Enhancing Problem Solving and Critical Thinking in STEM: Evaluation of the IDEAS Programme

Zarith Sofiah Othman[1], Wan Anis Nabila Wan Abdullah Zawawi[2], Ahmad Khudzairi Khalid[3], and Nurhuda Ismail[4]

[1] Centre for Foundation Studies, Universiti Teknologi MARA, Cawangan Selangor, Kampus Dengkil, 43800 Dengkil, Selangor, Malaysia
[2] Faculty of Education, Universiti Teknologi MARA, Cawangan Selangor, Kampus Puncak Alam Bandar Puncak Alam, 42300 Puncak Alam, Selangor, Malaysia
[3, 4] College of Computing, Informatics and Mathematics, Universiti Teknologi MARA Cawangan Johor, Kampus Pasir Gudang, 81750 Masai, Johor, Malaysia
zarithsofiah@uitm.edu.my

Abstract. There has been much research that relates to the conventional and formal education for best delivery of science and mathematics (STEM) subjects, but little has been reported of the informal STEM learning that can deliver similar outcomes. The IDEAS programme is a successful non-formal approach to learning science and mathematics. It specifically focuses on competition design and prototype generation, building upon achievements in STEM education. This programme was developed to address the need for an alternative approach that can enhance students' interest and understanding of STEM subjects. Its primary goal is to improve students' skills and abilities in problem-solving and critical thinking. To assess the effectiveness of the IDEAS programme, this paper examines the outcomes measured by a pre- and post-test instrument administered to 65 secondary school students. The research instrument used a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) to gather the data. Descriptive analysis and correlation analysis were performed using SPSS software. The findings of the study indicate that significant improvements were observed in all components, except for engaging in debate and discussion based on evidence. The results support the efficiency of the IDEAS programme in enhancing students' interest and understanding of science and mathematics. The relaxed style of learning implemented in this programme has proven to be effective in increasing young people's engagement with STEM subjects. In conclusion, the IDEAS programme has demonstrated its ability to effectively improve students' interest and understanding of science and mathematics.

Keywords: Science and Mathematics, Secondary Schools, STEM Education, IDEAS programme.

1 Introduction

Science, technology, engineering, and mathematics (STEM) education plays a crucial role in fostering students' critical thinking, problem-solving skills, and innovation. To

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promote interest and understanding of STEM subjects, various educational programmes and initiatives have been developed. One such programme is the IDEAS (Innovation, Design, and Exploration in Arithmetic and Sciences) programme, which focuses on enhancing students' abilities in problem solving and critical thinking through competition design and prototype generation based on STEM education achievements. The IDEAS programme aims to provide an alternative approach to traditional classroom learning by sparking students' interest and improving their performance in STEM-related areas. The IDEAS programme was first introduced in 2017 and was organised to promote STEM education among secondary school students [1]. The success of the first IDEAS programme fueled more effort to organise a second IDEAS programme. The second IDEAS programme, with the theme "STEM: Consensus Aspiring to Knowledge," is expected to be able to form a complete consensus between the university and the school community based on teaching and learning outside the classroom with the implementation of edu-tainment concept. This programme is adapted from the "Master Chef" competition, where the students are required to build and produce the product required by a list of prepared questions. To produce the desired product, the basic knowledge needed is found in mathematics and science, especially physics. All the questions given are related to real-world problems that can be solved by applying the concepts of mathematics and science. Then the learning process occurs when the students solve the problem. In this STEM programme, the students are required to apply all the knowledge learned in class and think critically to complete the given task in order to win the competition.

This research aims to evaluate the effectiveness of the IDEAS programme in enhancing students' abilities in various components related to problem solving and critical thinking. Specifically, the study investigates the impact of the IDEAS programme on students' skills in questioning and problem identification, model development and usage, investigation planning and execution, data analysis and interpretation, mathematical and computational thinking, solution clarification and design, as well as engagement in evidence-based debate and discussion. By examining the outcomes measured by a pre- and post-test instrument administered to secondary school students participating in the IDEAS programme, this study seeks to determine the extent to which the programme contributes to improve student's performance in the targeted areas.

To assess the effectiveness of the IDEAS programme, a pre-experimental design with a pretest-posttest approach is employed. The participants are selected through simple random sampling to ensure an equal chance of selection for all members of the population. A structured questionnaire is used to collect the data, with Likert-scale items measuring students' perceptions and attitudes towards the IDEAS programme modules. The collected data are analysed using descriptive analysis and correlation analysis to evaluate the impact of the IDEAS programme on students' abilities.

The findings of this study contribute to our understanding of the effectiveness of non-traditional educational approaches, such as the IDEAS programme, in promoting student engagement and achievement in STEM subjects. The results will inform educational policymakers, curriculum developers, and educators of the potential benefits in incorporating similar programmes into formal educational settings. Ultimately, the goal is to enhance STEM education and cultivate students' problem-solving and critical thinking skills, preparing them for future challenges and opportunities in STEM-related fields.

2 Literature Review

STEM education, an instructional approach that integrates science, technology, engineering, and mathematics, has garnered significant attention due to its potential impact on student learning outcomes. Extensive research indicates that STEM education not only fosters student's interest in STEM subjects but also enhances critical thinking and problem-solving skills while yielding improved performance on standardised tests [2]. In Malaysia, the significance of science and mathematics has prompted researchers to delve into the subject [3], [4], [5], with the government recognising the importance of STEM education in cultivating a competitive workforce and implementing initiatives and volunteerism to promote STEM education [6]. Nonetheless, the recruitment and retention of the younger generation in STEM fields pose challenges [7]. While STEM subjects are traditionally taught in formal school settings, there is a growing interest in exploring the potential of informal STEM education programmes [8] that warrant further investigation.

In Malaysian studies, students who participated in STEM education have higher achievement scores in science and mathematics, as well as improved problem-solving skills and critical thinking abilities [9]. The authors concluded that STEM education is an effective approach to improve student learning outcomes [10]. Moreover, STEM education has had a big impact on 21st-century skills. In 2018, a study found that STEM education can help to develop 21st century skills such as critical thinking, problem-solving, creativity, and collaboration [11]. Now, all students need to acquire as many skills as they can in preparation to be a better workforce. The role of motivation in STEM education in Malaysia is often discussed. One of the findings of the study was that student motivation in STEM subjects is influenced by a variety of factors, including teacher support, peer support, and parental support. The authors emphasised the importance of designing STEM modules that are engaging and relevant to students' lives and promoting a positive learning environment that supports student motivation [12].

STEM education is a growing area of focus in many countries around the world. This approach to education emphasises the integration of science, technology, engineering, and mathematics which aims to develop students' critical thinking, problem-solving, and practical skills [13], [14], [15]. To support STEM education in secondary schools, various modules have been developed and implemented to enhance students' learning experiences. Many studies have been conducted to assess the development and implementation of STEM modules in secondary schools. A study by [16] described the development of a STEM-based module for teaching physics in secondary schools. The module was designed to enhance students' understanding and interest in physics concepts and was developed based on the latest curriculum requirements. Another study [17] presented the development of a module for teaching science process skills. The module was designed to improve students' understanding and application of science process skills such as observation, inference, and data analysis. The module was found to be effective in enhancing students' science process skills and attitudes towards science [17]. In addition to these examples, there are also STEM modules that focus on teaching 3D printing in secondary schools. The module was developed to enhance students' understanding and practical skills in 3D printing technology and was designed to be interactive and engaging. The study found that the module is effective in improving students' 3D printing skills and knowledge, as well as their attitudes towards technology [18].

STEM programmes are created by using modules that have been developed for the community. Universiti Sains Islam Malaysia (USIM) introduced a STEM module that was implemented on September 20, 2021, to strengthen STEM education towards a skilled workforce and a consistent learning society. This STEM programme was conducted for 20 students at School A in Putrajaya. In the module, five (5) activities, which are the Inspirational Module, Reactivity of Metals, Adruino, Gas Around Us, and Ninja, have been used as an attraction for students who participated through the mentor-mentee system. The study found that the module and mentor-mentee system is effective in improving students' communication and thinking skills [19]. Furthermore, University Kebangsaan Malaysia (UKM) developed a STEM module based on the directed creative process model by applying four (4) creative teaching strategies. The module was titled "Creative Teaching STEM Module" and implemented to high school students of 26 grade 11 students and 31 grade 8 students. The module was designed to be hands-on and practical, with a focus on developing students' five (5) main and necessary skills: problem solving skills, high-level thinking skills, humanity skills, communication skills, and active learning education skills [20].

The effectiveness of STEM-based programmes has been a subject of inquiry in society, raising questions about their positive impact. To address these concerns, some researchers have undertaken studies to determine the efficiency of such aid in increasing academic achievement by delivering classes, workshops, and hands-on activity programmes to students. These studies, for example, have looked at critical thinking abilities and learning success techniques in connection to their effects on anxiety [21], motivation, academic achievement, and general coping strategies [22]. One crucial aspect of STEM education is the ability to ask questions and devise solutions to everyday challenges. Students who engage in STEM education develop this skill by leveraging their understanding of mathematics, science, technology, and engineering, which enhances their problem-solving abilities [23].

Furthermore, the link between STEM education and problem-solving abilities extends to the engineering design cycle utilised in STEM education. By employing the engineering design process, students are equipped to solve real-life problems using fundamental scientific and mathematical concepts, providing practical solutions that can be applied beyond the classroom [24]. Additionally, the problem-solving abilities acquired through STEM education have proven valuable in engineering procedures such as planning, designing, constructing, and evaluating solutions for specific problems [25].

Numerous studies have shown that STEM education positively impacts students' academic success, problem-solving abilities, scientific process skills, conceptual knowledge, and self-efficacy across all educational levels [26]. However, limited research that specifically focused on secondary school students' STEM education, particularly in the Malaysian context, exists. Existing studies are limited, young, and primarily compilation based. Given these circumstances, there is a clear need for experimental research that investigates the impact of STEM education. This study aims to explore the association between STEM education programmes and problem-solving skills among secondary school students.

3 The IDEAS Programme Modules

The purpose of the IDEAS module development is to explore and enhance students' critical thinking skills by tasking them to produce a prototype of the modules at the end of the competition. The modules are focused on five skills of critical thinking, such as analysis, interpretation, inference, explanation, and problem-solving. The IDEAS module is divided into three smaller modules, namely Lift It Up, House of Cards, and A Bottle Boat. These three modules are accomplished in three different levels of the competition; the quarterfinal round, the semifinal round, and the final. A final prototype is produced at the end of each level of competition. Four students work in a group and each group is given an estimated time range of one hour to one hour and thirty minutes to complete the task. The final prototype is then tested and judged based on the assessment criteria for the module.

3.1 Module 1: Lift It Up

The first module presented in the quarterfinal round for about one hour and thirty minutes is Lift It Up! According to this module, the students must design a prototype of a hydraulic lifter machine. This module instructs the students to build a prototype hydraulic lifter machine based on an X-scissors-typed design. In addition, the prototype should be designed at a minimum height of 15 cm. This minimum height is determined when the prototype is lifting the load upwards. Fig. 1 shows the fundamental design of a hydraulic lifter machine.

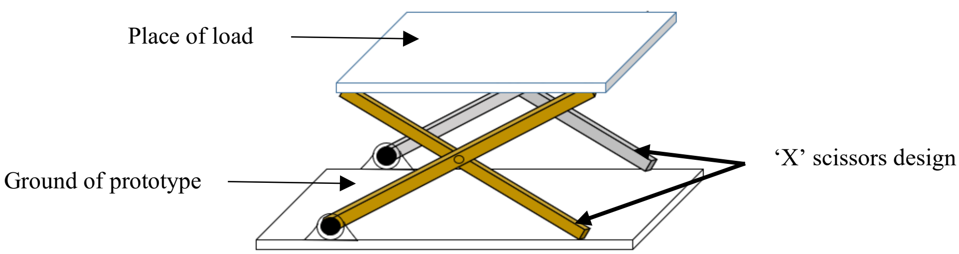

Fig. 1. Fundamental design of a hydraulic lifter machine.

After the completion of this module, the prototype is tested by lifting a single book. A hydraulic system is used to lift the load smoothly upward and downward. Based on this module, the hydraulic system represents a shrink that is filled with water (hydraulic fluid), and the shrink is attached to the structure of the prototype (the X-shaped scissors design). Then, the students push the shrink to lift the load upward. For evaluation purposes, the main criteria is the stability of the prototype's structure and hydraulic system efficiency while the prototype is loading a book at minimum height. After completing this module, the students should be able to explore the knowledge of science's application by designing a prototype structure and developing the hydraulic system.

3.2 Module 2: House of Cards

The second module of House of Cards is the toughest module to prepare compared to the other modules. This module is conducted by selecting students in a group for the quarterfinal round which takes about an hour. This module requires the students to build a house of 50 cm using only 36 playing cards. The students also need to meet the other criteria, which is to ensure that the top of a house must have two pieces of paper labelled K. At the end of the completion process, the house of cards is assessed based on the stability of cards that can stand on the ground during the process of making a house until judging time. This module is able to enhance the creativity of the students by having them build a house using cards at a certain minimum height. Generally, we know that this house of cards is not easy to build and stand on the ground.

3.3 Module 3: A Bottle Boat

The last module completed by students in the final stage is A Bottle Boat, which takes about an hour. This module instructs the students to build a boat using bottles by implementing a scientific principle called the floating principle. The boat's prototype is built from recycled materials such as bottles, straws, papers, and others. The choice of materials should enable the boat to float on the water. The module encourages students to creatively design a boat using recycled materials and to ensure that the boat is stable by carrying loads on the water. At the end of the completion, the boat's prototype is assessed by carrying two types of loads, such as 1.0 kg and 2.0 kg, on the top of the boat. The prototype that could meet the criteria of this evaluation is declared as the best prototype.

4 Research Methodology

In this research, the researchers employed simple random sampling to ensure an equal chance of selection for all members of the population, with a specific focus on secondary school students. The research design utilised a pre-experimental design with a pre-test-posttest approach. A random sample of 65 secondary school students participating in the IDEAS programme completed a structured questionnaire which is divided into four parts: modules, programme location, facilitators, and the programme itself. This study primarily focuses on the module section, further divided into seven parts as presented in Table 1. The effectiveness of the IDEAS programme is assessed through pre- and post-test instruments administered to the 65 participants. The research instrument employed a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Descriptive analysis and correlation analysis are performed using SPSS software. Respondents provided ratings for each item both before and after the programme, with the remaining items rated only after the programme. The internal consistency of the instrument is measured before and after the programme, as indicated by [27]. The collected data from the pre- and post-tests are analysed to evaluate the effectiveness of the IDEAS programme in enhancing students' abilities in various components related to problem-solving and critical thinking.

Table 1. Reliability Statistics pre- and post-program for each item.

Module	Cronbach's Alpha	N of items
Questioning and identifying problem	Pre-program	.703
	Post-program	.817
Develop and use models	Pre-program	.801
	Post-program	.801
Plan and conduct investigations	Pre-program	.692
	Post-program	.668
Analyse and interpret data	Pre-program	.837
	Post-program	.861
Using mathematical thinking and computational thinking	Pre-program	.792
	Post-program	.843
Clarify and design solutions	Pre-program	.755
	Post-program	.776
Engage in debate, and discussion based on evidence	Pre-program	.821
	Post-program	.839

5 Findings and Discussion

The reliability of the instrument as measured by Cronbach's alpha for *questioning and identifying problems, developing and using models, planning and conducting investigations, analysing and interpreting data using mathematical and computational thinking, clarifying and designing solutions, and engaging in debate and discussion based on evidence* was 0.703, 0.801, 0.692, 0.837, 0.792, 0.755, and 0.821, respectively for the pre-program, and 0.817, 0.801, 0.668, 0.861, 0.843, 0.776, and 0.839, respectively for the post-program (Table 1). Since the Cronbach's alpha value for all items is above 0.7, all items are accepted as being reliable.

Table 2. Descriptive summary and paired sample t-test of each factor and its item.

	Pre-Program M	Pre-Program SD	Post-Program M	Post-Program SD	Paired diff.	*t*-value
Questioning and identifying problem						
1. I was able to identify the problem in a short time.	3.34	0.735	4.20	0.666	0.86	-8.599
2. I am able to list information in detail.	3.38	0.678	4.03	0.706	0.65	-6.864
3. I am able to think creatively and logically in solving a problem.	3.75	0.751	4.38	0.578	0.63	-7.537
Overall mean score	3.49		4.20		0.71	
Develop and use models						
1. I was able to develop the model according to the given time.	3.49	0.886	4.25	0.71	0.76	-8.331
2. I am able to create a product that is strong and meets the desired specifications.	3.32	0.937	3.92	0.797	0.60	-5.387
3. I am able to use the information from the assignment given.	3.65	0.799	4.25	0.708	0.60	-5.286
Overall mean score	3.49		4.14		0.65	
Plan and conduct investigations						
1. I am able to plan things according to the given time.	3.74	0.853	4.29	0.678	0.55	-5.382
2. I am able to investigate problems very well.	3.55	0.867	4.12	0.718	0.57	-5.961
3. I am able to carry out an activity earnestly.	4.02	0.800	4.55	0.613	0.53	-6.325
Overall mean score	3.77		4.32		0.55	
Analyse and interpret data						
1. I am able to analyse the information from the assignment.	3.68	0.731	4.20	0.712	0.52	-5.193
2. I am able to interpret data.	3.60	0.787	4.18	0.659	0.58	-5.978
3. I am able to relate problem analysis with available data.	3.55	0.771	4.15	0.734	0.60	-6.311
Overall mean score	3.61		4.18		0.57	
Using mathematical thinking and computational thinking						
1. I am able to interpret information based on logic and mathematics.	3.74	0.853	4.25	0.638	0.51	-5.439
2. I am able to apply problems with mathematical knowledge.	3.68	0.752	4.22	0.739	0.54	-6.325
3. I am able to make evaluations, decisions and hypotheses based on logic and mathematics.	3.57	0.706	4.18	0.659	0.61	-5.342
Overall mean score	3.66		4.22		0.56	

Clarify and design solutions						
1. I can create products.	3.68	0.886	4.31	0.748	0.63	-7.067
2. I am able to explain the solution easily and concisely.	3.69	0.828	4.22	0.800	0.53	-5.074
3. I like to design things.	3.83	0.977	4.22	0.875	0.39	-4.428
Overall mean score	3.73		4.25		0.52	
Engage in debate, and discussion based on evidence						
1. I am able to engage in discussions.	3.95	0.759	4.43	0.728	0.48	-5.791
2. I can discuss with friends well.	4.14	0.864	4.55	0.708	0.41	-5.493
3. I am able to explain the debate based on facts.	3.80	0.887	4.29	0.843	0.49	-6.449
Overall mean score	3.96		4.42		0.46	

Table 2 shows the mean, the standard deviation, and the findings of the paired t-test for seven components. It also includes the individual survey items for both the pre- and post-program. A higher value indicates the effectiveness of the programme among students.

Table 2 indicates that for factor *questioning and identifying problems*, the 65 participants produced an average difference of 0.71 between pre- and post-program scores, demonstrating that the program leads to a significant boost in identifying problems, $t(64) = -9.710$, $p<0.05$. Thus, the programme resulted in a significant increase in students' ability to identify the problem. For *developing and using models*, the result in Table 2 shows that 65 participants produced an average difference of 0.65 between pre- and post-program scores, showing that the programme significantly increases students' capability to construct and use a model, $t(64) = -7.520$, $p<0.05$. Hence, the result demonstrates that students' capacity to create and use models has been considerably improved by the programme.

In addition, for the factor *plan and conduct investigations*, the result indicates that the average difference of 65 participants is 0.55 between pre-program and post-program, resulting in the fact that the programme enhances students' potential in planning and executing the investigation with $t(64) = -7.184$, $p<0.05$. The outcome shows that students' ability to plan and carry out the investigation is improving.

Besides that, *analysing and interpreting data* had an average difference of 0.57 for 65 participants in this study between pre- and post-program, showing that the programme assists the students to improve their skills in analysing and interpreting the data, $t(64) = -6.865$, $p<0.05$. Hence, it demonstrates how the programme helps the students to develop their abilities in analysing and evaluating the data.

For the factor *using mathematical and computational thinking*, the 65 participants had an average difference of 0.56 between pre-program and post-program, revealing that the students are able to use mathematical and computational thinking better after the programme, $t(64) = -7.216$, $p<0.05$. Thus, the programme benefits the students since they can employ mathematical and computational thinking more effectively after following the programme.

The 65 participants had an average difference of 0.52 for the factor *clarification and design solutions* between pre- and post-program, displaying that the program improves the students' ability to explain and design the solutions, $t(64) = -6.749$, $p<0.05$. As a result, the programme gives advantages to the students since it helps them to explain and create the solutions more efficiently.

The 65 participants' pre- and post-program scores for the factor *engage in debate and discussion based on evidence* had an average difference of 0.46, demonstrating that the programme results in a significant increase of students' engagement in evidence-based debate and discussion, $t(64) = -7.074$, $p<0.05$. Hence, the outcome shows that students' capacity to participate in evidence-based debate and discussion has improved.

Analysis of individual items revealed that the paired differences are significant except for items *engaged in debate and discussion based on evidence*. This resulted from these items receiving high marks prior to the start of the program. The seven highest increments after the programme are *questioning and identifying problems, developing and using models, planning and conducting investigations, analysing and interpreting data, using mathematical and computational thinking, clarifying and designing solutions,* as well as *engaging in debate and discussion based on evidence*.

Next, the comparison between the mean scores of the pre-programme and post-programme stages aims to determine whether there is a significant difference between the two scores. The hypotheses are defined as follows: H_0 (null hypothesis): There is no significant difference between pre- and post-programme scores, and H_1 (alternative hypothesis): There is a significant difference between pre- and post-programme scores.

Table 3. Paired samples statistics for IDEAS program.

	Mean	N	Std. Deviation	Std. Error Mean
Pre-Program	77.1538	65	10.97188	1.36089
Post-Program	89.2000	65	10.80683	1.34042

Table 4. Paired samples test for IDEAS program.

Paired Differences								
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pre- & post-program	-12.04615	10.12489	1.25584	-14.55498	-9.53733	-9.592	64	.000

By analysing the mean and standard deviation values presented in Table 3, it is evident that there is a significant difference between the pre- and post-programme scores. The pre-programme's mean is 77.1538 with a standard deviation of 10.97188, while the post-programme's mean is 89.2000 with a standard deviation of 10.80683. These results indicate an increase in scores from the pre- to post-programme stage.

The paired t-test, as shown in Table 4, further confirms the statistical significance of the difference. The t-value is calculated as $t(64) = -9.592$, and with a significance level of $p<0.05$; thus, the alternative hypothesis is accepted. Consequently, the null hypothesis is rejected. This implies that the IDEAS programme modules have proven to be effective for the students, as the post-programme scores are significantly higher than the pre-programme scores.

Furthermore, the analysis of individual items revealed that all components show significant improvements except *for engaging in debate and discussion based on evidence*. Due to the students' excellent performance on these tests before the start of the programme, there has not been much change in this particular area.

In summary, the IDEAS programme has successfully improved students' abilities in various components, such as questioning and problem identification, model development and usage, investigation planning and execution, data analysis and interpretation, mathematical and computational thinking, solution clarification and design, and engagement in evidence-based debate and discussion. The analysis of the data further supports the conclusion that there is a significant difference between the pre- and post-programme scores. This indicates that the IDEAS programme modules have effectively enhanced students' performance, as evidenced by the higher mean scores and the rejection of the null hypothesis. These findings highlight the positive impact of the programme on student learning outcomes.

6 Conclusion and Recommendations

In conclusion, the IDEAS programme has demonstrated its effectiveness in enhancing students' abilities across multiple components related to problem solving and critical thinking. The programme has successfully improved skills in questioning and problem identification, model development and usage, investigation planning and execution, data analysis and interpretation, mathematical and computational thinking, solution clarification and design, as well as engagement in evidence-based debate and discussion. The analysis of the pre- and post-programme scores revealed a significant difference, indicating the positive impact of the IDEAS programme on student learning outcomes. The IDEAS programme modules have been developed based on STEM education achievements by utilising inquiry-based learning approaches. The results of this study suggest that these modules effectively support students in various areas of STEM education.

Furthermore, the IDEAS programme modules are designed to promote a more enjoyable and leisure-style learning experience, aiming to foster an overall interest in science and mathematics among young learners. This study concludes that the IDEAS programme has had a positive impact in improving students' enjoyment of mathematics.

To further improve the implementation of the IDEAS programme, it is recommended to increase participation by scheduling it during weekends or school holidays, allowing more schools and students to be involved. Additionally, enhancing the activities to be more challenging and intriguing can foster students' curiosity and engagement. Conducting activities in dual languages, such as English and Malay, will cater a wider range of students. Collaboration and financial support from relevant parties, including the Mathematics Department of a university, the District Education Office, schools, and grant-providing agencies, should be sought to ensure the sustainability and accessibility of STEM education initiatives like the IDEAS programme. Furthermore, fostering collaboration with other institutions to continuously improve the programme modules and sharing them with schools for internal implementation will enhance the reach and impact of the IDEAS programme in enhancing STEM education.

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