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DEVELOPMENT OF A PHYSICS LEARNING ACTIVITY FOR THE TOPIC OF BOYLE'S LAW USING THE STEM APPROACH

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ABSTRACT

This paper reports on the development of a Physics learning activity based on the STEM approach for the topic of Boyle's Law and the tests conducted to determine its validity and feasibility. The population of this study was fifth-semester bachelor of education in Physics students from one of the public universities in Malaysia. Nineteen participants sampled using the simple random sampling technique. Two instruments used were self-developed questionnaire for determining the content validity of the learning activity and a feasibility questionnaire adapted from the Structured Assessment of Feasibility (SAFE) questionnaire. Most of the data on feasibility shows that the activity is feasible to be implemented in schools albeit will require extra teaching and learning time and cost compared to the usual teaching and learning time and cost allocated. The research successfully developed a tested learning activity based on the STEM approach for the topic of Boyle's Law that is quite feasible. This result implies that it can be used as a reference for teachers who are interested in conducting a STEM-based lesson with the awareness that the lesson will take more time and additional cost to implement.

Keywords :STEM approach; Boyle's law; physics learning activity.

I. INTRODUCTION

The Ministry of Education Malaysia's new Secondary School Curriculum Standards [1], with the acronym KSSM, demand that Science, Technology, Engineering and Mathematics (STEM) be part of a student's education. STEM as an approach to teaching and learning incorporates the four core subjects of STEM. They are science, technology, engineering and mathematics from all grade levels from pre-school to doctorate level formally and informally [2]. The STEM approach is an integrated approach to teaching and learning, where discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study [3]. STEM is also considered as part of the teaching and learning method that integrates knowledge, skills, and also the value of STEM disciplines into students [4]. For this study, the STEM approach is defined as the application and integration of engineering practices with the content and practices of science and mathematics to produce a technology that can solve real-world problems [5]. Some of the benefits of the STEM approach that are gleaned from the literature are that the approach motivates students and promote non-routine problem-solving skills [6][7].

In science classes, a lesson using the STEM approach should integrate mathematics, technology, and engineering to support the learning of a science concept [8]. Physics is one of the sciences and mathematics forms parts of the language of physics. Technology usage has also been the normal practice in physics classes especially during investigative activities albeit less so in the use of technology and as a solution to a problem. However, the component that is truly lacking is engineering [9]. As KSSM and the STEM approach are recent developments in the Malaysian education scenario, it is a challenge for teachers to design and implement engineering-infused lessons [8]. There is also a lack of appropriate and meaningful tested resources. The Ministry of Education

Malaysia in collaboration with other agencies are developing STEM resources [7] and several other independent researchers [11][12] but they are limited in numbers.

Thus, this study was empowered to design and develop a Physics learning activity for the topic of Boyle's Law using the STEM approach by specifically infusing the engineering design process in the 'Elaborate' phase of the teaching and learning that was planned using the 5E instructional model [9]. The engineering design process has six steps namely define a problem, research, imagine, plan, create prototype, test prototype and improve [8]. This topic is suitable for a STEM approach learning activity as students are provided with the opportunity to apply the idea of Boyle's Law in building a teaching aid for learning the law. The absence of a concrete teaching aid for teaching the relationship between the volume of a fixed mass of gas and its pressure by directly measuring the pressure is the real-world problem that students need to solve. The teaching aid was therefore the technology and the solution to the real-life problem encountered by teachers. To ensure that the designed activity is feasible for implementation in schools, we tested the activity with a group of physics undergraduates learning to be teachers as there were constraints to access school teachers because of the Covid-19 pandemic.

II. METHOD

2.1. Research design

The research methodology includes the overarching research design and the specific ways of conducting the research. This study is developmental research using the ADDIE model to develop a learning activity based on the STEM approach. ADDIE model is commonly used for designing instructional activities. The five phases in the ADDIE model are Analysis, Design, Development, Implementation and Evaluation [10]. In this study, the research activities based on the ADDIE model are presented in Table 1.

Table 1. Research activities based on the ADDIE model

ANALYSE	• Analyse research objectives, research sample and the scope of content • Determine the learning standards as documented in Curriculum and Assessment Standard Document (CASD) [1]
DESIGN	• Design a learning activity using the STEM approach for Boyle's Law topic for the 'elaborate' phase of the 5E instructional model
DEVELOP	• Develop the activity and related T&L materials (Lesson plan, teaching slides, student worksheet, rubric for assessment of the process and product, and a teaching manual showing the step-by-step procedure for building the teaching aid using Arduino technology)
IMPLEMENT	• Distribute the activity resources and feasibility questionnaire to the participants using a google form to determine the feasibility of the activity
EVALUATE	• Content Validity of the activity by three experts • Feasibility of the activity

2.2. Instruments, population, and sample

Three experts validated the activities for content validity and the data were analysed using the Content Validity Index (CVI). For feasibility measure, the sample was 19 physics undergraduates in their fifth semester of study from one of the public universities in Malaysia selected using the simple random sampling technique. The data were collected using a questionnaire that was adapted from the Structured Assessment of Feasibility questionnaire (SAFE) [16] and was subsequently validated for face and content validity along with the reliability measure. There are four options to choose from for every item but each option has a different statement since every option was customised to respond to the different items. In general, participants were asked to rate agreement with the statements, ranging from "yes", "partially", "no", to "unable to rate" numbering from one to four. The questionnaire was distributed using Google Form to the participants together with a link to the activity materials. Data were analysed using descriptive statistics of percentage agreement.

III. RESULTS AND DISCUSSION

The results are the developed activity and from the validity and feasibility data. The discussion relates the findings with past research and the theories underpinning the activity's development.

3.1. Development of Boyle's Law Teaching Aid

The STEM approach learning activity was planned for the 'Elaborate' phase of the teaching and learning where the engineering design process was explicitly embedded. Figure 1 shows a part of the activity where a problem that was embedded in a problem scenario as the context for the problem was posed to the students. The 'Elaborate' phase is where learning is enhanced by having students apply their understanding that was gained from 'Explore' and 'Explain' phases in a new real-world context. Students solve the problem by designing and developing a teaching aid for the teaching of Boyle's Law. The duration allocated for this phase was 120 minutes face-to-face in-class time but teachers can choose to reduce the in-class time by having students build their prototype (the 'create' step of the engineering design process) at home and using in-class time for the planning part and students' presentation of their work.

Elaborate
Day 2
120 min

In the Laboratory and at Home

ENGINEERING DESIGN PROCESS

DEFINE PROBLEM

- Pose a problem scenario to the students that have a real-world problem that requires a solution. Ask students to identify the problem and its constraints.

"Sir Ikmal is a Physics teacher at SMK Klang Aman. He is an experienced teacher with 20 years of teaching physics. During those years he found the absence of a teaching aid that can be used to determine the relationship between the volume of a fixed mass of gas and the pressure of the gas by directly measuring the pressure of the gas. The only teaching aid that he usually used is a syringe. When the end of the syringe is covered with the fingertip and the piston is pressed, students could feel that the smaller the volume the harder it is to push. But students can not accurately measure the value of the gas pressure even though the volume of the syringe could be observed. You as an IT engineer need to design and built a teaching aid that can solve the problem that Sir Ikmal faced. The designed teaching aid should be able to measure the volume of the trapped gas in the container and the pressure of the gas"

- The constraints for building a prototype technology include using Arduino Uno, BMP280 and 150ml syringe as the main building materials.

RESEARCH

- Form groups of three to four students per group.
- Give out a students' worksheet to each group as a guide to conduct group activities.
- Students search for existing solutions.
- Students identify equipment and materials that are needed to build the Boyle's Law Teaching Aid.
- Students identify the physics concept involved that needed to be incorporated into the solution.

IMAGINE

- Students discuss in groups the characteristics and the design of the Boyle's Law Teaching Aid that can be built by using hard cardboard.
- Students incorporate the physics concept that they have learned.
- Students plan and label their designs.

PLAN

- Students pick the best solution available.
- Students share their drawings and plan with another group.
- Students do reflection and improvement based on the comments that they received from classmates and the teacher.

	CREATE PROTOTYPE • Students use their creativity to build a prototype of the Boyle's Law Teaching Aid by using given equipment, materials and tools. • Students apply their prior understanding of Boyle's Law. • The teacher shares the guideline to build the prototype.

Fig 1. A part of the activity in the 'Elaborate' phase

The activity explicitly integrated the engineering design process and engineering and science practices such as developing and using models, planning and carrying out investigation, analysing and interpreting data, designing solutions, etc. with Boyle's Law as the content of science.

In addition, students used simple arithmetic in designing and building the prototype of the teaching aid and subsequently did some routine problem solving using the mathematical formulation related to the relationship between volume and pressure of a fixed mass of gas. The teaching aid was thus the technology that solved the problem as depicted in the scenario. Figure 2 shows an example of a possible finished product of Boyle's Law teaching aid. The value of the gas pressure can be measured by attaching the prototype to a computer and using the Arduino application. This design and build activity followed closely the definition of the STEM approach adopted [5]. In addition, another type of technology, i.e. ICT, was used as an enabler for the learning process. Students went through the engineering design process of defining problem, research, imagine, plan, create prototype, test prototype, & improve [14] systematically since the process was explicitly outlined in a student worksheet.

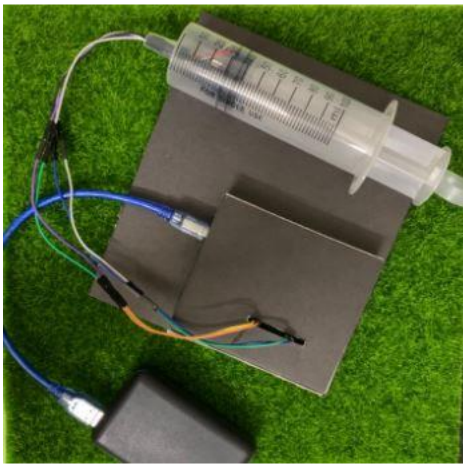

Fig 2. Boyle's Law Teaching Aid

3.2. Validity and Feasibility of Boyle's Law STEM-based Activity

Three experts were in full agreement for the content validity of the developed activity with a CVI value of one. They agreed that the activity followed the STEM approach and that the Physics content depicted in the activity and the related materials are correct and aligned with the curriculum. Table 2 shows the result of the feasibility of the activity.

Table 2. Feasibility measure: Percentage of the agreement for every item

ITEM	Scale (% agreement)
1. Teachers require specific training to deliver the intervention.	3 (100)
2. The intervention is complex (made up of several interacting components, e.g. teacher-student, student-student, student-parent, student-external expert, student-community)	3 (100)
3. The intervention is time-consuming to provide.	1 (100)
4. The intervention includes/requires ongoing support and supervision.	3 (100)
5. The intervention requires additional human resources.	3 (100)

6.	The intervention requires additional material resources.	2 (100)
7.	The intervention is costly	1 (36.8) 2 (63.2)
8.	There are known serious or adverse events associated with the intervention.	3 (100)
9.	The intervention is applicable to the population of interest.	1 (100)
10.	The intervention is manualised.	1 (100)
11.	The intervention is flexible (i.e. can it be tailored to the context and situation).	1 (21.1) 2 (79)
12.	The intervention is likely to be effective (i.e. evidence-based and expected to produce positive outcomes).	3 (100)
13.	The intervention is cost-saving.	2 (64.4) 3 (31.6)
14.	The intended goals of the intervention match the prioritise goals of the integrated STEM approach (foster problem-solving skills).	1 (100)
15.	The intervention could be piloted.	1 (100)

1: Yes, 2: Partially, 3: No, 4: Unable to rate

Three aspects did not receive positive responses for the feasibility measure. All participants agree that the activity is time-consuming (item 3) and almost all agree that more cost is needed to implement the activity (item 7). This opinion is warranted as building the teaching aid did require more time than the standard time usually allocated to the learning of Boyle's Law. Learning activities based on the STEM approach as gleaned from the literature all used the project-based method [10], [7], [4] and thus require a longer duration of learning time. However, Constructionist learning theory advocates learning by building a tangible product as the activity provides students with a meaningful context to apply their knowledge and understanding. An additional material (Arduino Uno microcontroller) that is not usually found in a standard laboratory is also required. The cost of the Arduino Uno was RM 40 (approximately USD 9.00) which was quite affordable if shared among groups of four or five students. The final aspect is the likelihood of the activity is effective. The participants were not provided with any references to past research that investigated the effectiveness of the STEM approach in general and a similar activity as in this study. Thus, it is expected that the participants would respond negatively to the likelihood of the activity being effective (item 12) but they all agree that the activity can foster problem-solving skills (item 14). Other than these three aspects, all of the other aspects of feasibility received positive responses.

IV. CONCLUSION

We succeeded in developing a validated activity based on the STEM approach for teaching Boyle's Law that was quite feasible. The activity comes with a lesson plan, teaching slides, a manual, a students' worksheet and a rubric for evaluating the process and product. The lesson idea and materials may give ideas and inspiration to teachers who are interested to implement lessons that integrate the four elements of the STEM approach to design and develop their learning activities. We especially wish to emphasise the need to make explicit to the students the specific practices that can better foster the kind of thinking that scientists, engineers and mathematicians do when they go about doing their crafts.

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