETs again in the next years (as a complement to traditional setup)
- They confirmed that MDETs have no global impact on pupils' learning or attitude toward physics, despite a marked impression of novelty effect

Perspectives for practice

- MDETs are a convenient and practical teaching alternative, complementing (and not replacing) the classical lab and/or exercises, they constitute an interesting educational tool, allowing (without side effects)

  - A faster implementation with a handy and light device, allowing to save precious time for other teaching moments, for the same content as a conventional activity

  - Potentially, an interesting opportunity for a better learning the underlying mathematics

  - Carrying out activities at home, for example as homework, or when the lessons are given at a distance or in an out-of school context

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Thank you!