Cultivating science process skills among physics students using PhET simulation in teaching

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Abstract. This paper concerns with the use of simulation as a pedagogical tool for a physics teaching strategy. This action research was conducted to investigate the scientific skills as a result of modelling learnt using PhET simulation. The cycle of action research involved in this study is planning, acting, observing and reflection. Through combining physics simulation with Science Process Skills (SPS) and Manipulative Skills (MS) to deliver real experimenting experience, the discussion is further to make connection with students’ achievement in Physics. One physics class involved in this study consist of 36 matriculation college students. Prior the study, students were briefed on the procedures for conducting the Harmonic Motion experiment using the PhET Simulations. Following this, students must completed the practical report for analysis, data interpretation and discussion. At the end of the teaching, a set of formative test was used to evaluate students’ mastery of Physics concepts after conducting the Simple Harmonic Motion simulation experiment. The results showed an increase in the percentage of frequency of study participants practicing Science Process Skills and Manipulative Skills (Conducting Experiments). In the Formative Test, the study participants showed a high average score of 13.9 marks, which is 93%. This study is able to develop the advantage of multimedia for physics laboratory works and explore its potential to strengthen scientific skills.

1. Introduction
Education in Malaysia as enshrined in the National Education Philosophy is a continuous effort to further develop the potential of individuals in a comprehensive and integrated manner to produce a balanced human being, in terms of intellectual, spiritual, emotional, and physical. The Primary School Science Curriculum Standard (KSSR) and the Secondary School Science Curriculum (KSSM) were developed to produce the desired human beings [1], in the National Philosophy of Education. KSSR and KSSM introduce six pillars that focus on the formation of balanced human capital in terms of physical, emotional, spiritual, intellectual, and social. One of the six pillars is the pillar of science which emphasizes the mastery of scientific knowledge, skills, and attitudes.

The Matriculation Program emphasizes inquiry as a way for enhancing students’ ways of knowing in subject matter discipline. In the process of inquiry, problem-solving scientific skills and thinking skills need to be used. Scientific skills are cultivated in any activity by performing the desire scientific method. Scientific skills consist of science process skills and manipulative skills [2,3].

Science process skills such as making accurate observations, taking measurements in the right way, using appropriate measuring tools, drawing conclusions, making hypotheses, predicting, interpreting data, and controlling for variables are further developed during practical sessions. Such processes are
integrated to help students improve Higher Order Thinking Skills such as analytical, critical, and creative thinking skills. These skills are very important to prepare students for the challenges ahead in the 21st century [4].

Manipulative skills such as operating instruments, setting up apparatus properly and drawing diagrams [5] can be extended through practical sessions. Laboratory experiments are designed to encourage students to have an inquisitive mind. It requires students to actively participate in science process skills before, during and after experiments by preparing pre-reports, making observations, analysing results, and drawing conclusions [4]. A combination of science process skills and manipulative skills can enhance students’ high-level thinking skills.

The spread of the Covid-19 pandemic in Malaysia has seen a very drastic shift in new norms, including in the aspect of physics education. At the ministry level, teachers are required to adopt the hybrid Teaching and Learning (T&L) as the counter measure due to pandemic [6]. There are three modes of teaching and learning in the science stream at matriculation, namely lectures, tutoring and practical. This study focuses on the changes made in designing the practical lessons. Practical Physics subject often implemented through face-to-face because it allows students to master the necessary skills and ways of thinking as scientist [7]. Unfortunately, with Covid-19 pandemic situation, face-to-face teaching and learning cannot be implemented to reduce the risk of infection since June 2020.

These changes are not unique in Malaysia only, since other countries in the rest part of the world are force to make drastic changes in teaching subject that require laboratory assessment. For instance, in United Kingdom, [8] reviewed challenges among tertiary education when it comes to transform traditional to online learning. Some of the similarities with Malaysia are the acceleration of multimedia and opportunity to popularize remote laboratory practice. In this study, from the simulation method, students can still conduct experiments and practice scientific skills even without physical laboratory facilities. For instance, works done by [9] report on collaborative strategy between asynchronous and synchronous to conduct laboratory activities during pandemic. One of the advantage highlighted by [9] with remote lab is the opportunity to activate student’s agency toward learning. [10] added that remote laboratory is way influential to activate practical skills of science and become useful resources that enhance accessibility to learning.

The Physics Education Technology (PhET) simulation program was developed by the University of Colorado at Boulder, USA [11]. Its’ main purpose is to facilitate teachers and students to do laboratory activities in the classroom. PhET simulation is a user-friendly simulation because it can be run using an existing web browser. Simulations in PhET are available free of charge and can be accessed through the website http://phet.colorado.edu.

PhET simulations use graphics with animated visuals [12]. These simulations are designed in an animated, interactive, and game-like form where students learn through exploration. PhET simulations combined the results of research and variables performed by students so that students can relate the phenomena of daily life with the correct Physics concepts. Thus the use of PhET simulation is recognized for its validity worldwide [11].

Based on the information from the University of Colorado Boulder, PhET simulations were developed using the following design principles. Firstly, to encourage scientific research, second, to provide interaction, third, to create something invisible to the naked eye, fourth, to feature visual mental models, fifth, to feature some representations (examples, object movements, graphs, numbers, etc.), the sixth connects users with the real world, the seventh gives users on implicit guidance in exploration, and the eighth makes flexible simulations and can be usable in a variety of educational situations.

Several tools in PhET simulation also provide an interactive experience [13], such as: first click and drag to interact with simulation features, secondly, launch the cursor to increase and decrease parameters and thirdly, make measurements in experiments with various instruments. Users who interact with the tool are immediately notified on the feedback of the impressions of the changes that they have made. This allows them to investigate cause-and-effect relationships and answer scientific questions through simulated exploration.
Physics is one of the core subjects for the Matriculation Program of the Ministry of Education Malaysia (MOE). The KPM Matriculation Program is divided into two systems, the Two Semester System (SDS) and the Four Semester System (SES). The researchers focused this action research on SES Module 1 students as the researcher was also teaching and supervising the class involved.

Scoring for Physics subjects is divided into two, written assessment 60% and continuous assessment (PB) 40%. Weighting for PB, 10% of practical test, 20% of practical report and 10% of assignment. Assessment of practical tests and practical reports involves the mastery of scientific skills by students.

Below are the reflections obtained in previous lesson when teachers are forced to adopt emergency remote teaching. The temptation to focus on educational outcomes during pandemic time, with learning outcome for face-to-face learning has created dissatisfaction among teachers and students with the learning experiences. Teachers on the other hand is force to create creative problem solving to generate various possible solution to meet the need of educational standard.

Lecturers’ Reflections
Following the increase in COVID-19 pandemic cases and the implementation of the Conditional Movement Control Order (MCO) by the National Security Council involving almost all states in Malaysia, the Ministry of Education (MOE) has decided that all Matriculation colleges implement a blended teaching and learning (T&L) process [6]. This blended teaching and learning practices a combination of face-to-face and non-face-to-face teaching and learning [14]. For practical mode, the time allotted is two hours per week for each class. Due to the large number of students coupled with the laboratory space and the limited number of laboratories, online face-to-face teaching and learning is implemented.

For teaching and learning practical mode, the supervising lecturer provides a video of the process of conducting the experiment up to obtaining readings from the experiments conducted. This video is uploaded through the YouTube platform to make it easier for students to download practical videos. Instructions to guide students in the teaching and learning process are uploaded through the Google Classroom (GC) platform. Finally, students will complete a practical report and uploaded it through the GC platform for their supervising lecturer review.

The researchers are aware that this teaching and learning process as a whole does not provide opportunities for students to practice scientific skills. Science process skills such as classifying, predicting, communicating, controlling variables and experimenting [4], cannot be practiced by students. Researchers feel that this needs to be improved because of this situation will have a great impact on students’ ability to improve their high-level thinking skills such as having analytical, critical, and creative thinking skills which is an important agenda in nation building and to face progress and challenges and global change waves in the 21st century.

Students’ Reflection

Through the Google Classroom (GC) platform, researchers have provided a special space for students to write down their weekly reflections. This reflection space is open to no compulsion or obligation to be written by the students. In addition, to encourage the writing of sincere reflection from the hearts of the students, no name or matriculation number is recorded. The information of the reflection writer remains the secret of the students.

Some scraps written by the students showed their difficulties in the teaching and learning process that they faced.

'Wasting time waiting for videos or loading work in google classroom'
'Learning using video'
'Ineffective learning.'
'I became more depressed'
'Difficult to download learning videos given by lecturers'
Looking at these reflections, thereby this study proposes as a solution to overcome issues with access to cultivate science process skills. The aims are to provide experience for students to do virtual experiments using PhET Simulation and to strengthen students' thinking skills in increasing their intellectual power.

Specific objectives:
1. To strengthen students' science process skills, through virtual inquiry.
2. To strengthen students' manipulative skills.
3. To strengthen students' knowledge and understanding of the facts and Physics concepts.

2. Method
Basically, every action research will involve two elements, namely research and action. These two elements are then developed and detailed into research models that action researchers follow. This study used action research model by Kurt Lewin 1947 [4]. Kurt Lewin (1890-1947) is known as the father of action research because he is considered to be the first person to mention the term action research through an article entitled Action Research and Minority [15]. He proposes a spiral process involving steps of planning, action and fact finding [16].

2.1 Planning
In this action research, the research instruments used are scientific skills checklists, student practical report rubrics and formative tests. Scientific Skills checklist is used to obtain information from students, science process skills and manipulative skills practiced during the teaching and learning process of practical mode in a non-face-to-face manner. The practical report rubric is an evaluation guideline to assess the practical reports prepared by students. Meanwhile, the formative test aims to test the students’ mastery of Physics concepts applied during the practical of Simple Harmonic Motion.

2.1.1. Scientific Skills Checklist.
The Scientific Skills checklist was prepared by a group of researchers based on the Primary School Standard Curriculum (KSSR). The checklist is prepared using Google Form uploaded in Google Classroom a week before the scheduled class. Information related to Scientific Skills consisting of science process skills and manipulative skills was also uploaded as a guide to the participants while completing the scientific skills checklist before the PhET Simulation intervention was introduced to the participants. This Scientific Skills checklist was given to the participants before and after the PhET Simulation intervention was introduced.

2.1.2. Student Practical Report Rubric.
Rubric is an assessment tool to evaluate performance of the participants through practical reports provided. This rubric allows the researchers to assess the mastery of Scientific Skills by the participants. The rubric was prepared by the researchers based on the basic rubric guideline from the Matriculation Division of the Ministry of Education Malaysia. The rubric is then uploaded in the Google Classroom a week before the scheduled class, so that the participants are aware of the criteria being assessed in the practical report that will be prepared by the participants. The researchers reminded the students to read and understand the Practical Report Rubric, as well as to contact the supervising lecturer if there are any problems occurred related to the practical to be conducted in the following week.

2.1.3. Formative test
Formative testing is a strategy in the teaching and learning process, beneficial to help students and lecturers. In this action research, formative tests were given to the participants after their practical of using PhET simulations were implemented. The main purpose was to obtain an immediate feedback on the level of mastery of the participants. This formative test had 15 questions that tested the participants...
related to the objectives of the experiment, the theory of physics in the experiment, the apparatus used in the experiment, the experimental procedure, recording the experimental data and the experimental discussion.

2.2 Practical lesson
Researchers used PhET simulations during practical mode. There were no control groups in this action research. Table 1, shows the work steps or actions taken by the researcher during the course of this action study.

| No | Description / Activity                          | Date                       | Remarks                                                                 |
|----|------------------------------------------------|----------------------------|-------------------------------------------------------------------------|
| 1  | Description of action research                  | 17th January 2021          | Using online face-to-face method through Google Meet platform           |
| 2  | Scientific Skills Checklist                     |                            | Scientific Skills Checklist using Google Form and uploaded in the Google Classroom. |
| 3  | PhET Simulation                                |                            | Scientific Skills Checklist using Google Form and uploaded in the Google Classroom. |
| 4  | Practical Report Rubric                         |                            | The preferred usage of smartphone, tablet or laptop by the participants. |
| 5  | Simple Harmonic Motion Experiment               | 24th January 2021          |                                                                        |
| 6  | Preparation of Participants’ practical reports. | 24th January until 30th January 2021 |                                                                        |
| 7  | Scientific skills checklist                     | 31st January 2021          | Scientific skills checklist using Google Form is uploaded through Google Classroom. |
| 8  | Formative test                                  | 31st January 2021          |                                                                        |
| 9  | Evaluation of practical reports                 | 31st January until 14th February 2021 | Supervised lecturer                                                     |

3 Result and Discussion
3.1 Distribution of participants by gender
A total of 36 study participants were selected for this action research and were classified into male and female participants. The distribution of participants by gender is shown in Table 2. It was found that 8 (22.2%) participants were male and 28 (77.8%) were female. This means that female participants are more numerous than male participants. The difference between female and male participants was 20 people which is 55.6%.

| Gender  | Frequency | Percentage |
|---------|-----------|------------|
| Male    | 8         | 22.2       |
| Female  | 28        | 77.8       |
| Total   | 36        | 100.0      |

3.2 Scientific Skills Checklist
Descriptive analysis uses frequency and is expressed in percentages. Table 3 shows the frequency and percentage of Science Process Skills practiced by participants before using PhET simulation (Pre) and after using PhET simulation (Post). The Science Process Skills listed are based on the Primary School Standard Curriculum (KSSR) issued by the Ministry of Education Malaysia. The Science Process skills involved are observing, classifying, using numbers, predicting, communicating, interpreting data, controlling variable, and experimenting. Table 3 shows a significant improvement for each Science Process Skills practiced by the participants, for example for Science Process Skills controlling variables and experimenting showed a 100% increment, this shows that participants were able to practice these Science Process Skills by using PhET simulations even when they were not in a real laboratory.
Table 3. Checklist of participants’ process science skills

| Scientific Skills checklist | Pre Frequency | Percentage of frequency | Post Frequency | Percentage of frequency |
|-----------------------------|---------------|-------------------------|----------------|------------------------|
| Observation                 | 18            | 50                      | 35            | 97                     |
| Classifying                 | 0             | 0                       | 16            | 44                     |
| Using Numbers               | 36            | 100                     | 36            | 100                    |
| Predicting                  | 28            | 77                      | 25            | 69                     |
| Communicating               | 21            | 58                      | 25            | 69                     |
| Interpreting Data           | 26            | 72                      | 36            | 100                    |
| Controlling variable        | 0             | 0                       | 34            | 94                     |
| Experimenting               | 0             | 0                       | 30            | 83                     |

Table 4 shows the Manipulative Skills conducting experiments practiced by the participants before using the PhET simulation (Pre) and after the use of the PhET simulation (Post). Table 4 shows a clear improvement for sorting materials and apparatus of 94%, according to all the procedures specified to conduct 97% experiments and conducted the process of collecting data 97%. By using PhET simulation, participants must assemble their own virtual apparatus during the PhET simulation before they can obtain data.

Table 4. Manipulative skills checklist (doing experiment) for participants’

| Participants’ Manipulative skills Checklist while doing Experiment | Pre Frequency | Percentage of frequency | Post Frequency | Percentage of frequency |
|-------------------------------------------------------------------|---------------|-------------------------|----------------|------------------------|
| Arranging materials and apparatus                                 | 1             | 3                       | 34            | 94                     |
| Follow all the procedures in conducting the experiment            | 9             | 25                      | 35            | 97                     |
| Data collection process                                           | 18            | 50                      | 35            | 97                     |
| Arrange and store back the apparatus                              | 1             | 3                       | 1             | 3                      |

Table 5 shows the Manipulative Skills Checklist (Data Presentation) practiced by the participants before using the PhET simulation (Pre) and after the use of the PhET simulation (Post). Based on table 5, the percentage of study participants practicing Manipulative Skills (Data Presentation) did not show a clear difference, however, still showing improvement. This situation occurred because the data and graph assessment format were emphasized to the participants at the beginning of the 1st semester study session again.

Table 5. Manipulative skills checklist (data presentation) of participants’

| Manipulative skills Checklist (Data assessment dan Graphs) | Pre Frequency | Percentage of frequency | Post Frequency | Percentage of frequency |
|-----------------------------------------------------------|---------------|-------------------------|----------------|------------------------|
| Construct appropriate tables (columns, rows, headings, and units) to record data | 31            | 86                      | 36            | 100                    |
| Identify variables                                        | 32            | 89                      | 36            | 100                    |
| Record data to the correct decimal place (consistent and constant) | 31            | 86                      | 36            | 100                    |
| Systematic, quality, and computational                     | 31            | 86                      | 36            | 100                    |
Table 6 shows the Manipulative Skills Checklist (Data and Graph Assessment) practiced by the participants before using the PhET simulation (Pre) and after the use of the PhET simulation (Post). Based on table 6, the percentage of participants practicing Manipulative Skills of data assessment and graphs showed no difference. This situation occurred because the data and graph assessment format were emphasized to the participants at the beginning of the 1st semester study session again.

### Table 6. Participants’ manipulative checklist (data assessment and graph)

| Manipulative Checklist (Data Assessment and Graph) | Pre         | Post         | Percentage of frequency | Percentage of frequency |
|---------------------------------------------------|-------------|--------------|-------------------------|-------------------------|
| Writing of title                                  | 36          | 36           | 100                     | 100                     |
| Stating the axes and units                        | 36          | 36           | 100                     | 100                     |
| Using an even scale                               | 36          | 36           | 100                     | 100                     |
| Data plotting                                     | 36          | 36           | 100                     | 100                     |
| Graph size 75% of graph paper                     | 36          | 36           | 100                     | 100                     |
| Draw the best lines                               | 35          | 36           | 97                      | 100                     |

3.3 Observation of Students’ Practical Report.

Meanwhile, Table 7 shows the Manipulative Skills Checklist (Practical Report Writing) practiced by the participants before using the PhET simulation (Pre) and after the use of the PhET simulation (Post). Based on table 7, the percentage of participants practicing Manipulative Skills of practical report writing did not show a clear difference, nevertheless, it still showed improvement. This situation occurred because the format of writing the Practical Report has been set in the Physics Laboratory Manual booklet for Semester I & II DP014 & DP024, 2018.

### Table 7. Participants’ Manipulative Checklist (Practical Report Writing)

| Participants’ Manipulative Checklist (Practical Report Writing) | Pre         | Post         | Percentage of frequency | Percentage of frequency |
|------------------------------------------------------------------|-------------|--------------|-------------------------|-------------------------|
| Objective                                                        | 35          | 36           | 97                      | 100                     |
| Theory                                                           | 35          | 36           | 97                      | 100                     |
| Apparatus Checklist                                              | 35          | 34           | 97                      | 94                      |
| Procedure                                                        | 36          | 36           | 100                     | 100                     |
| Data scheduling                                                  | 36          | 36           | 100                     | 100                     |
| Data Analysis                                                    | 35          | 36           | 97                      | 100                     |
| Discussion                                                       | 35          | 36           | 97                      | 100                     |
| Conclusion                                                       | 36          | 36           | 100                     | 100                     |

3.4 Simple Harmonic Motion Formative Test.

Table 8 shows the average Formative Test scores of participants for the Simple Harmonic Motion experiment. The total marks of the Formative Test are 15 marks. The average score of the study participants was 13.9 indicating a high level of mastery by the participants. This formative test has 15 questions which tested the participants related to the experimental objectives, the theory of physics in the experiment, the apparatus used in the experiment, the experimental procedure, recording the experimental data and the experimental discussion.

### Table 8. Simple Harmonic Motion Formative Test

| Participants | Average |
|--------------|---------|
| 36           | 13.9    |
3.5 Changes in Participants Behaviour.
The researcher found that all participants diligently prepared the Simple Harmonic Motion Practical Report. In addition, participants who were relatively passive in the classroom showed positive changes. They became more active in attempting to questions and answers session with the classmates based on the discussions of the study where participants used the WhatsApp group platform. Through the non-face-to-face teaching and learning mode, students were found to feel more comfortable learning and were not afraid to ask questions. They do not feel embarrassed when giving the wrong opinion. In addition, peers play an important role in mentoring other peers. The researcher through his observation in the WhatsApp group platform, found that the students had fun doing PhET simulation activities. They were able to process the experimental variables according to their understanding without fear. They were free to do experiment. However, in the end, the experimental findings do not deviate from the theory stated in the Physics Laboratory Manual Booklet for Semester I & II DP014 & DP024, 2018. The PhET simulations introduced by the researchers cannot only help students master Scientific Skills well but also have created a fun learning environment. Student-centered strategies and materials combined in a virtual simulation is a cooperative learning method giving the role of facilitator to the researcher, facilitating classroom control, and subsequently improving the teaching and learning practices of the researcher in the subject of Physics.

3.6 Strengths and Weaknesses of PhET Simulation.
The strengths of PhET Simulations can provide many benefits as researchers doing demonstrations using real equipment in a Physics lab. Participants can do experiment, where actual equipment is not available or impractical to install. They can also use PhET Simulations to perform experiments that are not possible for example experiments involving electrons. Participants found it easy to change variables that were difficult or impossible to change with real tools. In addition, participants were able to run simulations on their own equipment such as their own laptops, smartphones, or tablets anywhere, either to repeat or extend the experiments to further strengthen their understanding. The success of the learning process using PhET Simulation is highly dependent on the self-efficiency of the participants, this is one of the weaknesses of PhET Simulation. There was no monitoring from stakeholders to monitor the teaching and learning process of the participants. The second disadvantage, to use PhET simulation is very dependent on the equipment that the participants have, or computer equipment provided by the college. A third drawback is participants who were not proficient or less proficient in the use of computers would feel very unfavourable to use PhET simulations.

3.7 Objectives Achievement and Effectiveness of Action Research.
The researcher found that all the objectives of the study studied have been proven and achieved by the marks obtained by students during the formative test, evaluation of practical reports and checklist of Systematic Skills of participants. Through this action research study all the objectives of the study have been answered in detail and successfully proven that the Teaching and Learning (T&L) by using PhET simulation has been able to strengthen the Scientific Skills of students.

4 Conclusion
The researcher will maintain the use of PhET simulation because the researchers think that based on the findings of the study, this PhET simulation is the easiest and most effective way in empowering the Scientific Skills of students. In fact, the exposure of various teaching and learning methods to students such as the use of effective methods is necessary so that they do not face problems when they are in unexpected situations, for example the situation of Covid-19 pandemic. The researchers found that this action research can be conducted over a longer period than now and can use the various simulations available in PhET to get an effective effect. Therefore, a longer period will make the study more rational, effective, and efficient in terms of obtaining efficacy and validity on the effectiveness of the use of these PhET simulations. The researchers hope that this method will be extended to other classes and to other subjects such as science, biology, chemistry, and others.
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