LEARNING KINEMATICS THROUGH ANALYSING PHYSICS IN MOVIES

C. F. J. Pols
Delft University of Technology, Delft, The Netherlands, c.f.j.pols@tudelft.nl

ABSTRACT

In order to increase students' motivation of learning kinematics at senior pre-university education in the Netherlands, we developed and tested a series of five lessons in which movie scenes were used. Students had to analyse whether a spectacular stunt from a movie scene could be performed in reality. Gradually students developed conceptual and procedural knowledge and learned how to establish the physical accuracy of these stunts. However, not all conceptual knowledge was firmly rooted, and cohesion between different concepts was still missing. Therefore we advise to incorporate the analysis of physics in movies in regular lessons to increase motivation and learning outcomes.

INTRODUCTION

At the 'International Conference on Teaching Physics Innovatively 2015' (TPI-15) it became clear that Hungary has a decreasing amount of students interested in choosing science, or more specifically physics, as major subject. Due to a limited budget, teachers as well as researchers have to be innovative to reach a large audience. Next to that, popularization of science subjects has to go hand in hand with an educative component: Education should be fun but instructive as well. Dutch physics teachers face similar problems as students do not relate the different subjects covered in the physics course with their everyday life. They question why it is important to learn e.g. mechanics. This study investigates the benefits of analysing movie scenes in physics class where we try to link the three components mentioned: increase students motivation by introducing a practical and recognizable problem with an educative component.

Originating from lessons in which I used movies, cartoons and bloopers, a series of five lessons was developed in which students inquire the accuracy of movie stunts: Are the stunts potentially real? The initial idea was to let students, working in small groups, investigate the physics in movie scenes. Although the teacher should not intervene, some help could be provided using questions in worksheets. It was thought that intrinsic motivation, driven by students' curiosity, should be enough to let students develop or gain the necessary knowledge to find a solution to the problem and by doing so learn kinematics. Accordingly, the research question that arose was: *To what extent are students able to develop kinematic concepts based on the analysis of movie scenes?* While motivation is a key factor for success in this approach, known as a problem-based learning approach, the second research question that arose was: *Which components of the chosen approach are appreciated by the students?*

As this is a first exploration in a cyclic process (design research, [1]), a large quantitative study is unsuitable. Therefore we chose a small qualitative study in which small groups of students were intensively monitored. The outcomes of this study reveal whether it makes sense to further develop this teaching strategy.

THEORY

At the heart of science lie the inquiries in which existing knowledge is used and new knowledge is acquired. Inquiries in which students work in small groups on problems where they still lack the prior knowledge to solve the problem directly is known as a problem based learning (PBL) approach [2], [3]. By investigating and discussing the various problems, the necessary knowledge to answer the questions is developed along the way [4]. This creates a shift in responsibility for learning: The teacher does not tell students the relevant information but the students investigate themselves what is necessary to know to solve the problem. This approach is often used at university level with medical students. However, not much is known about the potential success of this approach at secondary school level. Still this approach can be useful as many benefits are known to exist, among them [2],[5],[6]: (1) PBL aligns with how people learn science; (2) PBL stimulates active engagement and responsibility for one's own learning; (3) PBL fosters the acquisition of lifelong learning skills; (4) PBL increases problem solving abilities; (5) PBL motivates students to learn; (6) PBL improves conceptual learning; (7) PBL positively changes students' attitude and interest in physics.

However, opponents of this approach suggest that this teaching method leads to incomplete and disorganized knowledge. Students can acquire misconceptions [7]. It is questioned whether there is any room left for students to inquire themselves and students often lack motivation to continue an inquiry for longer times. So the question is whether this approach is suitable for less independent secondary school students.

One way to motivate students is to use movies, as these tend to appeal to a large audience. This certainly follows from the fact that students spend more and more time in front of the TV [8]. We could use this interest to teach physics as many physical phenomena can be seen in movies and even physical phenomena which cannot be seen in everyday life are produced within movies [9]. Many examples of using movie scenes have been mentioned in e.g. '*The Physics Teacher*' [10], [11]. Questioning whether the shown event is potentially real could arouse students' curiosity. This question is answered in many different ways by several TV programs such as '*The big bang theory*' and '*MythBusters*' to involve the viewers [12], [13]. Whether it is possible to use the same approach to bind students to the various science subjects for a longer time and instantaneously teach them to solve problems, remains a question for now.

Next to the potentially appealing way physics is presented, the visualisation of physical phenomena can also enhance student learning as they are able to see the phenomena over and over again, analysing them in detail. In this way, the mathematical equations for e.g. parabolic orbits, difficult for students, could come to life and could gain meaning and relevance to students. This could support them in a further analysis of the physics involved.

METHOD

In this design research we investigate possible affectional effects and the development of procedural and conceptual knowledge through analysing kinematic phenomena in movie stunts using a PBL approach. In order to do so, we developed a series of five lessons using recommendations on conceptual development in physics teaching and strategies for effective use of a PBL approach.

This series of lessons was tested in a single 5 VWO class (senior pre-university education) of 18 students. These students (aged 16/17) were divided into groups of three to four persons with the same academical abilities. Three groups were video recorded, the other two groups were audio recorded. After each lesson transcripts were made and subsequently students' activities, including chosen solution strategies and given answers, were analysed. In addition, we studied the development of kinematical concepts during the small group discourses. In order to do so, first the different kinematical terms were highlighted and subsequently we investigated how these terms came forward: e.g. by discussing or questioning and whether these terms were given the right interpretation of physical meaning.

DESIGN

A literature study on the use of an effective PBL approach in class yielded many recommendations. A PBL problem should at least [5,6,14]: (1) not have a single solution or solution strategy; (2) be authentic, concrete and have value; (3) match the students' level of prior knowledge; (4) engage students in discussions (5) lead to the identification of learning issues; (6) stimulate self-directed learning and (7) be interesting to students. As we use a PBL approach in a physics class, recommendations on effective physics teaching should be used in the design as well. Knight [15] summarizes that physics lessons are more effective when: (1) students are actively engaged; (2) lessons focus on phenomena rather than abstractions; (3) students have to explicitly deal with alternative conceptions; (4) students develop problem solving skills and strategies and (5) problems with a quantitative and qualitative character which go beyond symbol manipulation are used. The combination of these 12 recommendations has led to a series of lessons where:

1. Forrest Gump [16] is running across the countryside at a constant speed. In various instances, his speed can be determined and compared with that of an average jogger, showing that he is fairly slow. Students' prior knowledge was activated (uniform linear motion) and they gain experience in using the interactive whiteboard (IWB) in combination with movie scenes.
2. Criminal Bohdi is chased by agent Johnny [17]. With a 15-second interval they jump out of an airplane. Still Johnny overtakes the felon in mid-air by minimising his frontal area. Again, prior knowledge (free fall) was activated but their knowledge was extended by introducing friction.
3. Trinity [18] escapes from agent Smith by jumping from one building to another across a two-way street. Her trajectory is fairly well shown in slow-motion, making a proper analysis of the jump possible and therefore this lesson served as start on projectile motion, where step by step the independency of motion in horizontal and vertical direction was introduced.
4. Four boys find themselves trapped with their car at a collapsed bridge, see Fig.1. [19]. They dare to jump across as one is certain that physics tells them it is possible to do so. They get across, although the car disintegrates. All necessary variables (and more) to solve the problem are mentioned in the conversation between the boys. Therefore, this lesson served as a practice on the topic of projectile motion.

Fig.1. The car jump in Road Trip (2000)

5. Raines escapes from the police by jumping over a bunch of stationary cars using a ramp loader at 100 mph [20]. All necessary variables to analyse the jump are 'hidden' in the scenes, students had to find these variables. This lessons served as a formative assessment where students showed their gain in procedural and conceptual knowledge during the series of lessons.

Questions in the worksheet served as stepping stones. Although these questions provided some help, there was enough room to discuss and inquire the different kinematical concepts.

RESULTS

As students worked in small groups, in each lesson and with each question a same process of inquiry was observed. We call these phases of inquiry: the *orientation phase*, the *analysis phase*, and the *solution phase*. These phases are elaborated consecutively.

In the *orientation* phase students discussed what the actual problem was and how to, qualitatively, describe the event shown in the movie, i.e. they made the problem understandable for themselves. In this phase, kinematical terms automatically came forward, although these were not always given the right physical meaning, as the following excerpt from lesson 2 shows, where students S1-S3 discuss a fall with friction:

1	S1:	But it is not like he is falling slower?
2	S2:	No, he falls constantly. You have to fall constantly otherwise you would smash into the ground.
3	S1:	But that is the case. Only the parachute will save him.
4	S2:	The acceleration isn't increasing? Is it?
5	S3:	No, not increasing.
6	S1:	Why not?
7	S3:	No, the acceleration is not increasing, while…
8	S1:	S9… Is the acceleration increasing when you jump out of a plane? Or is the acceleration constant? You will fall harder, isn't it?
9	S3:	You fall constantly, right?
10	S1:	The velocity increases.
11	S9:	The velocity increases, but not the acceleration.
12	S1:	So… You don't accelerate?
13	S10:	At a certain moment you won't accelerate anymore. You just fall with 150 mph downwards.
14	S2:	So, the gravitational force is constant.
15	S9:	The acceleration is getting smaller.
16	S10:	If you did not accelerate at the start you would float in the air.

As students reached consensus about the interpretation of the different kinematical terms, they proceeded to the *analysis phase* in which they investigated the relations between the different terms. In lessons 3, e.g. they explored how Trinity's vertical displacement depends on time. Stimulated by the movie, some groups displayed the movement to each other by gesticulation, see Fig.2. The movie stunt was shown over and over again, where students discuss the different relations between variables. In some cases they used a digital ruler to determine lengths or areas. Each time when this was done, they compared their answers with their prior-knowledge: Does the measurement make sense to what we already know?

Fig.2. One student trying to relate the actual jump with the velocity of the jumper. Her hand showing the jump

In this phase, discussing and questioning each other are the main types of communication. Most struggles in understanding the physics showed up in this particular phase, as students still lacked the necessary knowledge and had only each other, a formula sheet and the movie to develop new knowledge. Especially with transferring formulas and events to graphs was difficult for them. This is not surprising as this is a well-known problem in literature [21], [22]. However, when they reached an analysis that satisfied them, they moved on to the *solution phase* in which they formulated their final answer to the problem. It is worth noting in this phase that students evaluated their answers with their common everyday knowledge and the event shown in the movie, shown e.g. with this excerpt from lesson four:

1 S3: 104 km/h! That's fast.
2 S1: But it is logical that they make so much speed.
3 S3: Okay, but on such a small road…

As a teacher, we like to have students evaluate their answers, but often they do not see their own mistakes, even when answers diverge on the order of 10^6. In these tasks, students evaluated their answers spontaneously and referred to daily observables, i.e. link the physics with well-known events.

In the final assignment, students show what they learned as demonstrated in Fig.3. (Appendix) This student clearly shows which variables are necessary to analyse the jump, calculates the airtime and the jumping distance. This distance (127 m) is clearly greater than the jumping distance as shown in the movie.

Motivational aspects

As students started with a kind of eagerness to work with the movies, they quickly lost some of their interest during the series of lessons as they felt it was rather a matter of repetition. According to them, each lesson resembled the previous one. Although students said to lose some interest, this was hardly reflected in the lessons: most of the time they were cooperatively working on the problems. In the questionnaires as well in the interviews, students mentioned that working together on a problem that had a practical relevance appealed to them, illustrated by a quote of one of the respondents: "*It is more fun because you understand what it is you are actually doing.*" Working in small groups provided direct feedback and students appreciated the possibility to discuss several problems. Similar problems embedded in a series of lessons with instructional lessons would appeal to them even more as they were uncertain whether their approach was the right one.

DISCUSSION

During the various lessons we saw the same solution process over and over again. Students did not stick with only an analytical analysis but also tried to include the movie scene itself to solve the problem, e.g. by measuring jumping distance or airtime. Although not always successful in terms of giving a scientifically satisfying answer, students developed the procedural skills to analyse a movie scene in terms of physical accuracy. This was shown particularly in the formative assessment in which students directly knew which variables had to be determined and how in order to solve the problem. Furthermore, we see that the conceptual knowledge was extended during the various discussions held. During these discussions kinematical terms come forward and gained meaning for the students. However, not all kinematical terms obtained a scientific interpretation and the relationships between the various concepts and kinematical terms was missing. Students would like to obtain a summary of all the kinematical concepts involved. However, this can also be seen as a benefit from using this approach, as students know their own knowledge deficits, they ask more profound questions during instructional lessons and they have an intrinsic motivation to pay attention as they know why the instruction should matter to them.

CONCLUSION

The developed series of lessons has proven to offer interesting practical problems for students at the age of 16/17. The problems provide a link between physics and the context in which physics is present. Integrating these ideas in different lessons would lead to enthusiastic teenagers eager to debunk Hollywood movie stunts, who instantaneously learn physics.

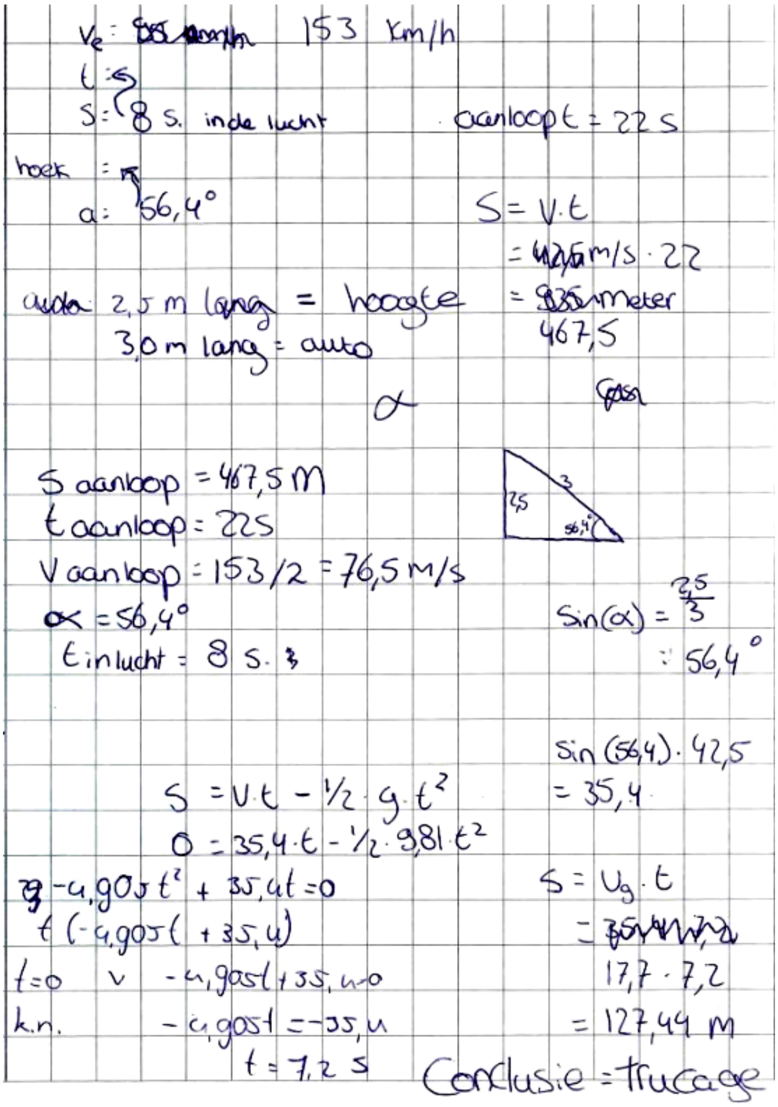
ACKNOWLEDGMENTS

This work is part of the research programme for teachers, which is (partly) financed by the Netherlands Organisation for Scientific Research (NWO).

REFERENCES

1. J. Van den Akker, et al.: *Educational design research*, Routledge, 2006
2. B. A. Crawford: From Inquiry to Scientific Practices in the Science Classroom, in: N. G. Lederman, S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 515-541): Routledge, 2014
3. H. G. Schmidt: Problem-based learning, Med. Ed. 17, 11-16, 1983
4. K. N. Drake, D. Long: Rebecca’s in the dark: A comparative study of problem-based learning and direct instruction/experiential learning in two 4th-grade classrooms. Journal of Elementary Science Education **21**, 1-16, 2009
5. C. E. Hmelo-Silver: Problem-based learning: What and how do students learn? Educational psychology review **16**, 235-266, 2004
6. H. G. Schmidt, J. I. Rotgans, E. H. J. Yew: The process of problem-based learning: what works and why. Medical education **45**, 792-806, 2011
7. P. A. Kirschner, J. Sweller, R. E. Clark: Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational psychologist **41**, 75-86, 2006
8. M. H. Shann: Students' use of time outside of school: A case for after school programs for urban middle school youth. The Urban Review **33**, 339-356, 2001
9. O. James, et al.: Gravitational lensing by spinning black holes in astrophysics, and in the movie Interstellar. Classical and Quantum Gravity **32**, 065001, 2015
10. C. M. Dennis: Start Using “Hollywood Physics” in Your Classroom! Phys. Teacher **40**, 420-424, 2002
11. M. L. Dark: Using science fiction movies in introductory physics. Phys. Teacher **43**, 463-465, 2005
12. Superman debate from the Big Bran Hypothesis, The Big Bang Theory, 2007, https://www.youtube.com/watch?v=DlB1PcgkYLU
13. Mythbusters, 2006, http://mythbustersresults.com/special9
14. P. C. Blumenfeld, et al.: Motivating project-based learning: Sustaining the doing, supporting the learning. Educational psychologist **26**, 369-398, 1991
15. R. D. Knight, J. R. Burciaga: *Five easy lessons: Strategies for successful physics teaching*, Addison Wesley San Francisco, 2004
16. Forrest Gump, 1994, scene: https://www.youtube.com/watch?v=QgnJ8GpsBG8
17. Point Break, 1991, part of scene: https://www.youtube.com/watch?v=0yeqtZrjhcA
18. The Matrix, 1999, scene: https://www.youtube.com/watch?v=u31OjOPF-ZI
19. Road Trip, 2000, scene: https://www.youtube.com/watch?v=xZOg8bzVT5s
20. Gone in 60 seconds, 2000, scene: https://www.youtube.com/watch?v=uH51wYU9Tr4
21. R. J. Beichner: Testing student interpretation of kinematics graphs. Am. J. Phys. **62**, 750-762, 1994
22. L.C. McDermott, et al.: Student difficulties in connecting graphs and physics: Examples from kinematics. Am. J. Phys. **55**, 503-513, 1987

APPENDIX



V_e : 153 km/h
t : ?
S : 8 s. in de lucht
aanloop t = 22 s
hoek = ?
α : 56,4°
S = V · t
= 42,5 m/s · 22
= 935 meter
467,5
auto 2,5 m lang = hoogte
3,0 m lang = auto
α
S aanloop = 467,5 m
t aanloop = 22 s
V aanloop = 153/2 = 76,5 m/s
α = 56,4°
t in lucht = 8 s.
2,5
3
56,4°
Sin(α) = 2,5/3
= 56,4°
Sin (56,4) · 42,5
= 35,4
$S = V \cdot t - \frac{1}{2} \cdot g \cdot t^2$
$0 = 35{,}4 \cdot t - \frac{1}{2} \cdot 9{,}81 \cdot t^2$
$-4{,}905\, t^2 + 35{,}4\, t = 0$
$t\,(-4{,}905\, t + 35{,}4)$
$t = 0 \quad \vee \quad -4{,}905\, t + 35{,}4 = 0$
k.n. $\quad -4{,}905\, t = -35{,}4$
$t = 7{,}2$ s
$S = V_g \cdot t$
17,7 · 7,2
= 127,44 m
Conclusie = trucage

Fig.3. A student’s answer on the question whether the jump could be made