Hayashi, Y., et al. (Eds.) (2017). Workshop Proceedings of the 25th International Conference on Computers in Education. New Zealand: Asia-Pacific Society for Computers in Education

Using 2D Simulation Applications to Motivate Students to Learn STEAM

Tercia-Marie Tafadzwa TEMBO* & Chien-Sing LEE

Department of Computing & Information Systems, Sunway University, Malaysia

*terciam.t@imail.sunway.edu.my

Abstract: In this paper, we discuss the declining interest in STEM subjects of high school students in Malaysia and delve into our ongoing research towards developing a learning activity that will motivate them to pursue learning STEAM. The activity is developed using a combination of Learning by Design pedagogy along with PhET and Algodoo Simulation applications to teach students Physics topics facilitated by a website with gamification features.

Keywords: 2D Simulations, Physics, Learning by Design, STEAM Learning

1. Introduction

The term "STEAM" refers to the fields of science, technology, engineering, and mathematics together with the arts. The integration of STEM subjects and art and design in education teaches students to think critically and have an interdisciplinary approach towards real-world problems while building on their mathematics and science knowledge. Individually the subjects are important in their own regard but once integrated, STEM is ubiquitous and shapes our everyday lives - one can't fully function without the other. For instance, engineering uses the findings of science research, the application of mathematics for calculations and uses technological tools to design solutions for real world problems, vital to a thriving economy. STEAM Education gives students meaningful experiences and allows them to explore real-world issues for themselves from another perspective. It encourages them to make connections they otherwise wouldn't have made from reading a single discipline textbook.

An adequate implementation of STEAM Education can create generations of critical thinkers and innovators, resulting in a more creative workforce, which will help in the economy's development.

However, Nasa and Anwar (2016) from New Straits Times reported that Malaysia is experiencing a drastic decline in STEM student enrolment, which may result in the country losing the developed nation status in comparison with other advanced countries. Arfudi (2016) reported that only 18% of 500,000 students sit for the SPM annually which is significantly less than the targeted 54%. He attributed the decline to students shying away from the field due to their perception of how difficult it is. In secondary school, the students are divided into science and non-science streams, with the high achievers automatically being placed into the science classes. This segregation instilled the notion that STEM can only be pursued by top students as they are difficult subjects. Similarly, Jayarajah, Saat, and Rauf (2014) and Bunyamin and Finley's (2016) studies on STEM education in Malaysia found that STEM integration was lacking in schools. Furthermore, there is more emphasis on science and technology but the least attention is given to engineering education. However, it is the latter which helps to educate students about the design process.

The ability to motivate students to learn with just direct instruction classes is also a major challenge. If teaching methods focus on reiterating textbook content alone and doesn't implement a more engaging and interactive form of delivery, the students may drift away from the subject with the belief that it is too difficult to understand. O.C (2016) reported that "The main reason students shy away from STEM subjects was because many experienced difficulty and complexity in grasping the basic conceptual knowledge." This shows that educators need to explore diverse teaching methods that can help students apply critical and scientific thinking to better comprehend the learning materials and gain more confidence in pursuing STE(A)M careers.

2. Theoretical Framework

Considering the aforementioned issues, the following literature review will explore methods of delivering STEAM content to students in a more intriguing and less intimidating way that gives the learner more confidence to pursue STEAM subjects while also making clear connections between the subjects and how to utilise them to solve real world issues.

2.1. Literature Review

While reviewing the physics curriculum in Malaysia, Bunyamin and Finley (2016) used a suggestion by Roehrig, Moore, Wang and Park (2012) who stated that there is a natural fit between physics and engineering at high school level. Furthermore, in a survey conducted by Wilkinson and Lancaster (2013) on 209 students, 97 were studying STEM subjects. Findings showed that technology can motivate STEM students. Using these studies as a base, we decided to motivate our students to take interest in STEM using technology to teach them Physics. We referred to Mellema's (2001) physics education pedagogy to determine what type of technology to use and how to integrate it. Mellema's (2001) pedagogy focused on students learning physics with the assistance of Web technology. The Web technology consisted of the WebAssign website that he used to assign tasks such as notes, problems and quizzes. He also used Physlets, interactive simulations of a physical phenomenon that students could interact with to help visualise the concepts and solve problems. His method incorporated testing students at multiple stages of their learning for just-in-time teaching and collaborative context-rich problem solving with ill-structured real-world problems to encourage learning in context. The pedagogy thus aided students to develop Bloom's Taxonomy progressively such as from recalling to understanding and applying conceptual information, while also building a flexible knowledge base, group collaboration and communication skills.

The latter stages of Bloom's taxonomy foster Higher Order Thinking Skills (HOTS). HOTS are important in STEM Education (Bunyamin and Finley, 2016 and O.C, 2016). Using the revised Bloom's taxonomy (Anderson and Krathwohl, 2001) as reference, the topmost level of cognitive ability is the creation skill, where the learner acquires the ability to produce their own original work based on information they analysed and evaluated, showing that they truly comprehended the concept. To work our way up Bloom's Taxonomy's educational objectives, we apply Case-Based Reasoning (CBR) with Problem Based Learning (PBL) in Learning-by-Design (LBD), a pedagogy developed by Kolodner, Crismond, Gray, Holbrook and Puntambekar (1998) and Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar and Ryan (2003). In CBR, students use solutions of past related problems to formulate a solution for a newly presented case. The CBR cycle of retrieving, reusing, revising and retaining cases, teaches students to decompose data, recognise patterns, abstract the essential information and analyse it to draw probable conclusions. This approach picks up where we left off with Mellema's (2001) pedagogy and further builds on the acquisition of Bloom's learning skills by sharpening the apply, analyse and evaluation skill bands. An example of learning outcome, is the ability to design mechanically-powered toy vehicles. Similarly, we will go back to our base theory of using technology and ask our students to first experiment, draw conclusions and subsequently, create a 2D Simulation to be shared with other students. Simulations are important as they can display abstract scientific concepts that may be difficult to recreate in the real world.

2.2. Research Gap and Rationale

Our research extends from Mellema's (2001) in terms of asking the students to design/create. While Mellema's participants only interacted with pre-created Physlets, our students will collaboratively design their own simulations from scratch with the facilitation of a website with gamification features such as points, badges and leaderboards. We believe that these factors have not been tackled in this combination and could contribute to STEAM education in Malaysia. Table 1 shows how our theoretical framework correlates to the problem statements that are causing the decline of interest in STEM subjects by high school students in Malaysia.

Table 1: Correlation between problem statements and theoretical framework.

Problem	Activity Design
Students shying away from STEM subjects due to their perception of how difficult it is.	The activity will be ordered in specified stages that adhere to Bloom's Taxonomy of learning objectives, gradually building on difficulty to ease the student to creation stage.
Difficulty and complexity in grasping the basic conceptual knowledge and connecting to real world situations.	Having an interdisciplinary class activity that makes connections between theory and how to utilise it to solve real world issues.
	The use of simulations while reading notes and designing a solution will help students understand how the theory and calculations are used to design solutions.
Students are divided by achievements, instilling the notion that STEM can only be pursued by top ranking students, therefore it must be a difficult subject.	To dispel this notion, students are grouped heterogeneously by ability so each group is balanced. With varying opinions and academic levels, each student learns that there are multiple ways to solve a problem much like in real world situations.
More emphasis is put on science and technology curriculum, giving the lowest attention to engineering and design process education.	The activity eases students to the final stage of creation, where they will solve a real-world problem using the physics theories they've learnt in the previous stages with mathematical calculations and the use of 2D simulation technology to design a solution, thereby developing an experimental approach to problems.
Motivating students to learn with just direct instruction classes and textbooks is a major challenge.	The use of 2D simulation apps and a website will break their usual direct instruction cycle making the new learning experience engaging. The website with gamification features will motivate students to play more while learning more and keep them excited throughout the activity without losing interest.

3. Methodology

3.1. Participants

The proposed sample group for this study are high school students enrolled in A-Level or SPM Physics programme at Sunway International School. Pre-University students who are still debating on their future careers would be a good sample group as we would capture their thoughts on a STEAM career before and after the activity. We are also in discussion of recruiting middle school students at the same school to gauge whether they would like to pursue STEAM subject electives in high school. A Physics teacher and technology coach there has expressed interest in collaborating for the study. Our sample size may be a class of approximately 25-100 students and we will adopt a participatory design approach with agile methodology in the next iteration of design in order to fit seamlessly with the teacher's plans and activities.

3.2. *Technological Experimental Platforms*

The technology to be used by the participants in this study includes PhET Simulations, Algodoo desktop programme and a complementary activity website. The website will serve as an online reference for the full activity so that the participants can keep track of their progress and records as adapted from Kolodner et al. (1998) and Staikopoulos, OKeeffe, Yousuf, Conlan, Walsh and Wade (2015). The site will feature physics notes, embedded PhET Simulations, multiple choice quizzes and a CBR case library. Other functionalities include a badge and point reward system with a leader board, assignment uploading, discussion forums and questionnaire answering tool.
The Physics Education Technology (PhET) project (phet.colorado.edu) has developed over 80 interactive simulations with many them dedicated to exploring physics concepts. These animated game-like environments emphasize the connections between real-life phenomena and the underlying science that help students to visualise what scientists see in experiments thereby aiding them to answer problems and develop better conceptual understanding (Perkins, Adams, Dubson, Finkelstein, Reid and Wieman 2006 and Wieman, Adams and Perkins 2008). A PhET example for Projectile Motion can be seen in Figure 1, where students can explore factors that affect a cannonball's motion. They are also able to adjust values and use the in problem solving calculations.

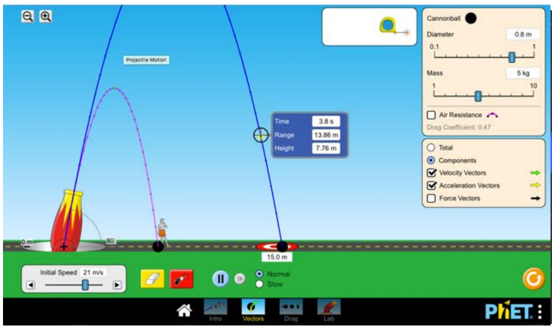

Figure 1. Projectile Motion PhET

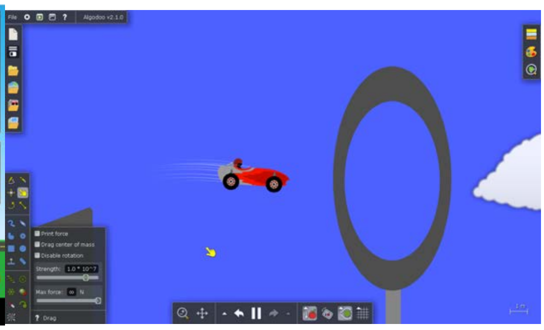

Figure 2. Deformable Race Car Scene

Algodoo (www.algodoo.com) is a 2D-simulation application which allows the user to create simulation scenes using simple drawing tools. Students can interact with your objects and explore the effects of various parameters such as gravity, friction and forces to name a few. It gives the students control to create their own simulations from scratch and investigate multiple physics concepts within one scene so they are not restricted to one topic but can make the connections between various subtopics and learn how they work together to solve a real-world problem. Figure 2 illustrates a realistic deformable race car that goes down an obstacle terrane and crashes if the speeds are not controlled appropriately. Participants can turn on force and speed values to work out what needs to be adjusted for the car to arrive at the finish line safely.

When Da Silva, Da Silva, Guaitolini, Gonçalves, Viana and Wyatt (2014) introduced Algodoo to their high school and undergraduate classes, they reported an increase in student's learning engagement and an improved understanding of the physical concepts when they were visualised and explored on Algodoo's simulation scenes. Research by Gregorcic and Bodin (2017) and Çelika, Sari and Harwanto (2015) saw similar results and agreed that the program was easy to use for all ages and enhanced mathematical and scientific knowledge by creating physics simulations. After scene creation, the application allows the student to save it and share with others which facilitates collaboration.

3.3. *Activity Description*

Figure 3 illustrates the complete workflow of the student activity. The participants will need to take a pre-activity questionnaire that will record their current interest in STEM. The first lesson will have physics notes on a kinematic topic and embedded PhET simulations for them to play with and get a visual on what they are reading. The final task of this lesson will be to take a quiz on the topic and the results of a quiz can be used to group the students by academic ability. Following Mellema's (2001) pedagogy, the facilitator can include low, middle and high achieving students in one group so they are balanced and no group feels under- or over-whelmed. Results will also reveal who is struggling with grasping the topic and allow application of Mellema's just-in-time teaching.

After students are divided into groups of 3 with balanced academic ability, they move on to the LBD-CBR lesson. They will be presented with Algodoo physics simulation cases where they must follow instructions on building objects that will show them how physics concepts work. They will be presented with questions and submit their prediction and evaluations, where their responses will serve as a good measure to see which concepts are hard for them to grasp and should therefore be emphasised in the following cycles.

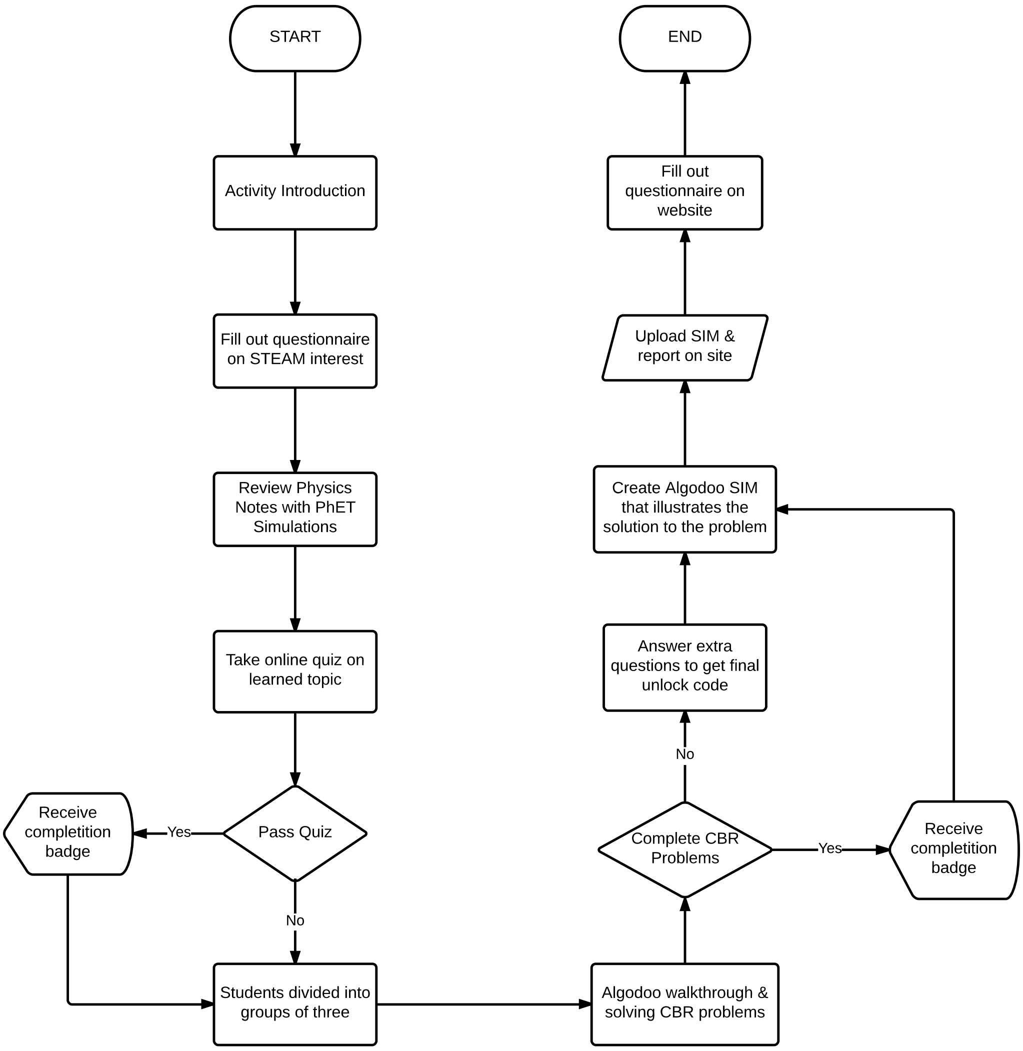

Figure 3. Student Activity Flowchart

All the tasks in the first and second lessons will earn them badges and points. The more cases they practice the more points they receive. A certain number of points will unlock the final activity where they are presented with a real-world problem. Students can go off for self-directed research and brainstorming and then regroup to share their ideas and come up with a final solution. Using Algodoo, they must create a scene illustrating the physics phenomena behind their answers and upload to the website. This will serve as a showcase walkthrough and allow other groups to see and download different solutions thereby opening further discussions on the physics concepts in question.

3.4. Data Collection

The work submissions collected on the website will serve to assess whether they have indeed achieved Bloom's Taxonomy and the learning objectives. The participants will then fill out a post-activity 5 Scale Likert questionnaire to determine their perceptions of the learning experience and if they felt more motivated to take interest in STEAM subjects afterwards. The questionnaire is developed using the Technology Acceptance Model (TAM) and the questions are divided into 6 sections; perceived ease of use, perceived usefulness, perceived playfulness, attitude toward using, intention to use and STEAM interest. These were adapted from research by Jeffrey (2016) and Donaldson (2010) where they investigate user perception towards Learning Management Systems (LMS) and E-Learning Systems respectively. Questions on learners' motivation and intention to use learning systems and how they impact students' STEM interest were selected from research by Huang and Liaw (2014) and Hsu, Lin, and Yang (2016) respectively.

Conclusion

This proposed activity will need to be interdisciplinary to convey how STEAM works together in real-world situations. Science will be fulfilled by teaching Physics concepts. Mathematical skills needed for quantitative reasoning when working with these concepts will be cultivated with the use of Technology to create virtual models that answer real-world problems which is what Science is about. This process should be fun and make scientific concepts easier to grasp while also nurturing higher order thinking skills. This will make STEM less intimidating and motivate students to pursue it the future and learn more about how STEM and STEAM apply to real-world problems on a deeper level.

References

Anderson, L. W., & Krathwohl, D. R. (Editors) (2001). A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. Abriged. NY: Longman.

Arfudi, Z. (2014). *Declining Number of Malaysian Students Taking Science and Math in School, Here's Why*. Malaysian Digest. Retrieved from http://www.malaysiandigest.com/news/614553

Bunyamin, M. A. H. & Finley, F. (2016). STEM Education in Malaysia: Reviewing the Current Physics Curriculum. *International Conference of Association for Science Teacher Education*.

Çelik, H., Sarı, U., & Harwanto, U. N. (2015). Evaluating and Developing Physics Teaching Material with Algodoo in Virtual Environment: Archimedes' Principle. *International Journal of Innovation in Science and Mathematics Education*, *23*(4), 40–50.

Da Silva, S., Da Silva, R., Guaitolini, J. J., Gonçalves, E., Viana, E., & Wyatt, J. (2014). Animation with Algodoo: A simple tool for teaching and learning physics. *arXiv*.

Donaldson, R. L. (2010). *Student acceptance of mobile learning*. The Florida State University.

Gregorcic, B., & Bodin, M. (2017). Algodoo: A Tool for Encouraging Creativity in Physics Teaching and Learning. *The Physics Teacher*, *55*(1), 25–28.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3), 235–266.

Hsu, Y.-S., Lin, Y.-H., & Yang, B. (2016). Impact of augmented reality lessons on students ́STEM interest. *Research and Practice in Technology Enhanced Learning*, *12*(1), 2.

Huang, H.-M., & Liaw, S.-S. (2014). A case study of learners' motivation and intention to use augmented reality learning system. *WIT Transactions on Information and Communication Technologies*, *49*.

Jayarajah, K., Saat, R. M., & Rauf, R. A. A. (2014). A review of STEM education research from 1999-2013: A Malaysian perspective. *Eurasia Journal of Mathematics, Science & Technology Education*, *10*(3), 155–163.

Jeffrey, D. A. (2016). *Testing the technology acceptance model 3 (TAM 3) with the inclusion of change fatigue and overload: A revised model*. Andrews University.

Jolly, A. STEM vs. STEAM: Do the Arts Belong? *EdWeek.org*. Education Week: Teacher. Retrieved form http://www.edweek.org/tm/articles/2014/11/18/ctq-jolly-stem-vs-steam.html

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design into Practice. *Journal of the Learning Sciences*, *12*(4), 495–547.

Kolodner, J. L., Crismond, D., Gray, J., Holbrook, J., & Puntambekar, S. (1998). Learning by design from theory to practice. In *Proceedings of the international conference of the learning sciences* (Vol. 98, pp. 16–22).

Mellema, S. (2001). A physics lecture for the 21st century. *Physics Education*, *36*(4), 306.

Nasa, A. & Anwar, Z. (2016). *Too few STEM Students*. New Straits Times. Retrieved from http://www.nst.com.my/news/2016/05/147260/too-few-stem-students

O.C. (2016). *Is Science too daunting for too many students?* New Straits Times. Retrieved from https://www.nst.com.my/news/2017/03/151648/science-too-daunting-too-many-students

Perkins, K., Adams, W., Dubson, M., Finkelstein, N., Reid, S., & Wieman, C. (2006). PhET: interactive simulations for teaching and learning physics. *The Physics Teacher*, 44, 18-23.

Roehrig, G., Moore J., Wang, H.-H., & Park, M. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. School *Science & Mathematics*, 112(1), 31– 44.

Staikopoulos, A., OKeeffe, I., Yousuf, B., Conlan, O., Walsh, E., & Wade, V. (2015). Enhancing Student Engagement through Personalized Motivations. In *2015 IEEE 15th International Conference on Advanced Learning Technologies* (pp. 340–344).

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008) PhET: Simulations that enhance learning. Science, 322: 682–683. doi:10.1126/science

Wilkinson, R., & Lancaster, T. (2014). Improving student motivation using technology within the STEM disciplines. In *A paper from the STEM Annual Conference* (Vol. 2014, pp. 1–6).