MRS Advances © 2017 Materials Research Society
DOI: 10.1557/adv.2017.61

Physical Physics – Getting students Active in Learning Materials Science

Yvonne Kavanagh[1], Noel O'Hara[1], Ross Palmer[1], Peter Lowe[1], Damien Raftery[2]

[1] Computing & Networking Department, Faculty of Science, Institute of Technology Carlow, Carlow, Ireland

[2] Teaching & Learning Centre, Institute of Technology, Carlow, Carlow, Ireland

ABSTRACT

Physics forms the core of any Materials Science Programme at undergraduate level. Knowing the properties of materials is fundamental to developing and designing new materials and new applications for known materials.

"Physical Physics" is a physics education approach which is an innovative and promising instruction model that integrates physical activity with mechanics and material properties. It aims to significantly enhance the learning experience and to illustrate how physics works, while allowing students to be active participants and take ownership of the learning process. It has been successfully piloted with undergraduate students studying mechanics on a Games Development Programme. It is a structured guided learning approach which provides a scaffold for learners to develop their problem solving skills.

The objective of having applied physics on a programme is to introduce students to the mathematical world. Today students view the world through smart devices. By incorporating student recorded videos into the laboratory experience the student can visualise the mathematical world. Sitting in a classroom learning about material properties does not easily facilitate an understanding of mathematical equations as mapping to a physical reality. In order to get the students motivated and immersed in the real mathematical and physical world, an approach which makes them think about the cause and effect of actions is used. Incorporating physical action with physics enables students to assimilate knowledge and adopt an action problem solving approach to the physics concept. This is an integrated approach that requires synthesis of information from various sources in order to accomplish the task. As a transferable skill, this will ensure that the material scientists will be visionary in their approach to real life problems.

INTRODUCTION

Having physics on a Material Science or engineering programme involves introducing students to the properties of materials through a mathematical lens. Initially, the equations of motion are introduced as these usually describe the motion of cars, something that all students are familiar with. However, this does not immerse the students and it can be difficult to engage them as this approach depends on prior knowledge. A key skill fostered and developed in the Physics modules is being able to solve real life mechanics problems. Using traditional methods, forces such as buoyancy can be difficult to explain and fit into an experimental structure.

Physical Physics is an approach which combines traditional lectures with innovative physically engaging activities which are videoed by the students. The video footage is then critiqued and analysed by the students to achieve specific defined goals. The undergraduate games development students develop a software model to emulate the problem given (as captured by the video) and then develop this into a computer game which can be played. For material science or engineering students, the captured video can be used as a starting point for developing a mathematical model of the concept. In this case there are several simulations that can be used in developing this [1, 2].

Good teaching, according to Ramsden, [3] involves 'engaging students in ways that are appropriate to the deployment of deep approaches' (1992, p.61). For Biggs (2012) [4], this is achieved by constructively aligning the learning objectives, the learning activities and the assessment. The emphasis is on active learning, on what students actually do. In general, for active learning in science, the design goal is to get the students to 'think scientifically' [5]. All Physical Physics tasks and activities are defined to accomplish this goal and lead to deep learning. It has been shown by Freeman (2014) that active learning can increase student performance [6]. The affordances of technology can enable novel learning activities, such as Physical Physics. It supports the process of getting information to stay in long term memory and be retained by the student.

Integrating technology into the pedagogy and using it to engage students can aid in concept comprehension. In this case the definitions of interactive engagement as 'activities which yield immediate feedback through discussion with peers' and traditional as courses which rely 'primarily on passive-student lectures, recipe labs', as described by Hake (1998) [7] are adopted. When students take part in laboratory sessions, which are a necessary and important component for engaged learning, there is traditionally a known process and 'correct' answer. This has been described as science instruction [8] and by internalising this approach, students are prepared for solving unknown problems. In Physical Physics, the controlled experimental setups are designed to reduce cognitive load. This increases the link between the working memory and the long term memory in order to develop the students' critical thinking pathways [8]. Formulating a solution to physical problems using previously learned mathematical tools is something which undergraduate students find difficult.[9] This approach allows the student to reflect on their work and actively engage in finding a solution, making the mathematical modelling a real tool to be used. The students become active partners in their learning.

Another facet of the Physical Physics approach is the collaborative nature of the experiments. By working collaboratively the learners can effectively materialise conceptual artefacts together. As described by Damşa et al (2010) [10]

> 'Constructing shared knowledge objects involves more than just carrying out dialogic interaction. It requires combining individual and collective contributions and learners becoming actively involved in the materialization of ideas in order to give conceptual artefacts a concrete shape and to create a tangible representation of what they are making.'

In Physical Physics, the group approach to observation, problem setup and problem solving aids the student in articulating the problems and therefore internalising the concepts being demonstrated. It has been shown, that if balanced challenges are created by implicit scaffolding, student engagement is increased [11]. By setting up a situation where the student must find the optimum solution in order to make a subsequent task easier, the student has a defined reason for engaging. This approach takes this further by engaging students physically rather than using a simulation. The laboratory sessions are very noisy and the energy level is high.

METHODS

This approach was tested over a two year period with third year undergraduate students on a Games Development Programme. The students study Applied Mathematics in first year, Applied Physics I in second year and Applied Physics II in third year.

During the laboratory session the students are required to demonstrate understanding of the theory by incorporating it into real programming scenarios. Traditionally, comprehension of the equations on motion involved programming an interactive computer game where a cannon ball is shot from a cannon. The user can vary the height of the cannon and the initial velocity of the cannon ball. The most difficult part of this exercise is the actual programming of the scene and the artefacts. The relevance of the physics is easily lost in the process. It is an individual project which requires no engagement with other students.

Catch game

The approach, in Physical Physics, is developing a software model for a game of "catch" which is subsequently developed into an interactive computer game. In this case the students are placed in groups of three and given a football or a basketball. They film one person throwing the ball to another member of the group. They must develop a software model of the trajectory of the ball over the actual path of the ball. Initially this seems trivial, but the students soon realise they must first observe the path of the ball and make sure that the throw will show the trajectory which is easily programmable. This normally involves a lot of discussion and many attempts. Uploading and synchronising the video and programming the physics simulation are now real tasks which require critical thinking to accomplish. Tracking the ball by identifying the relevant parameters is required in order to accurately programme the game. The physics is central to the exercise and comprehension of the trajectory in mathematical terms in apparent.

Buoyancy

This is followed by a laboratory session in which the students must demonstrate comprehension of buoyancy force. Bringing the experiment into the students' laboratory and allowing the students to observe the way in which materials of different density float or sink in water engaged the students. Working in groups, they videoed the different density materials falling into the water. This was followed by the students modelling the material using the equations which were introduced beforehand in lectures. The students see exactly how the equations actually work at predicting the interaction. The students again overlaid the video footage with the mathematical simulation. Following the philosophy of Brenda Romero, that everything has the potential to be developed into an interactive game [12], the Games students were required to develop this footage and mathematical model into an interactive computer game.

Engineering students could use online resources and interactive simulations to model the mathematical concepts and compare them to their own video footage.

RESULTS

In order to evaluate the success of this approach the students completed a survey on their experiences. The survey contained twelve questions which asked the students to express their views. The survey was circulated to the students in third year just after completing the module and to the fourth years who completed the module in the previous year.

The majority of the respondents were male with only one female participant. The age profile of the respondents follows the standard undergraduate student profile with over 80% in the 19-25 age group. This pilot study with Games undergraduate students focuses on the equations of motion and the game of Catch. The survey was sent out to 43 students and 14 responded representing a 32% response rate. Of the participants in the survey 64% were from third year and 36% were fourth year. The fourth year participation rate reflects this gap between the students and completing the module.

The students were asked about their learning experiences in each scenario. The statements used were rated on a five point Likert scale (1- strongly disagree, 2- disagree, 3-ok , 4-agree and 5- strongly agree). The results from the study of the cannon compared to the catch have been previously presented [13].

In Figure 1, the Catch laboratory session is perceived to be the most successful laboratory session. However, making a game out of the Catch laboratory session, was not considered as successful. As developing an interactive game is not a requirement for understanding and using physics concepts, success in this task is not significant in this study. Similarly, the buoyancy video and overlaid mapping was considered more successful than the production of the buoyancy game.

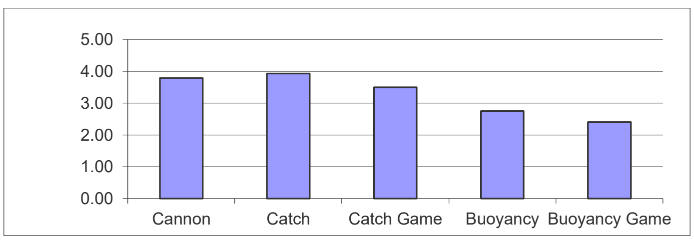

Figure 1. Perceived success of each laboratory session.

Figure 2 and Figure 3 show the different responses from the students when asked how well the laboratory session helped with game concepts and physics concepts. Fields 1-3 concentrate on the learning outcomes required for comprehension and use of physics. The fields 3-6 are evaluating the learning outcomes related to developing an interactive computer game. Comparing Figure 2 and Figure 3 the catch laboratory session is perceived by the students as more successful at demonstrating the physical concepts of motion. The successful focus in the catch laboratory session is on the programming skills of game control and setting up the programming environment. For Games Development students acquiring a comprehension of the time step in programming games can be difficult and this approach is very successful in allowing students to become familiar with time step issues. Given the small numbers in the pilot study, the results are promising and further research is required. Verbal feedback from the students during the laboratory exercises was very positive and they enjoyed facing the challenges involved in this approach.

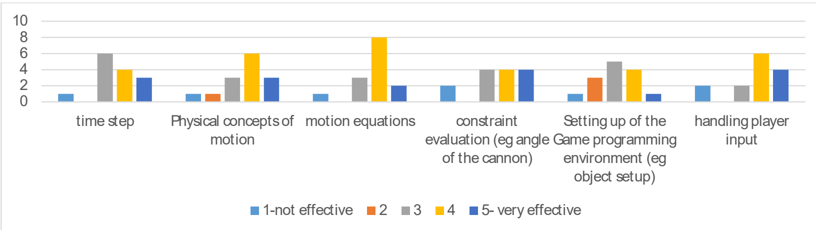

Figure 2. Results from Cannon labaratory exercise.

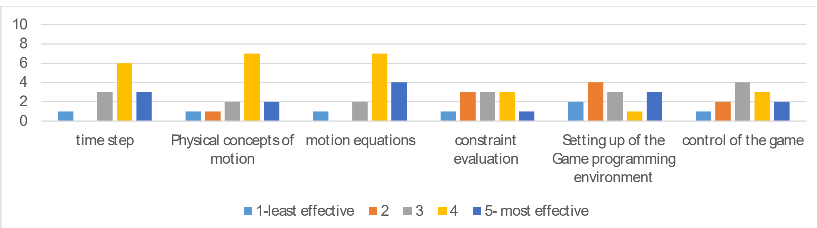

Figure 3. Results from Catch laboratory exercise.

DISCUSSION

In Figure 4a, a sample output screenshot of the actual path of the ball overlaid with the programmed approximation of the trajectory, is shown. This is from the game developed with the user being able to input a speed and angle for the ball until they match the trajectory exactly in order to win the game.

The Physical Physics approach follows the work of Eric Mazur, who advocates that the delivery of information is not enough and that the student needs to build mental models that they can use in different contexts in order that the subject is not reduced to just applying recipes making the subject boring [14]. Using the Physical Physics approach confirms his principle that "better understanding leads to better problem solving". According to Etkina et al, (2010) [15]

> '..when solving an experimental problem, a scientist needs to decide which features of the problem are relevant and which can be ignored; how to represent the problem in different ways, including through the use of mathematical expressions; how to use available equipment to collect necessary data; how to evaluate the quality of the measurements; and how to make sense of the results.'

These steps are observed in how the students approach and complete the "catch" laboratory session. It is also apparent in the buoyancy laboratory session. Here the students accurately simulate the interaction between the material and the water. The screenshot in Figure 4b. captures the physical block experiencing the buoyancy force and the simulated block experiencing the same force.

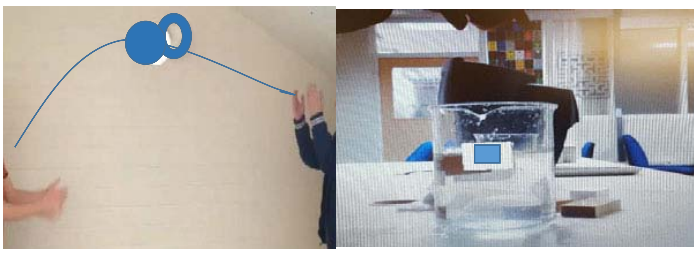

Figure 4. (a) The trajectory of the ball (marked with a "0" for clarity) with the overlaid programmed simulation ( ). Path added for clarity. (b) The block experiencing the buoyancy force overlaid with the programmed block. (is added for clarity)

It is evident that the simulations are accurate and that both the programing and the physics skills can be easily assessed. This gives the students clear and formative feedback instantly. It allows the student to direct their own learning. This gives the students independence in their learning while still being supported. It is important that the scaffold mathematical tools and skills required to accomplish these tasks are covered and that the students have received traditional practice with problems on paper before completing this approach [8]. Physical Physics is a guided approach to experiential and active learning.

CONCLUSIONS

Students who have completed this programme have been surveyed and the outcomes are reported. In general, students considered the interactive nature of the approach to be beneficial and more engaging than the traditional methods they previously experienced.

As well as giving students an appreciation for future augmented reality, this approach to learning brings physics to life, makes physics enjoyable and allows the use of simple equations to highlight complex concepts. It focuses the student on the concept, how to visualize it and program it effectively. This exercise engages the students, enabling them to analyse the effectiveness of their own learning.

ACKNOWLEDGMENTS

The authors would like to thank the Games Development undergraduate students who were willing to participate in this study.

REFERENCES

1. C. Wieman, W. Adams, P. Loeblein, K. Perkins, The Physics Teacher, **48**(4), 225-227 (2010)
2. D. Meyer, Three Act Maths Tasks, www.blog.mrmeyer.com (2016) (accessed 30 October 2016)
3. P. Ramsden (1992) Learning to teach in higher education, (London: Routledge.1992), p 210
4. J. Biggs, Higher Education Research & Development, **31**(1), 39-55
5. L. Deslauriers, E. Schelew, C. Wieman, Science, **332** 862-864 (2010)
6. S. Freeman, S.L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, M.P. Wenderoth, PNAS **111**(23), 8410-8415 (2014)
7. R. Hake, Am. J. Phys. **66**, 64- 74 (1998).
8. P. A. Kirschner , J. Sweller and R. E. Clark, Educational Psychologist, **41**(2), 75-86 (2006)
9. L. Bollen, P. van Kampen, C. Baily, and M. De Cock, Phys. Rev. Phys. Educ. Res. **12**, 020134-1-020134-14 (2016)
10. C. I. Damşa, P. A. Kirschner, J. E. B. Andriessen, G Erkens and P H. M. Sins, Journal of the Learning Sciences, **19**(2), 143-186 (2010)
11. N. S. Podolefsky, K. K. Perkins, W. K. Adams, Physical Review Special Topics-Physics Education Research, **6:2** 020217 (2010)
12. B. Romero, Fulbright Lecture, IT Carlow (2014)
13. Y. Kavanagh, N. O'Hara, R. Palmer, P. Lowe and D. Raftery, presented at EdTech, Dublin, 2016 (unpublished)
14. E. Mazur, Science **323** 5910 50-51,(2009)
15. E. Etkina, A. Karelina, M. Ruibal-Villasenor , D. Rosengrant , R. Jordan and C. E. Hmelo-Silver, Journal of the Learning Sciences, **19**(1), 54-98, (2010)