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# THE PROJECT-BASED LEARNING (STEM MODEL) IN FUNDAMENTAL PHYSICS LEARNING

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**Abstract:**

The education involves STEM combines four fields: S for Science, T for Technology, E for Engineering, and M for Mathematics. STEM education is under the Malaysian Education Development Plan (PPPM) 2013-2025, to enhance the high interest and motivation to study these four fields. Subsequently, the academic achievement of the STEM subjects can be improved. Therefore, this study aims to study the usage of the STEM model in the learning process of fundamental physics subject, characterized by higher-order thinking skills. The sample in this study was students from the Centre of Foundation Studies in Science of Universiti Putra Malaysia. Two groups are formed: the group that will produce the model (developer groups) and the group that will use the model in the learning process (user groups). The user groups are given a Pre-Achievement Test (Pre-AT) to determine their initial skills on the related topic. At the same time, the developer groups develop the STEM model, which acts as a learning tool for the usage groups. Then, after being exposed to the STEM model for 2 months, the user groups are requested to answer a Post-Achievement Test (Post-AT). The performance of Pre-AT and Post-AT are compared since these tests use a similar level of Bloom's taxonomy. Moreover, both groups need to answer the same surveys regarding the model's formation and evaluate the model's satisfaction in the learning process. Based on the analysis results, it was found that using the STEM model enhances the understanding of physics concepts, and subsequently increase the critical thinking and problem-solving skills among students. In addition, the STEM model development enhances the skills of project-based learning (PBL) among students.

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**Keywords:**

STEM Model, Fundamental Physics, Achievement Test, Critical Thinking, Problem-Solving

## Introduction

In 2021, the U.S. National Science Foundation (NSF) introduced the educational curriculum or the career field in the disciplines of science, technology, engineering, and mathematics. This combination is introduced as STEM - Science, Technology, Engineering, and Mathematics. Since then, the STEM curriculum has been extended to many countries beyond the United States, including Asia countries (Ting et al, 2023). Based on the National Education Blueprint (PPPM) 2013-2025, the Ministry of Education Malaysia changed the existing curriculum to the Standard Secondary School Curriculum (SSSC). This is the main strategy to reinforce STEM in the Malaysia education system.

A STEM model is a representation of an idea, object, event, process or system regarding the field of science, technology, engineering, and mathematics (Gilbert et al., 2000). The three types of STEM models are physical model (Brown et al., 2014; Burgher et al., 2016), mathematical model (Chamberlin et al., 2022; Syamsul et al., 2019), and conceptual model (Al-Kumaim et al., 2021; Guizzardi et al., 2021). Besides, STEM education is a teaching approach that combines science, technology, engineering and mathematics. Therefore, one of the major advantages of STEM education to the students is the exposure to the real-world applications (Dare et al, 2021). STEM education offers real-world situations, compared with only reading books and students can relate subjects in real life. Therefore, the comprehension of the subject matter can be enhanced and the students will appreciate the knowledge they have gained. STEM education also encourages hands-on learning (Budiyanto et al., 2020), Hands-on learning is the type of learning by doing, where the students involve in activities rather than passively reading a book or attending a lecture. In addition, STEM encourages students to think critically as they work to solve problems. Therefore, it improves critical thinking skills (Hacıoğlu & Gülhan, 2021). Subsequently, from the critical thinking skills, it promotes problem solving skills (Alatas & Yakin, 2021). STEM lessons naturally encourage students to think creatively and apply their most creative ideas to solve the STEM problem (Sirajudin & Suratno, 2021). Science literacy is knowledge of science, as well as the scientific framework by which people make decisions based on facts, research and knowledge. Therefore, STEM lesson is reported to increase scientific literacy (Yuliati et al., 2018). STEM encourages independent exploration out of lessons and continues exploring what interests them, under the minimum guidance by a teacher or lecturer (Puspaningsih, 2021). Moreover, STEM lesson creates an environment that encourages students to work in groups to find the best solution, and improves collaboration skills (Shofiyah et al., 2022). On top of that, STEM lesson sparks career interest (Wiebe et al. 2018) and the opportunity of an exposure to the new technologies (Liu et al., 2020).

Physics is a natural science with the concept of matter and its movement in certain dimensions and time, together with the external factors which affect the movement such as forces. However, there are still many factors that contribute the difficulties in the Physics learning. Some of the factors are Physics involves critical thinking (Jamil et al., 2024), requires problem-solving skills (Widya et al., 2023), requires strong skills in calculation (Alquran, 2023;

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Bhattacharjee, 2022), and so on. Therefore, the learning process involving the method of project-based learning helps to overcome these difficulties among students. Project-based learning (PBL) requires students to design, develop, or construct a project or a model. The model can be physical or virtual. The main goal of PBL is to induce creative thinking (Loyens et al., 2023) and problem-solving skills (Zhang and Hwang, 2023) among students dealing with projects, individually or in a group. In addition, PBL will expose the students with hands-on experience (Malik & Zhu, 2023), projects can be used or run by students with the same education levels (Escoto, 2020), and PBL will enhance communication skills among students (Saimon et al., 2023). Besides, the lecturer is a supervisor, and the students independently run the project under the supervision of the supervisor. The roles of PBL supervisor are to give the project guidelines, brief the method's steps before the project is initiated, monitor project progress, ensure the applied concept or theory is appropriate, and so on.

As a result, this study aims to determine how implementing STEM model affects the performance among students about several physics concepts, such as vector and optic. In addition, the effectiveness, characteristics and the limitations of the developed model also being studied. The performance of Physics subjects, based on the topics of vector and optic have been compared between the usage and after the usage of STEM model.

**Methods**

This study was conducted by forming the pretest-posttest control group design, together with the survey. The research sample is 72 students from the Centre of Foundation Studies in Science of Universiti Putra Malaysia. Each model groups consists of 4-5 students. The period of this study is 16 weeks. There are 2 groups: developer group (designing and developing the STEM model) and the user group (using the STEM model in their learning lesson). Since the chosen topics in this study are Optic and Vector, then the developer group of STEM model in Optic will become a user group in a Vector STEM model, and vice versa. Therefore, the developer group in Optic will answer the Pre-Assessment Test (Pre-AT) at Week 2, Post-Assessment Test (Post-AT) at Week 14 to evaluate the effectiveness of the STEM model in Vector. This procedure is similar with the developer of the STEM model for Vector. The Likert scales for the survey is tabulated in Table 1, which contains 5 scales. The list of elements in the survey are presented in Table 2 (the benefits of the STEM model), Table 3 (characteristics of the STEM model), and Table 4 (the limitations of the STEM model). The Pre-AT and Post-AT are the structured questions which have 2 sets: Optic questions and Vector questions. The methodology flowchart is illustrated in Figure 1.

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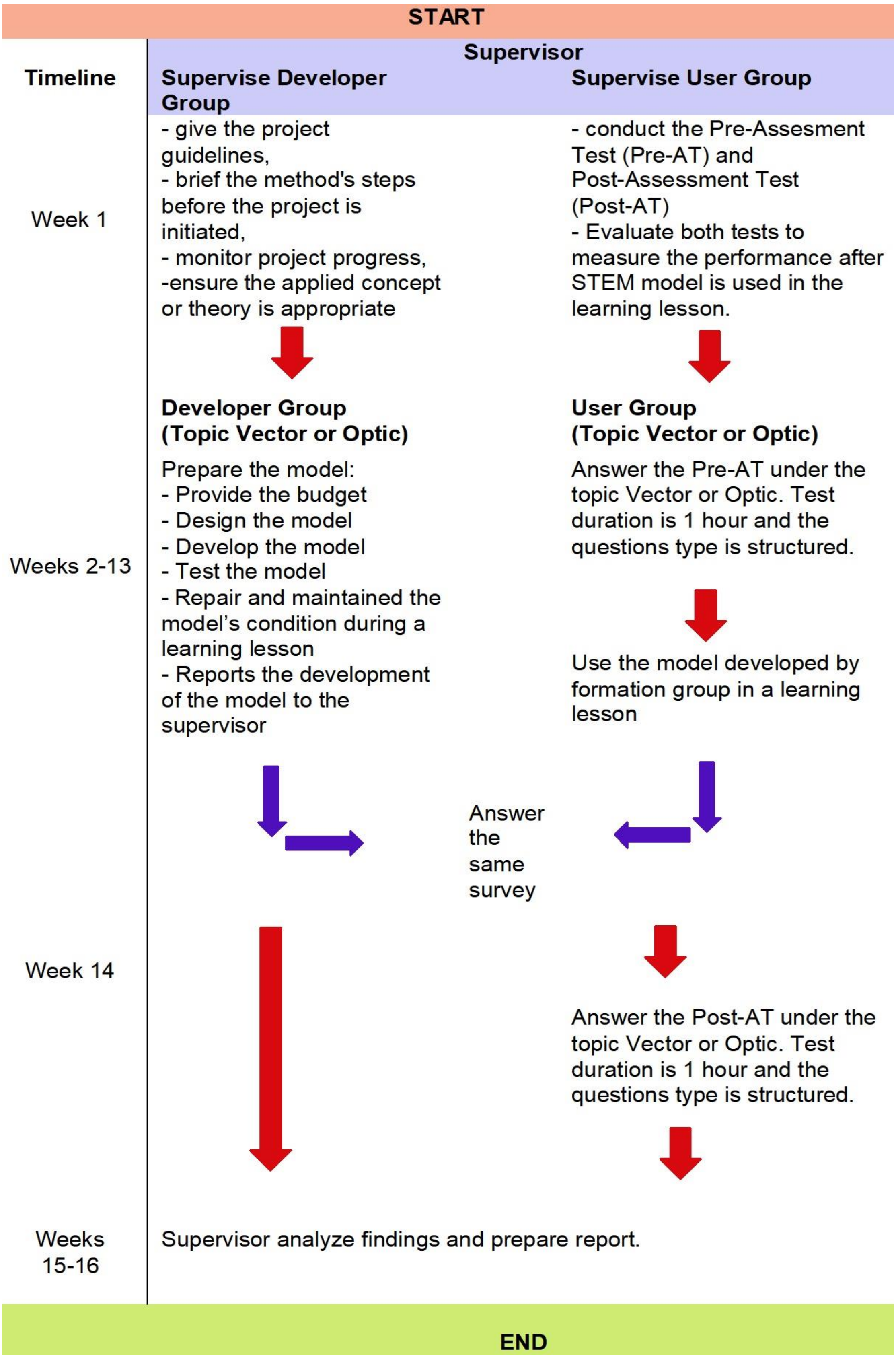


**Figure 1: The Flow Charts Of Of The Methodology Performed By Developer Groups And User Groups**

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**Table 1: Likert Scales For The Model's Formation And Model's Satisfaction Questionnaire**

| Likert Scales | Elements |
|---|---|
| 5 | Strongly agree |
| 4 | Agree |
| 3 | Neither agree nor disagree |
| 2 | Disagree |
| 1 | Strongly disagree |

**Table 2: The List Of Elements Represents The Model's Benefits**

| Elements Code | Elements |
|---|---|
| A | Reduce the study period |
| B | Increase the passion in a learning process based on the specific topic. |
| C | Increase the motivation among students. |
| D | Enhance the comprehension on the specific topic. |
| E | Help to memorize facts |
| F | Increase the excitement in studying and reduce boredom |
| G | Students become more independent under less guidance from the lecturer. |
| H | Offer the real experience on the specific topic, compared with the theory |
| I | Meaningful learning |
| J | Encourage creativity in learning process |
| K | Generate cooperation and interaction among students |

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**Table 3: The List Of Elements Represents The Model's Characteristics**

| Elements Code | Elements |
|---|---|
| A | Reduce the study period |
| B | Increase the passion in a learning process based on the specific topic. |
| C | Increase the motivation among students. |
| D | Enhance the comprehension on the specific topic. |
| E | Help to memorize facts |
| F | Increase the excitement in studying and reduce boredom |
| G | Students become more independent under less guidance from the lecturer. |
| H | Offer the real experience on the specific topic, compared with the theory |
| I | Meaningful learning |
| J | Encourage creativity in learning process |
| K | Generate cooperation and interaction among students |
| L | Model safe to use and does not cause injury. |
| M | Model as a learning method enhance communication skills |
| N | The selection of materials or equipment in model is considered according to the nature of the material or equipment. |
| O | Model is not easily damaged due to rough use. |
| P | Model equipment or materials consume a high cost (more than RM 100). |
| Q | Each component in the model has its own function. |
| R | Model does not cause environment pollution. |
| S | The development and the usage of model gain the scientific research skills. |

**Table 4: The List Of Elements Represents The Model's Weakness**

| Elements Code | Elements |
|---|---|
| A | The difficulty of the preparation or implementation of the appropriate model |
| B | Time restriction for the preparation or the implementation of the model |
| C | Lack of skills in the implementation of the model |
| D | Other learning method is easier |
| E | Conventional learning involving the lecturer as a mentor is preferred |
| F | Referring to the topic of learning, there is another learning method which is more appropriate than implementing the model in the learning process. |

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## Results and Discussion

The survey's outcomes for the user groups are illustrated in Figures 2-7. These figures show the percentage of the students' total versus the elements in the survey. This survey has 3 parts: a) the evaluation of the model's benefits (Figures 2 and 3), b) the evaluation of the model's characteristics (Figures 4 and 5), and c) the limitations/weaknesses of the model (Figures 6 and 7). Since the user groups are categorized under the learning lesson of Optic and Vector, then the odd figures refer to the topic Optic (Figures 3, 5, and 7), and the user group of the Vector STEM model are presented in the even figures (Figures 2, 4, and 6).

The measurements of opinions among users and developers, as shown in Figures 2-7 are subjected to the Likert scales. The users or developers can select the option that best corresponds with their opinions about the statement or question in the scope of a) the evaluation of the model's benefits, b) the evaluation of the model's characteristics, and c) the limitations/weaknesses of the model. It ranges from 1 to 5: a) 1 representing "Strongly Disagree," b) 2 representing "Disagree," c) 3 representing "Neutral" or "Neither Agree nor Disagree," d) 4 representing "Agree," and e) 5 representing "Strongly Agree."

The benefits of the model as shown in Table 2 should be evaluated, to check the suitability of the STEM model in the learning process by specific topic. Besides, the characteristics of the model (Table 3) should be recognized, to improve the model's benefit. On the other hand, to enhance the model's benefit, the developer of the STEM model should minimize their weaknesses or limitations, as shown in Table 4.

The evaluation of the STEM model efficiency in the learning process is depicted in Figure 8 (Vector group) and Figure 9 (Optic group). Pre-AT is indicated by the green bar, whereas Post-AT by the pink bar. This evaluation is conducted among user groups only. The tests are under the scope of the topic, and the questions' format is structured. These questions are subjected to the 4 stages of Bloom's taxonomy: 20% remembering, 30% understanding, 30% applying, and 20% analysing.

### *The Evaluation of the Model's Benefits*

The elements of Figures 2 and 3 are tabulated in Table 2. For the Vector STEM model (Figure 2), the high percentage for scale 5, which is 66.7% are the elements: a) increasing the motivation among students (element C), b) the implementation of the STEM model encourages creativity in the learning process (element J), and c) the PBL of producing STEM model generates cooperation and interaction among students (element K). However, most/all the students in the Optic STEM model (Figure 3) agree with these elements: a) It offers real experience on the specific topic, compared with the theory (77.8%). Moreover, the elements with a high percentage in the Optic STEM model are element J: 88.9% and element K: 100%. Therefore, the STEM model for both topics encourages creativity and teamwork among students in developing PBL (Latip & Supriatna, 2023). However, 16.7% of students disagree with the benefit of the STEM model as stated in element G: Students become more independent under less guidance from the lecturer, for the Vector STEM model. This is because vector involves calculations, and the students also require practice in the calculations on Vectors. Besides, 11.1% of the users of the Optic STEM model disagree with the benefits of the Optic STEM model, as stated in element A (the usage of the model will reduce the study period), element D (enhance the comprehension of the specific topic), and element I (meaningful learning). Since the percentage of the disagree scale is low, the students are considered more

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passionate about other learning methods/tools, instead of the physical model, such as study groups, use graphics in learning lessons, etc.

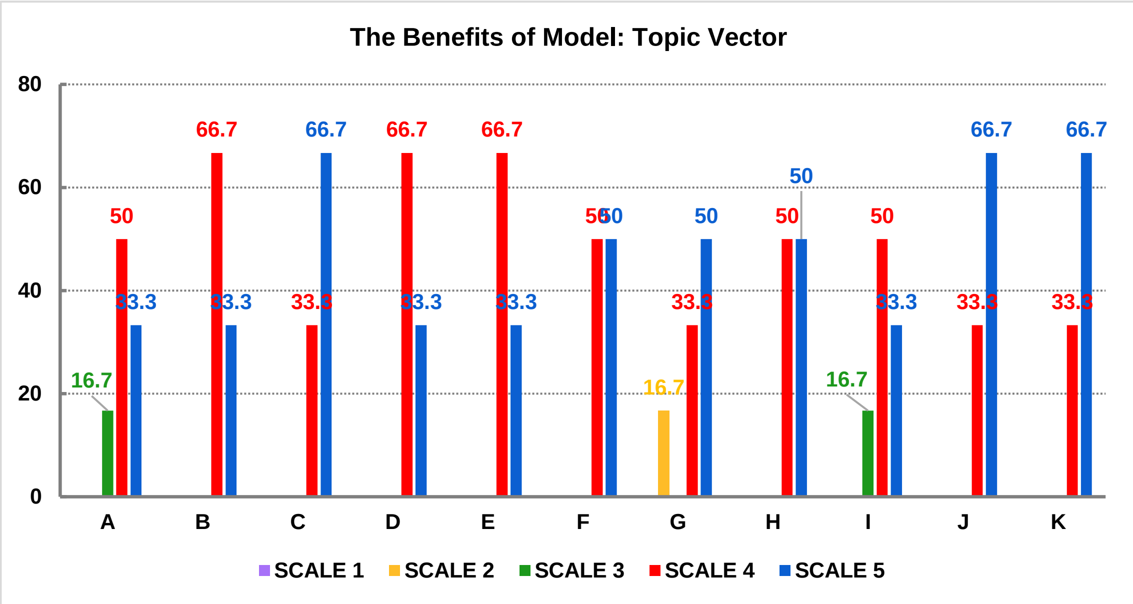


**Figure 2: The Bar Graph Shows The Percentage Of Students Versus The Elements As Tabulated In Table 2 Under The Topic Vector**

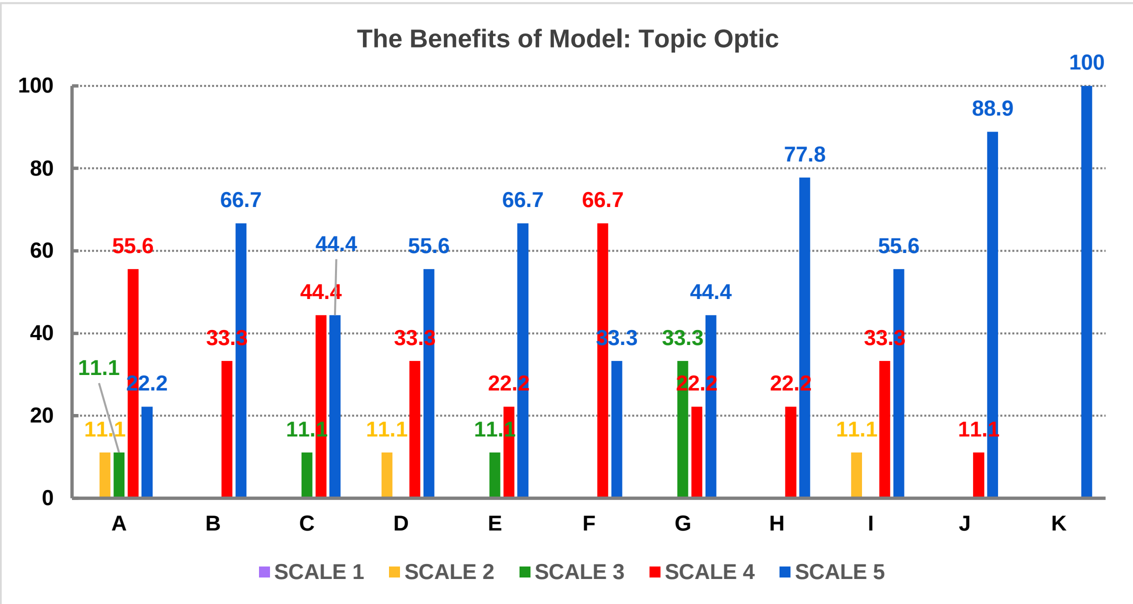


**Figure 3: The Bar Graph Shows The Percentage Of Students Versus The Elements As Tabulated In Table 2 Under The Topic Optic**

### *The Evaluation of the Model's Characteristics*

Figures 4 and 5 represent the characteristics of the STEM model which can attract the student to learn in the specific topic (Vector in Figure 4 and Optic in Figure 5). The details of the elements in Figures 4 and 5 are tabulated in Table 3. For the Vector STEM model (Figure 4), all students strongly agree that it should not cause environmental pollution (element R). In

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addition, 83.3% of Vector STEM model users strongly agree with the element S: The development and the usage of model gain the scientific research skills. Meanwhile, 100% of users of the Optic STEM model (Figure 5) strongly agree with elements L and R (L: Model safe to use and does not cause injury, and R: Model should avoid environmental pollution). In conclusion, safety remains a core component of STEM education (Love et al., 2023). However, half of the students strongly disagree with the cost of the model equipment or materials consume a high cost (more than RM 100). This proven that designing STEM model enhance the creativity among students to control their budget without reducing the STEM model quality. In conclusion, Figures 4 and 5, together with their elements (Table 3) evaluate the characteristics that should be had on the model to act as a learning tool, and the top quality of the STEM model should fulfil most of the elements, except for the cost to produce it (element P). Therefore, this part is an evaluation towards the developer, and they should take into account these elements to produce a good STEM model for a learning tool. The main elements in Figures 4 and 5 are the effect of the STEM model in a learning lesson, such as study period (A), comprehension (D), memory (E), independent lesson (G), real experience (H), meaningful (I), creativity (J), and scientific research skills (S). Besides, other elements are under the scope of the motivation and passion among students in the learning lesson, together with the related soft skills such as passion (B), motivation (C), excitement versus boredom (F), cooperation (K), and communication skills (M). Additionally, the physical conditions of the model are also being taken into account, such as safety (L), appropriate material (N), minimum undamaged (O), cost (P), functionality (Q), and not a contributor to pollution (R).

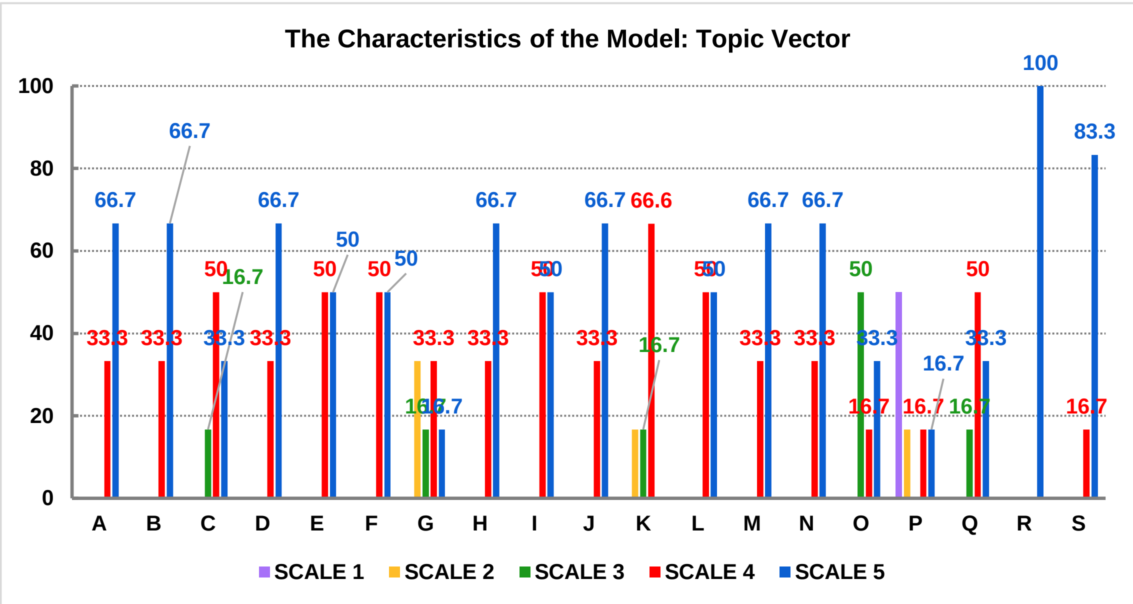


**Figure 4: The Bar Graph Shows The Percentage Of Students Versus The Elements As Tabulated In Table 3 Under The Topic Vector**

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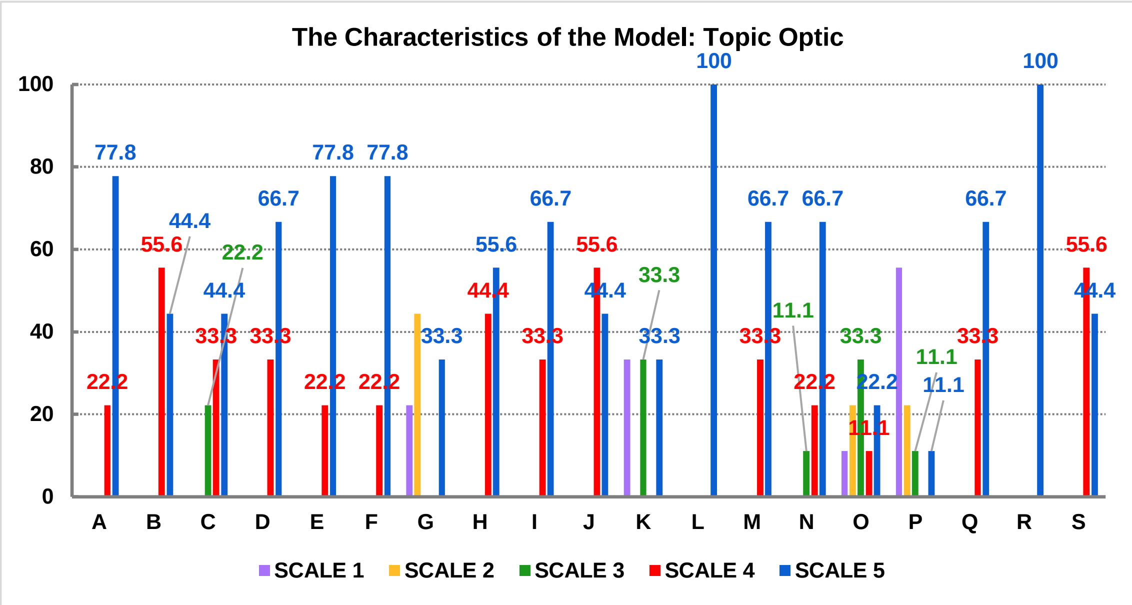


**Figure 5: The Bar Graph Shows The Percentage Of Students Versus The Elements As Tabulated In Table 3 Under The Topic Vector**

***The Limitations/Weaknesses of the Model***

The weaknesses/limitations of the Vector model and Optic model are shown in Figures 6 and 7, respectively. The elements of weaknesses/limitations are presented in Table 4. For the Vector model, 16.7% of students strongly agree that this model requires more time to develop (element B), other learning methods are easier than using the STEM model (element D), and there is another learning method which is more appropriate than implementing the model in the learning process (element F). However, 66.7 students disagree that the developer Vector STEM model is difficult to prepare (A), and 50% of students disagree that the developers are facing time restrictions in the development stage (B), lack skills in the implementation of the model (C), other learning method is easier (D), and referring to the Vector as a topic, there is another learning method which is more appropriate than implementing the model in the learning process (F). Meanwhile, the Optic group also strongly agree with the Vector group for the elements D (22.2%) and F (11.1%). The optic group also reports that 55.6% disagree with the limitations of the model such as elements C and D, and they also strongly disagree with the limitations B, D, E, and F. Therefore, it can be concluded that the STEM model for both topics produced have minimized the limitations/weaknesses since the percentage of disagree is higher than agree with the weaknesses.

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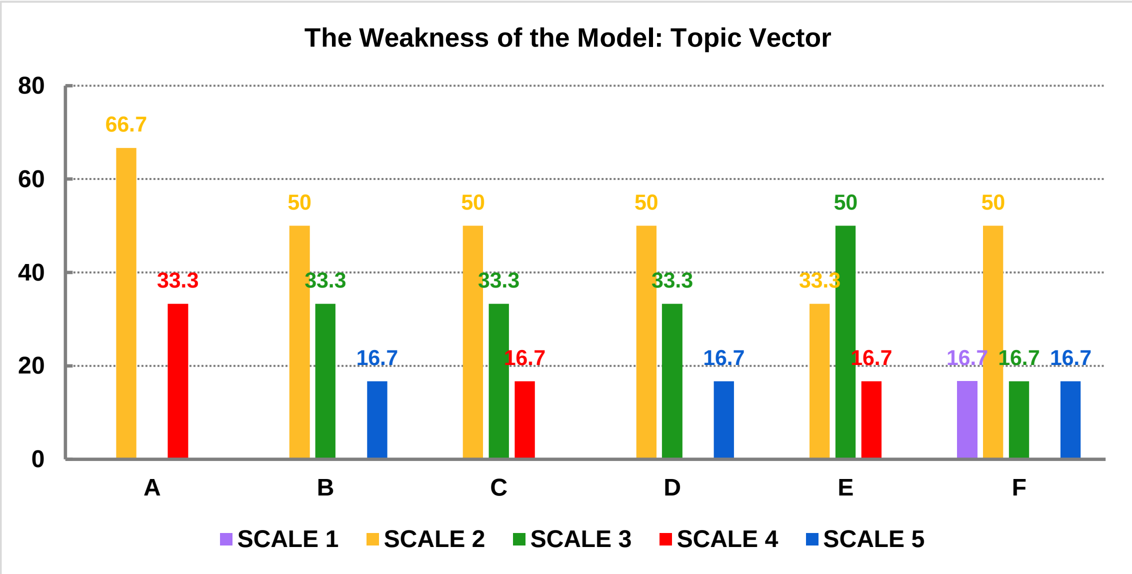


**Figure 6: The Bar Graph Shows The Percentage Of Students Versus The Elements As Tabulated In Table 4 Under The Topic Vector**

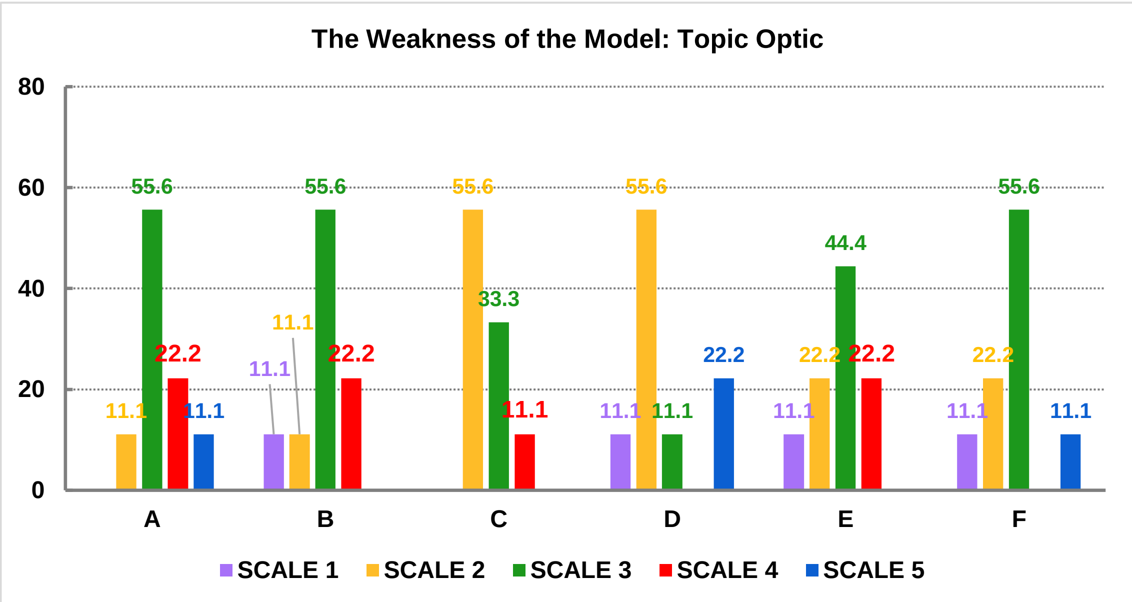


**Figure 7: The Bar Graph Shows The Percentage Of Students Versus The Elements As Tabulated In Table 4 Under The Topic Optic**

***The Comparison of Performance among User Group in Vector and Optic Groups***

The performance comparison between the Pre-Assessment Test and the Post-Assessment Test is depicted in Figure 6 (Vector group) and Figure 7 (Optic group). The percentage of getting A is increased from 18.17% to 25.14% for the Vector group, whereas the progressive increment is reported for the Optic group (44.78% enhancement). Both groups report the enhancement for the greater grades and the decrement for the lower grades. Since the Optic group rises significantly in grade A, then this group increases the grade B by 0.54% and the lower grades (below A-) record the decrement. In conclusion, the learning method using the STEM model

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successfully reduces the failed students to zero in the results of Post-TA. This finding also proved that the STEM model shows a progressive positive effect based on the topic with lower usage of calculations (Optic).

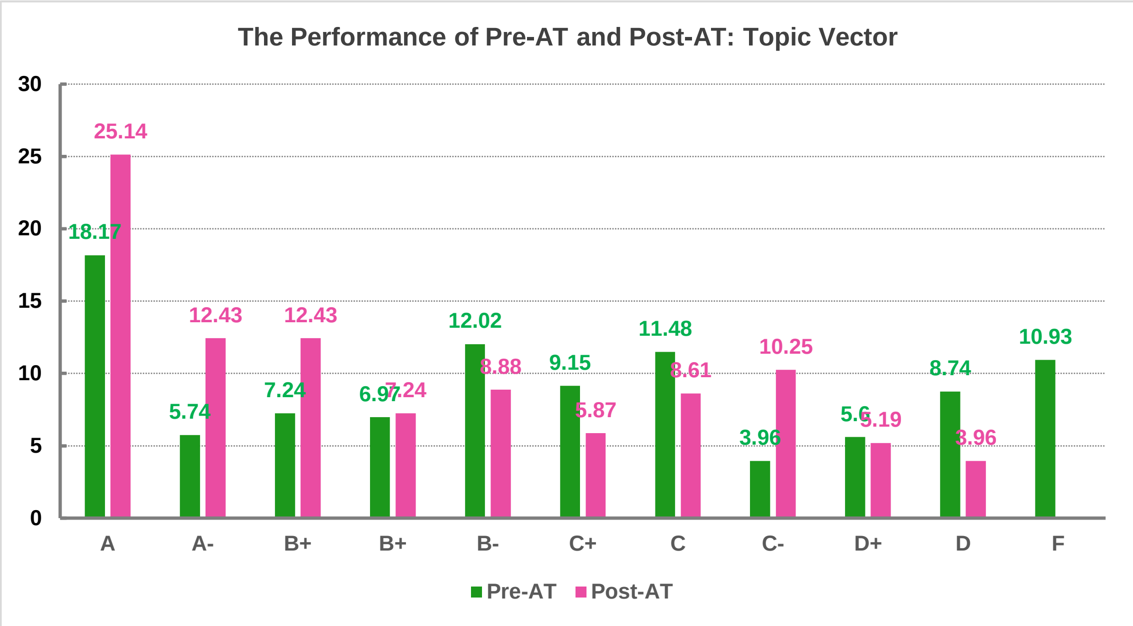


**Figure 8: Comparison between Pre-AT and Post-AT for the topic Vector**

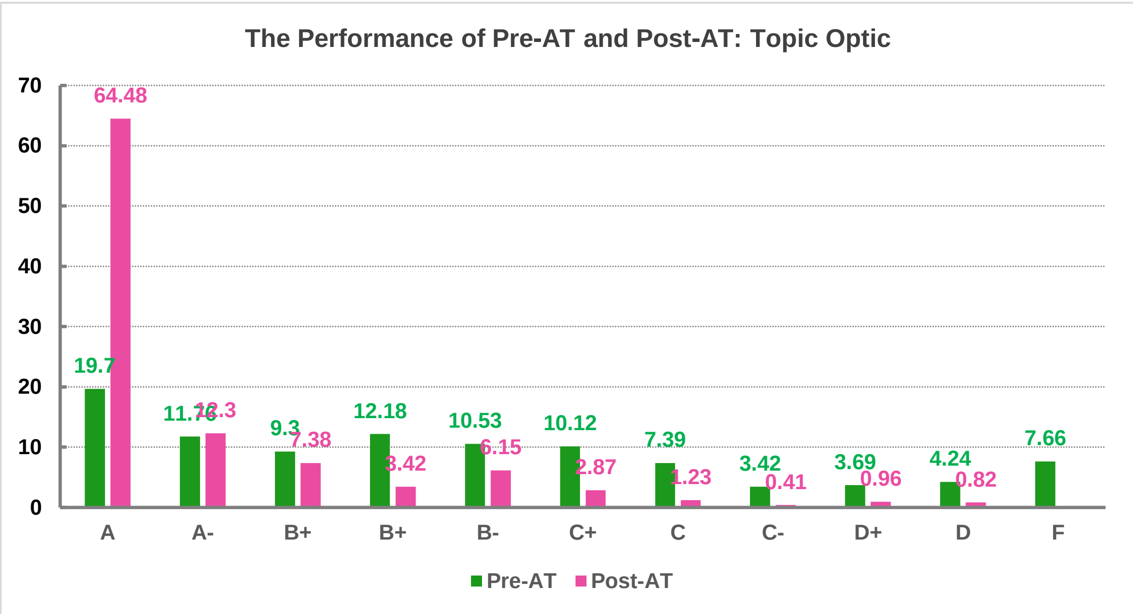


**Figure 9: Comparison between Pre-AT and Post-AT for the topic Optic**

## Conclusion

The research outcomes prove the application of the STEM model provides a direct influence on the student's performance. Furthermore, integrating STEM through project-based activities has the potential to increase the quality of learning. Students in STEM-based learning projects

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need to understand the characteristics of the model, the benefits of the model, and the limitations of the model that help them to produce an effective STEM model. In addition, the topics also contribute to the performance by using the STEM model. It is observed that the topic with the less/easier formula (Optic) is appropriate with the involvement of the STEM model, rather than the topic involving more calculation/formula (Vector). Also, it is suggested that the lecturer can use this as an alternative learning by taking into account the appropriate topic. Therefore, the students can learn more actively and construct their knowledge based on inquiry learning stages. In future, similar studies can be performed by reviewing aspects of STEM more widely with another subject (not Physics subject). In addition, the related skills required in that subject (for example: calculating, memorising, drawing, etc) can be considered to obtain more optimal results.

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