Developing and Piloting Interactive Physics Experiments for Secondary Schools in Tanzania

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Abstract

Students in secondary schools in Tanzania have been facing difficulties in conducting laboratory experiments. This has been due to the acute shortage of laboratory facilities and poor teaching methodologies. Consequently, students perceive science subjects as unattractive, difficult and irrelevant to understanding the world around them. An interactive physics experiment was developed and piloted in two schools with 157 students to investigate whether interactive experiments can be used as an alternative to physical experiments. Results show that students found the interactive experiment was easier and more efficient, and, therefore, can be used as an alternative to physical experiments.

Introduction

The current failure rate and lack of interest among students in science subjects in secondary schools is a serious problem in our society (Siabeycius & Poicin, 2012). Students encounter numerous difficulties when learning science subjects. These subjects require students to engage in collaborative learning, problem solving, and to conduct intensive laboratory practical experiments. Nonetheless, students tend to learn mechanically, memorizing facts without gaining true understanding (Schauer, Ožvoldová, & Lustig, 2009). It becomes even more difficult when they are required to learn how to conduct practical experiments.

At the moment, science experiments are conducted in laboratories with assistance from teachers and laboratory technicians. Teachers perform experiments by following step-by-step instructions, and demonstrating physical principles with various apparatus while students passively observe (Schauer et al., 2009). In schools where laboratories and/or apparatus are not available, teachers use chalk and blackboards to explain the laboratory work in the classrooms. In both cases, teachers tend to over-emphasize theoretical concepts that are not explicitly linked to practice (Stutchbury & Katabaro, 2011).

Due to an acute shortage of laboratories, poor teaching methodologies, and other challenges, students perceive science subjects as unattractive, very difficult, tedious, incomprehensible, boring, and irrelevant to understanding the world around them (Siabeycius & Poicin, 2012; Wieman & Perkins, 2005). Consequently, students have lost interest in taking these subjects at the higher levels of education (Speering & Rennie, 1996). Experiments play a key role in the teaching of science subjects as they allow students to observe phenomena, test hypotheses, and apply their understanding of the physical world (Chiaverina & Vollmer, 2005).

It has been observed that the number of students dropping science subjects in secondary schools, especially Physics, in Tanzania has increased significantly. For instance, 74% of students dropped Physics in 2010 compared to 54% who dropped Biology and 60% who dropped Chemistry (Mabula, 2012). Similarly, the pass rates in Physics in secondary schools in Tanzania remained very low. For example, the pass rate in Physics was 26.3% in 2008 and dropped to 13.7% in 2011 (MoEVT, 2012).

The poor performance in science subjects and continuing dropouts have triggered the government of Tanzania and other stakeholders to find various alternatives to make these subjects more interesting and understandable while reducing the failure rates (Beauchamp & Parkinson, 2008).

It is believed that Information and Communication Technologies (ICTs) can play a crucial role in overcoming the problem (Siabeycius & Poicin, 2012). As a result, the Government of Tanzania has been improving ICT infrastructure and establishing relevant policies that promote the integration of ICT in education. The most notable efforts include the implementation of the National ICT Backbone, the development of National ICT Policy (URT, 2003), and ICT Policy for Basic Education (MoEVT, 2007). The National ICT Backbone has reduced telecommunication costs (Swarts & Wachira, 2010) and increased Internet speed up to 155Mbps (Lwoga, 2012). The government also exempted all Value Added Tax (VAT) on ICT facilities (Sife, Lwoga, & Sanga, 2007) as well as cutting mobile phone interconnection charges by 69% (ITU, 2013).

Despite these initiatives, the application of ICT to enhance education, especially in secondary schools, is still limited. Speaking at the conference for science and technology organized by Tanzania Commission for Science and Technology (COSTECH) in 2010, the President of the United Republic of Tanzania emphasized the utilization of ICT to develop and share quality teaching aids and textbooks (Mabula, 2012). In line with this call, under this study an interactive experiment was developed that will be used by students to enhance their competencies in conducting physics experiments.

Experiments are very important in the teaching of science subjects as they give students an opportunity to have direct contact with natural phenomena. More specifically, experiments can motivate students, provide concrete examples of complex concepts, increase understanding of technical apparatus, and verify predictions, theories or models (Chiaverina & Vollmer, 2005). So far, studies to enhance science experiments in secondary education, especially in developing countries like Tanzania, are limited.

In this study, an interactive Physics experiment was developed and piloted to 157 students from Canossa secondary school and Loyola high school in Dar es Salaam. Out of 157 students, 57 had not performed a similar experiment in a laboratory before. The study aimed at investigating whether interactive experiments could be used as an alternative to physical experiments. The simple pendulum experiment was used as a case prototype, and was made available via the Internet and Compact Discs (CD) for students to access. With this experiment, the students are expected to gain understanding of the concept of gravitational force and be able to determine acceleration due to gravity “g”.

Theoretical Background

The use of computer animations to develop educational resources, famously known as “interactive content”, is regarded as a promising instructional strategy for enhancing science education (Beauchamp & Parkinson, 2008; Chien & Chang, 2011). Interactive content is a dynamic representation that can be used to make complex processes explicit to the learner (Rosen, 2009). It can be used to present difficult concepts in the subject (Peeraer & Petegem, 2010), and enhance students’ understanding of basic and complex concepts (Voogt, 2003).

Since interactive content is characterized by interaction (Aloraini, 2012), it is well suited for demonstrations and simulations that can be used as an alternative to experiments conducted in face-to-face settings. This is because, interactive content presents information through visual and/or auditory channels via multiple formats, such as graphics, on-screen text and narrations (Lin & Atkinson, 2011). These experiments can support students with different learning styles, for example, those who prefer video or those who prefer audio (Mtebe & Twaakyondo, 2012).

Several studies have demonstrated the usefulness of interactive experiments in various contexts. For instance, Rieber (1990) developed an interactive experiment to describe Newton’s law of motion using both static and animated graphics. The author found that participants in the animated graphics scenario had a better understanding of the concepts and rules of Newton’s law than those participating in the static graphics scenario. Similarly, Yang et al. (2003) found that participants demonstrated better understanding of chemistry concepts when using interactive experiments.

Schauer et al. (2009) developed a comprehensive interactive experiment—“the INTe-L”—that consisted of electromagnetic induction, oscillations and photovoltaics. These three experiments demonstrated the usefulness of interactive experiments in enhancing students’ mastery of experiments. Other studies that have demonstrated how interactive experiments can be used to enhance student learning include ones in cell biology (Stith, 2004), histology (Brisbourne, Chin, Melnyk, & Begg, 2002), molecular chemistry (Falvo, 2008), and mathematical concepts (Taylor, Pountneya, & Malabara, 2007).

Students can repeat these experiments as much as they want at any time and thus maximize learning time. Teachers in schools with an acute shortage of apparatus and laboratories can also use them to show and demonstrate experiments in classrooms that would not otherwise be possible in face-to-face settings. Generally, appropriate use of interactive experiments can potentially reduce significantly the current students’ dropouts and failures in Physics and other science subjects in secondary schools in Tanzania.

The Interactive Experiment

A simple pendulum experiment was developed based on a 3-tier architecture to give the user full control over the experiment as well as to enable it to run in real time. The prototype of the experiment was developed using Action Script. Two Physics teachers and two students from two different schools reviewed and recommended some improvements before finalizing the prototype.

Coding was done to create the variables and buttons to be used, such as play, pause and reset buttons and to add an event listener to the buttons so that they could respond when clicked. The pause and reset buttons were made invisible while the play button is visible. The bob was then made and given a position at which it will appear on the screen. A stick was made for one of its ends to hold the bob while the other end is fixed. Figure 1 shows the view of the developed pendulum experiment.

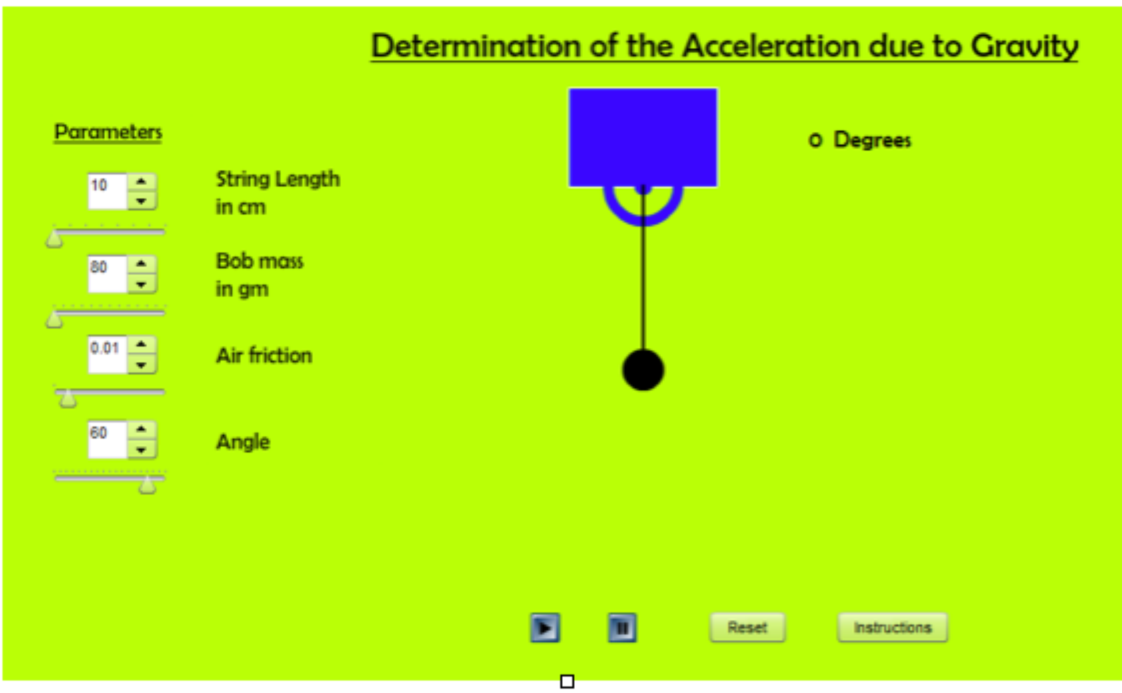

Figure 1: Experiment to Determine Acceleration due to gravity, "g"

At the beginning of the experiment, the student sets the parameters of the string length, angle, air friction and bob mass. Thereafter, the play button is clicked and immediately the user starts the stopwatch while counting the oscillations. For this particular experiment, the student has to count up to 10 oscillations. After ten oscillations, he/she will immediately stop the stopwatch and record the time taken for the pendulum bob to swing at that particular length. The student have to repeat this procedure five times and calculate the average time for the same length and then repeat the same procedure for different lengths. The collected data will be filled in the sample table as shown in Table 1.

Table 1. Experimental Data Collection Form

String length L (cm)	Time t for 10 Oscillations (sec)	Period T = (t/10) (sec)
10		
30		
50		
70		

The time t recorded on the table is the average time obtained after repeating the same procedure for the same length. The period T of one oscillation is thereafter calculated, after which T2 is determined. The values of L, t, T and T2 are recorded in a table. The above-mentioned procedure is replicated for different values of L, for example, 70 cm, 50 cm, 30 cm and 10 cm at a constant bob mass, angle and air friction. After that, the values of T2 (y-axis), against L (x-axis) are plotted on a graph to obtain its slope, as a result of which the gravitational acceleration, g, will be calculated with the SI units of length being in metres.

Research Methodology

Research Design and Data Collection

Data was collected using both quantitative and qualitative research techniques from students. The schools were selected on the basis of convenience. The main criterion being the presence of computing facilities at a given school.

The study adopted the questionnaires and semi-constructed interview data collection tools. Students were given an e-experiment to test with sample data for two days. The experiment was left in the computer lab and, after some instructions, students were left to test and use it independently. The same copy of the experiment on CDs was distributed to students. After two days, students were asked to fill in the questionnaire and return it to their teachers. Out of 250 questionnaires distributed to students, 157 students completed and returned the questionnaire. The response rate was 62.8%.

Qualitative measures were considered to usefully supplement and extend the quantitative analysis. Students were asked to provide their general comments and opinion about the interactive experiment and if such experiments could be used in the future.

These were collected through semi-structured interviews with selected students. The data collection was undertaken between February 2014 and April 2014. Data management and analysis was performed using Statistical Package for the Social Sciences (SPSS) version 20.

Demographic information

The demographic information indicates that, there were 157 students who participated in the study with 55% being males and 45% females. Nearly two thirds (66.9%) of students were from Canossa secondary school and one-third (33.1%) of them were from Loyola high school. Moreover, 86 students were in form III while 71 were in form IV of the Ordinary Level of Education in Tanzania. Figure 2 shows respondents' demographic information.

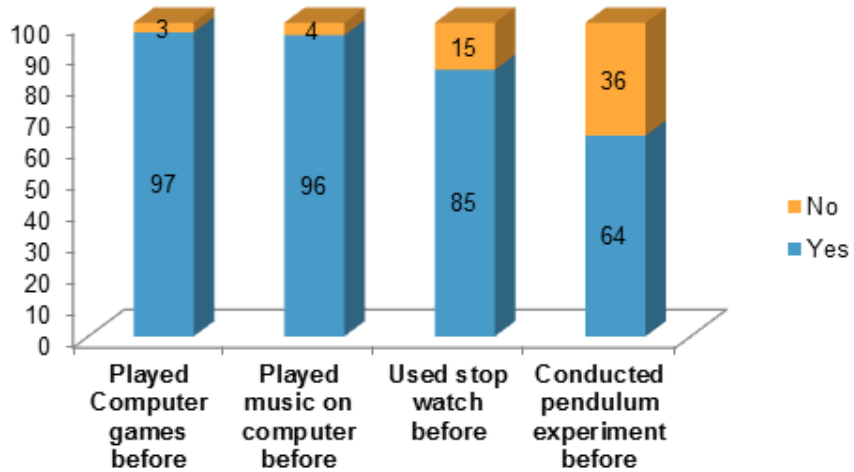

Figure 2: Respondents' Demographic Profile

Research Results

Prior Computer Knowledge and Skills

The use of interactive experiment requires students to have some prior knowledge and skills of related technologies. Therefore, respondents were asked to indicate whether they had used computer games, played music on computer and used a stopwatch before. They were also asked to indicate whether they had conducted the pendulum experiment before.

The study revealed that the majority of students (97%) had played computer games, 96% had played music on a computer, and 85% had used a stopwatch before. Furthermore, more than two-thirds (64%) of students indicated that they had conducted the pendulum experiment in the laboratory before. However, 36% of students had not conducted this experiment in the laboratory before. Figure 3 shows the distribution of respondents based on prior computer experience.

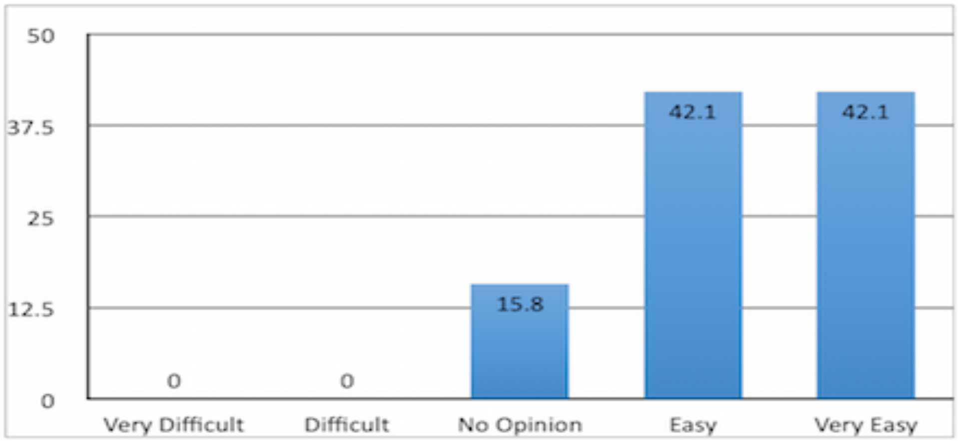

Figure 3: Prior Computer Knowledge and Skills

Students had not conducted the experiment before

As shown in Figure 3, 36% of students who performed the interactive experiment had not conducted the same experiment in the laboratory before. We were interested to find out whether the explanations provided in the experiment were satisfactory and whether students were able to understand how to perform the experiment. The majority of respondents (89.5%) indicated the instructions were clear and that they were able to conduct the experiment without any guidance. However, 10.5% said the instructions were not adequate.

Finally, respondents were asked to rate the level of difficulty of the interactive experiment in a 5-point Likert scale. The results revealed that the majority of students found the experiment easy (42.1%) or Very Easy (42.1%) as shown in Figure 4.

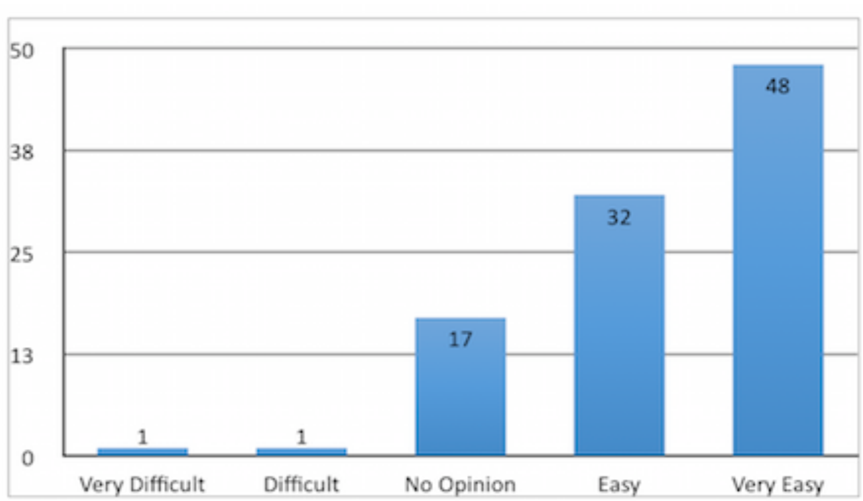

Figure 4: Level of Difficulty of the Interactive Experiment

Ease of use of the interactive experiment

Developing an attractive, aesthetic and easy-to-use experiment is key to help students perceive an experiment as being effective. Furthermore, if the interactive experiment is not easy to use, students will spend more time learning how to use it rather than learning how to conduct experiments (Falvo, 2008; Lanzilotti et al., 2006).

Therefore, respondents were asked to describe the level of ease of use of the interactive experiment on 5-point Likert Scale [1 = Very Difficult, 2 = Difficult, 3 = No Opinion, 4 = Easy, 5 = Very Easy]. The overall response to this question was very positive. The majority of respondents (80%) indicated that the interactive experiment was easy to do, with 32% indicating it was easy and 48% indicating it as very easy (Figure 5).

Figure 5: Level of Ease of Use of the Interactive Experiment

Ability to use the interactive experiment independently

After testing the interactive experiment for two days, respondents were asked to indicate if they could do it without help from the developer or the teachers. The majority of respondents (84%) said 'Yes', while only 16% of the respondents said they could not use the experiment without help.

General Comments and Suggestions

Finally, students were asked to provide their general comments and opinion about the interactive experiment and if such experiments could be used in the future. The majority of students commented that the interactive experiment was more accurate, easier, enjoyable and efficient than the laboratory experiment. Moreover, they pointed out that doing interactive experiments give them another opportunity to learn computer skills. Here are some of their comments:

“It’s better than normal experiments because there is much time and you don't need very many apparatus as in the lab.”

“Doing the experiment online gives someone the capacity of understanding than just learning theoretically, so we should get use of that to increase our understanding capacity.”

“Online experiments are faster than laboratory experiments, so I would like to do more online experiments than in the laboratory.”

“Online experiments give more challenges than the one in the laboratory since students do it individually and practically.”

“It is very interesting and makes me develop new different knowledge, skills in using computer and at the same time as doing experiment.”

“It is easier and it requires less time compared to the real practical.”

Some students worried that one needs computer skills to be able to conduct such experiment. Many students in secondary schools in Tanzania do not have computer skills; therefore, it would be very difficult to deploy such kinds of experiments in many schools in the country. Similarly, one student was skeptical about such experiments and stated “…they are not beneficial because no apparatus is seen by the student to understand and learn”.
Some students had specific comments related to the interactive experiment itself. For example, one individual stated “The stopwatch should be on the computer so as to avoid errors in recording time by manual stopwatch”.

And another commented, “The pendulum experiment does not consider the deceleration factor of the bob. But online experiment is easier to do”.

Discussion

This case study aimed at investigating whether interactive experiments can be used as an alternative to physical experiments and, therefore, overcome the existing shortage of laboratories and apparatus in secondary schools in Tanzania. An interactive simple pendulum experiment was developed and piloted with 157 students. The findings from this study revealed that interactive experiments could be used as an alternative to physical experiments. Students found the simple pendulum experiment was easier, more enjoyable, and more efficient than the laboratory experiments.

The present findings seem to be consistent with other research conducted previously (Brisbourne et al., 2002; Falvo, 2008; Mtebe & Twaakyondo, 2012; Stith, 2004; Taylor et al., 2007). For example, Mtebe and Twaakyondo (2012) found courses developed using animations and simulations enabled students to grasp difficult concepts more easily in a study conducted with 108 students at the University of Dar es Salaam in Tanzania. Similarly, Falvo (2008) reported that students found conducting Biochemistry experiments using animations was easier and faster than physical experiments.

The most interesting finding emerging from this study was that even students who had not done a similar experiment before in the laboratory were able to do it without guidance. More than 80% of students who had not conducted the same experiment previously described the experiment as easy and possible to do without guidance from teachers. This implies the possibility of conducting interactive experiments with new students, especially in schools with an acute shortage of laboratories, apparatus and teachers.

This study has come at the time when the MoEVT has introduced ICT curricula for secondary schools and teachers education, coupled with continued improvement of ICT infrastructure in the country. Many secondary schools continue to be equipped with computers and the Internet. The price of ICT equipment and mobile devices is becoming affordable to the majority of people in the country. Therefore, students can easily access these experiments via mobile devices anywhere and any time.

Suggestions for Future Research

Despite these findings, our study is subject to at least three main limitations. First, our study used a single experiment, i.e., a simple pendulum experiment (due to time constraints). Future research could include more than one experiment and compare the findings from multiple experiments to gain more understanding of the usefulness of interactive experiments in enhancing science subjects.

Second, our case study relied on students as respondents. Although students are the key stakeholders in the use of interactive experiments, other important stakeholders, such as school management and teachers, were not considered. More research is needed to better understand the perceptions of these stakeholders to get a wider picture of the use and usefulness of these experiments. For instance, teachers might be asked if they could adopt and use these experiments in face-to-face classrooms.

Third, the schools involved in the study were selected from those with computer facilities. More research on this topic needs to be undertaken in schools without computer facilities, especially those located in remote areas in Tanzania. Such studies will enable researchers to find out if these experiments can be used with students who have not done similar experiments and who do not have computer skills.

Finally, another possible area of future research would be to compare the validity of data obtained from interactive experiments and physical experiments. In our case study we did not do such comparison due to time constraints, and the design considered the environmental wind condition to be zero so ther

Conclusions

The failure rate of science subjects in secondary schools in Tanzania is alarming. For many years now, the Government of Tanzania and other stakeholders have been finding various ways to alleviate this problem. Studies have consistently described how the appropriate use of ICT can overcome the challenges facing students to learn science subjects. As demonstrated in this case study, interactive experiments can be used in schools with a shortage of laboratories and/or apparatus. Teachers can also use these experiments to demonstrate various experiments in the classrooms.

However, it may be noted that interactive experiments cannot replace real laboratories. Students need to have hands-on skills using real equipment. Interactive experiments can be used as a substitute and/or a support in cases where there is inadequate laboratory equipment. Though interactive laboratory experiments cannot fully replace physical experience, they are better for students than learning experiments only using theory.

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