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Impact Of Simulations On The Learning Of Kinematics

Investigating the Impact of Simulations on Students’ Conceptual Understanding of Kinematics Graphs

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Abstract

In the study of kinematics, students’ concepts of displacement, velocity and acceleration are not well differentiated and they often have difficulties in plotting and interpreting motion graphs. This study investigates the impact of simulations on students’ conceptual understanding of motion graphs. This study was guided by the research questions of whether there was any significant difference in the conceptual understanding of motion graphs between students who underwent simulation-based lessons versus those who did not and how students perceived the use of simulations in the learning of Physics. A quasi-experimental research design was chosen. The experimental class (N = 24), underwent simulation-based lessons for 2.5 weeks. The results of the post-test MCQ t-test analysis revealed that the experimental class did not perform significantly better than the control class. However, results from the structured questions t-test analysis, on the other hand, showed that the experimental class performed significantly better than the control class. Taken together, we can perceive that students who used simulations performed just as well, and at times, significantly better than students who did not use simulations. The findings of the focus group discussion suggested that the students had positive experiences in using simulations in the Physics lessons. Students perceived the use of simulations allowed them to “discover things for yourself” and enabled them to achieve a “deeper understanding” of concepts. It is hoped that this study will add to the body of knowledge on the role of simulation-based learning on Physics students’ learning outcomes in a Singapore secondary school.
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Investigating the Impact of Simulations on Students' Conceptual Understanding of Kinematics Graphs

Educators mostly agree that the teaching and learning Physics in the 21st century needs to move away from a system that emphasises on recall of factual information and application of knowledge without deep understanding to one that promotes conceptual understanding through the process of self-directed inquiry and collaboration (Cochran & Sabella, 2008; Dancy & Anderson, 2006). Indeed, research has shown that students learn better when they are able to make sense and construct their own knowledge and understanding of scientific phenomena within the framework of their existing knowledge (Bransford, Brown, Cocking, 2000).

Without sufficient conceptual understanding, students often find it difficult to apply what is learned. For example, in the study of kinematics, students' concepts of displacement, velocity and acceleration are not well differentiated (Jimoyiannis & Komis, 2001; Trowbridge & McDermott, 1980) and they often have difficulties in plotting and interpreting motion graphs (Beichner, 1994; McDermott, Rosenquist & van Zee, 1987). Another example would be in the study of forces where students often have an alternative conception that a force must be acting on an object if the object is moving (Halloun & Hestenes, 1985; Thorton & Sokoloff, 1998). Overall, perceived difficulty in Physics and the way the subject is presented leads to boredom, disengagement and ultimately poor learning outcomes (Chandra & Walters, 2012).

As McDermott (1993) contended, correcting misconceptions and transforming ideas in Physics is often beyond the reach of traditional teaching approaches as these approaches usually ignore the different conceptions that students may have as compared to the teacher. In
the past decades, instructional strategies have been developed to address students’ learning
difficulties, misconceptions and enhance conceptual understanding in Physics. These include
approaches that are lecture-based e.g. Peer Instruction (Crouch & Mazur, 2001), tutorial-
based e.g. Activity-Based Physics (Wittmann, Steinberg & Redish, 2004),
laboratory/workshop-based e.g. Physics by Inquiry (McDermott et al., 1996) and Simulation-
based e.g. Physics Education Technology project (PhET) (Perkins et al., 2006).

These approaches are common in that they use student-centred, inquiry approaches to
learning. The inquiry approach is based on the constructivist theoretical foundations of
learning (Kuhlthau, Maniotes & Caspari, 2007) and refers to the processes that students
engage in to construct their own knowledge and understanding of scientific ideas, similar to
how scientists investigate phenomena (National Research Council, 2000). The inquiry
approach is explicitly stated as the desired approach in Singapore’s Science Curriculum
Framework, which aims for students to be “inquirers” and the teacher, a “leader of inquiry”
(Ministry of Education, 2008).

Many technologies have emerged as viable tools to support students’ inquiry
(Howland, Jonassen & Marra, 2011). As technology becomes increasingly pervasive, the
impact and the conditions in which technology can support and enhance students’ learning
are continually studied. Among many available technologies, computer simulations represent
a promising type of technology that can support student-centred, inquiry-based learning.
According to de Jong and van Jooolingen (1998), computer simulations are considered as
programs that “contain a model of a system or a process”. Simulations may be in the form of
animations, visualisations and interactive laboratories. Simulations embedded in a learning
environment can afford students with a way to explore hypothetical situations, interact with a
process and confirm predictions which may lead to a better conceptual understanding of the
phenomenon investigated (Windschitl & Andre, 1998).
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In science, simulations encourage students to explore and discover information and conceptual relations and hence allowing scientific discovery (de Jong, 2006). By providing a bridge between students’ prior knowledge and the learning of new concepts, simulations can help students develop scientific understanding through a reformulation of their misconceptions (Jimoyiannis & Komis, 2001). Students are able to manipulate the values of the variables in the simulations and observe the outcomes that follow. Through this self-discovery process accompanied by appropriate scaffolds, students are able to experience elements of self-directed learning as they formulate questions, generate relevant inquiries, reflect on their own learning as well as apply what they have learnt to new contexts (Tan, Divaharan, Tan & Cheah, 2011).

In a critical review of 61 recent studies, Smetana and Bell (2012) suggested that simulations could be as effective and in many ways more effective than traditional instructional practices especially when i) used to supplement other instructional modes, ii) high-quality support structures are provided to students and, iii) used to promote cognitive dissonance. However, there are studies that also caution about making any conclusion about effectiveness of simulations on learning especially when students engage the simulations in a superficial and playful level (Yaman, Nerdel & Bayrhuber, 2008). It is also possible that students retain their difficulties and alternate between alternative and correct conceptions from one context to another even after a simulation-based intervention (Tao & Gunstone, 1999).

As with any inquiry-based approaches, students need to be given some form of scaffolding or support when engaging with simulations. Scaffolding implies that given appropriate assistance, a learner is able to attain a goal or engage in a practice that is otherwise out of reach or too difficult (Davis & Miyake, 2004). Overall, there is a positive influence on learning when some form of scaffold is provided to students engaging in
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Simulations (de Jong & van Joolingen, 1998). A common form of scaffold is providing students with questions that require them to predict the outcome of a phenomenon. Prediction questions increase student engagement and help them to identify what is important as well as to build a mental framework for examining the phenomena (Adams, Paulson & Wieman, 2008). Without the mental framework, students might digress from the intended outcomes. Questions and prompts provided by the teacher are also common and significant forms of scaffolding (Kawalkar & Vijapurkar, 2011).

In simulation-based learning, students can either work individually, in dyads or in a small group. Competencies in collaborative learning are key desired traits of a 21st century learner - a dynamic and life-long learner with a “serious yet playful attitude towards ideas” (Chai et al., 2011). In this knowledge age where the demand is on collective intelligence, the ability to collaborate is a critical skill and is valued by employers (Johnson, Adams & Cummins, 2012). The merits of student collaboration in learning science are well established. Learning science should not be an activity done in isolation but is a collaborative process in which students construct knowledge together (Yeo & Tan, 2011). However, there exist several barriers to teachers adopting collaborative methods in class. Besides time constraints and a fear of a loss of control in the classroom, another barrier is the examination-oriented mentality in Asian schools in which individualized achievement rather that collaboration achievement is valued (Lee, Chang & Tsai, 2009).

Smetana and Bell (2012) contended that research on computer simulations deserve continued attention and calls for researchers to explore further on what successful instruction involving computers simulations looks like. Smetana and Bell noted that there exist several methodological limitations that should be addressed by future researchers. For example, many studies do not clearly describe teacher experience, instruction details, simulation
quality and treatment conditions. As the quality and features of simulations advance, Smetana and Bell further noted that earlier studies on simulations need to be replicated in the modern classroom to explore how new features contribute to student learning.

This study attempts to address the aforementioned limitations. Furthermore, as most simulation-based studies are situated in the western context, this study, situated in an Asian-Pacific context, is useful for researchers and educators to make comparisons on the effectiveness of simulations based learning across cultural contexts. This study will propose simulation-based learning as a pedagogical approach to learning Physics. The focus of the intervention is on students' plotting and interpretation of motion graphs.

This study was guided by the following research questions:

Is there any significant difference in the conceptual understanding of motion graphs between students who underwent simulation-based lessons versus those who did not?

How do the students perceive the use of simulations in the learning of Physics?

Method

Participants

A total of 46 students from an all-boys secondary school in Singapore participated in the study. The 46 students were from two classes of 24 students and 22 students each. The ages of the boys were between 14 to 15 years old. The boys were from the Sec 3 Integrated Programme, which is a scheme in Singapore that allows students to take the GCE “A” Levels after a six-year secondary education, bypassing the GCE “O” Levels. The boys are considered to be high ability students.

Procedure and data analysis

The study is based on a quasi-experimental research design. Students (all male) from two Secondary 3 classes will be involved in this study. The topic area to be taught using the
simulation-based approach is motion graphs. The topic covers the plotting and interpretation of distance-time, displacement-time, speed-time, velocity-time and acceleration-time graphs.

A pretest was administered to both classes before the teaching of the topic. The purpose of the pretest was to determine whether there was any significant difference between the students’ prior knowledge on the topic. The pretest instrument consisted of 20 multiple-choice questions adapted from the Test of Understanding Graphs in Kinematics (TUG-K), developed by Beichner (1994). The test was selected as it was reported to have good content validity and is reliable (KR20 = 0.83).

A total of 5 structured questions (with a total of 20 marks) were also included in addition to the posttest. The rationale for the inclusion of the structured questions was to complement the multiple choice posttest by testing students’ ability to provide correct qualitative explanations as well as their ability in sketching and plotting of motion graphs. The structured questions were formulated as part of the Continual Assessment paper for the level and was administered a week after the administration of the posttest. The questions were set by two experienced teachers teaching the level and have been examined by all the Physics teachers teaching the level. The Head of Department of Science then vetted the questions. Through the process of examination and vetting, the questions have been checked to ensure that the questions were clear and tested concepts pertaining to Kinematics and its associated motion graphs. Before the questions were marked, the teachers went through a standardization process to ensure that the scoring was done fairly. Cross-marking was done (teachers do not mark their own students’ scripts) to avoid bias.

The teaching on Kinematics consisted of 6 lessons over three weeks, with each lesson lasting an hour each. A teacher with 12 years of experience taught the control class whereas a teacher with 9 years of experience taught the experimental class. The lesson structure and sequence for both classes were the same. The topic on Kinematics began with an introduction...
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on the topic, followed by a description of terms and concepts, application of concepts and conclusion. In the experimental class, students were brought to the computer lab for a total of five 1-hour lessons to use a simulation to fulfill the learning outcomes (e) to (h) as listed in the syllabus stipulated by the Ministry of Education (2013). The learning outcomes were on students’ ability to plot, interpret and deduce distance-time, displacement-time, speed-time and velocity-time graphs.

The simulation chosen for the experimental group was “Moving Man” which is a PhET (Physics Education Technology) Interactive simulation. PhET simulations are free for educational use and accessible through a standard web-browser. PhET simulations were chosen as they have been given good research coverage and are deemed to be good quality simulations (Wieman, Adams & Perkins, 2008; Podolefsky Adams, Lancaster & Perkins, 2010). For each 1-hour lesson, students worked in pairs and were each given an inquiry worksheet to guide them in the process of self-discovery. Following the recommendations of Adams, Paulson and Wieman (2008), the questions in the worksheet consist of “driving questions” that includes open, conceptual and predictive questions. After answering the questions, students were asked to use the simulation to check their predictions and reflect on their initial predictions. These driving questions enabled students to “explore more deeply” and serves to “direct the students’ attention to a specific concept” (Adams et al., 2008).

The control class adhered to the same syllabus and with the same lesson sequence and duration. However, the teacher did not utilise any simulations in her teaching. Instead, the teacher used verbal explanation accompanied with Powerpoint slides to deliver the stated learning outcomes (e) to (h).

At the end of 3 weeks, all 46 students were given the posttest, which was identical to the pretest. A week after the posttest, the structured questions test were also administered. The scores from the pretest, posttest and structured questions test were imported into SPSS
software for data analysis. Differences in the pretest scores between both classes were
analysed using independent sample t-tests. Similarly, the differences in posttest scores and
structured questions scores were assessed using independent sample t -tests. In addition, the
effect size was determined using Cohen’s (1988) d statistic.

To address the second research question, “How do the students perceive the use of
simulations in the learning of Physics?” a focus group discussion was held after the posttest.
Six students from the experimental class were randomly chosen to take part in the discussion.
The discussion centred on what the students like or do not like about the simulation based
lesson and how the students were able to learn using the simulation.

Results and discussion

Is there any significant difference in the conceptual understanding of motion graphs between
students who underwent simulation-based lessons versus those who did not?

The results of the pretest t-test analysis demonstrated that statistically, there was no
significant difference in the students’ prior conceptual understanding of motion graphs in the
experimental class (M = 8.54, SD = 2.72) and control class (M = 8.32, SD = 2.50), (t = -2.90,
$df = 44, p = .773$), at the .05 significance level. The results show both classes’ prior
conceptual understanding can be considered equal before the lessons were conducted.

The results of the posttest t-test analysis, revealed that although the experimental
class’ mean score was 1.48 higher than that of the experimental class, statistically, the
experimental class ($M = 14.21, SD = 2.67$) did not perform significantly better than the
control class ($M = 12.73, SD = 3.55$), (t = -1.61, $df = 44, p = .115$) at the .05 significance
level.

Results from the structured questions t-test analysis, on the other hand, showed that
the experimental class ($M = 14.83, SD = 1.95$) performed significantly better than the control class ($M = 12.55, SD = 2.24$), ($t = -3.70, df = 44, p = .001$) at the .05 significance level. The effect size was large ($d = 1.09$). Table 1 summarises the results.

Table 1

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<td>Mean</td>
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<td>Experimental</td>
<td>8.54</td>
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<td>14.21</td>
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<tr>
<td>Control</td>
<td>8.32</td>
<td>2.50</td>
<td>12.73</td>
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*indicates significant difference, $p < .05$

From the results obtained by the multiple-choice based Posttest and the structured questions test, we can see that students who used simulations performed just as well, and at times, significantly better than students who did not use simulations. Although the intervention lasted only 3 weeks, we can already see encouraging results in the use of simulations.

**How do the students perceive the use of simulations in the learning of Physics?**

The findings of the focus group discussion suggested that the students had positive experiences in using simulations in the Physics lessons. Students perceived the use of simulations allowed them to “discover things for yourself” and enabled them to achieve a “deeper understanding” of concepts. Students were able to “change the numbers ourselves” and from then they can “see the results”.

The group described the usual way they learnt science was through “memorizing formulas and all that theories” and they learnt “what the teacher teaches us and memorise the format”. The students remarked that the learning experience in using simulations was
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different from the usual way in that they must “predict what is happening” and they use the simulation to “find out whether is wrong or right” and to “gauge where we are in our thinking”.

Working on the simulation in pairs proved to be a positive experience for most students in the group. They described that working in pairs is “actually more effective than working by yourself” and they were able to “discuss things that you are unsure with your partner and if he is unsure also, both can discuss what is the correct answer.... two people can produce more inference and results than by himself”.

Conclusion

In this study, the impact of using simulations in the learning of kinematics was investigated. Students’ perceptions and experiences in using simulation were also explored. Results showed that students who used simulations did just as well, and sometimes significantly better compared to students who did not use simulations. Students’ experiences in using the simulations were generally positive. Students related that they were able to discover for themselves the key concepts in the topic and this led to deeper understanding.

There are several limitations that can be addressed in future studies. One such limitation is that the students in the experimental class may have been “distracted by the novelty of using simulations” (Smetana and Bell, 2012) as the majority of students never had prior hands-on learning experience using simulations. To reduce this novelty effect, students could have been given more exposure to simulations in preceding topics. It would also be uncertain if students’ positive perceptions will be sustained if the intervention was carried out for further topics. Other limitations include the relatively small sample size and an all-male higher ability sample - this would make it harder for the results to be interpreted and generalised for the general population.
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Research on the impact of interactive computer simulations on students’ learning is still relatively limited (Adams, et al., 2008). It is hoped that despite the limitations, this study will add to the body of knowledge on the role of simulation-based learning on Physics students’ learning outcomes in a Singapore secondary school.

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