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The Effectiveness of PRO-STEM Module on Students' Higher Order Thinking Skills (HOTS)

(Keberkesanan Modul PRO-STEM terhadap Kemahiran Berfikir Aras Tinggi (KBAT) Pelajar)

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ABSTRACT

The development of higher order thinking skills (HOTS) requires a teaching approach that encourages students' inquiry skills as being emphasized in science, technology, engineering, and mathematics (STEM) education. This study aims to develop and examine the effectiveness of the PRO-STEM Module on students' HOTS. The module employed project-based learning (PjBL) approach with the integration of the STEM concept in Biodiversity and Ecosystem topics. This study involved quasi-experimental design to study the effectiveness of the module. A total of 63 secondary school students were involved in this study. They were divided into control group (30 students) and treatment group (33 students). The findings showed that the intervention using PRO-STEM module has significantly increased their HOTS mean score (t(61)=- 2.61, p=.01). This implicates that PjBL with the integration of the STEM concept in the PRO-STEM Module is an innovation in the teaching and learning of science that further enhances students' HOTS and understanding in Biodiversity and Ecosystem topics.

Key Words: STEM; Project Based Learning, Teaching Module, Effectiveness, Higher Order Thinking Skills

ABSTRAK

Kemahiran berfikir yang lebih tinggi (HOTS) memerlukan pendekatan pengajaran yang menggalakkan kemahiran inkuiri pelajar seperti yang ditekankan dalam pendidikan sains, teknologi, kejuruteraan dan matematik (STEM). Kajian ini bertujuan untuk membangunkan dan mengkaji keberkesanan Modul PRO-STEM dalam meningkatkan kemahiran berfikir aras tinggi pelajar. Modul ini menggunakan pendekatan pembelajaran berasaskan projek (PBPj) dengan integrasi konsep STEM dalam topik Biodiversiti dan Ekosistem. Kajian ini melibatkan reka bentuk eksperimen kuasi untuk mengkaji keberkesanan modul. Terdapat 63 pelajar sekolah menengah yang terlibat dalam kajian ini. Pelajar-pelajar telah diagihkan kepada kumpulan kawalan (30 orang pelajar) dan kumpulan rawatan (33 orang pelajar). Keputusan menunjukkan bahawa intervensi yang menggunakan modul PRO-STEM telah meningkatkan skor kemahiran berfikir aras tinggi pelajar secara signifikan, t(61)=-2.61, p=.01 (p<.05). Implikasinya, PBPj dengan penyepaduan konsep STEM merupakan sebuah inovasi dalam pengajaran dan pembelajaran sains yang dapat membantu meningkatkan pemahaman pelajar terhadap dalam topik Biodiversiti dan Ekosistem.

Kata kunci: STEM, Pembelajaran Berasaskan Projek, Modul, Kemahiran berfikir aras tinggi

INTRODUCTION

The Malaysian Education Blueprint 2013-2025 advocated a prominent position of Science, Technology, Engineering and Mathematics (STEM) education as to gear Malaysia towards higher achievement in *Trends in International Mathematics and Science Study* (TIMSS) and *Program for International Student Assessment* (PISA) (Ministry of Education Malaysia 2013). Students' achievement in TIMSS and PISA is also deemed the best international benchmark to illustrate the students' level of knowledge in Science and Mathematics, as the test items are built to assess students' Higher Order Thinking Skills (HOTS) (Ministry of Education 2015). In STEM subjects, HOTS is highly valued as it is required in problem-solving.

However, even up until 2018, the average achievement of Malaysian students in TIMSS and PISA for Science and Mathematics subjects was still lower than the average score of all 42 participating countries, according to the 2019 Organisation for Economic Cooperation and Development (OECD) report (Hin 2020). The results illustrates that a large proportion of students in Malaysia are still lacking HOTS, especially in the skills of interpreting complex information and identifying appropriate problem-solving strategies. Sukiman et al. (2014) also argued that HOTS is still

poorly integrated in the teaching and learning of STEM subjects in Malaysia. Part of the reason is that the inculcation of HOTS is time-consuming.

Brookhart (2010) argued that HOTS is important to help the students realize the relevance of the scientific concepts in real applications, instead of rote memorization of the concepts. Therefore, a relevant teaching approach is needed to help students improve their HOTS. Newhouse (2017) and Nyet et al. (2016) claimed that the interdisciplinary integration of Science, Technology, Engineering and Mathematics (STEM) subjects in the teaching and learning would help improve students' HOTS, as the approach exposes students to the real applications of the scientific concepts. Blessinger and Carfora (2015) claimed that it will encourage students to learn collaboratively by engaging in problem-solving activities through investigations, designing, evaluating, inquiring, innovating and reflecting. In addition, they also stressed the need to change the current rote memorization teaching method and emphasize more on hands-on activities while learning the concept. Ministry of Education (2016) recommended student-centred teaching and learning approach, such as inquiry-based learning (IBL), problem-based learning (PBL) and project-based learning (PjBL).

However, STEM interdisciplinary integration in teaching and learning is still considered a challenge among teachers. It is based on several factors such as time constraints, lack of teacher knowledge in implementing STEM and lack of STEM teaching materials (Duran et al. 2014; Guzey et al. 2017). Lesseig et al. (2017) also argued that teachers need to be supported with STEM integration teaching materials to help them implement STEM effectively. Due to this need, a teaching module employing PjBL approach that integrates STEM in teaching Science with the focus on developing HOTS among students was developed and validated, called the PRO-STEM module (Nurul Huda & Che Nidzam 2018). Following the development, this present study was done to test the effectiveness of the PRO-STEM module in developing students' HOTS. The following is the research question and the hypothesis tested in this study.

1. Is there a significant difference between the pre-test and post-test HOTS mean scores of the treatment group?
2. Is there a significant difference between the pre-test and post-test HOTS mean scores of the control group?
3. Is there a significant difference in the post-test HOTS mean score between the treatment and control group?

H_{o1}: There is no significant difference between the pre-test and post-test HOTS mean scores of the treatment group

H_{o2}: There is no significant difference between the pre-test and post-test HOTS mean scores of the control group

H_{o3}: There is no significant difference in the post-test HOTS mean score between the treatment and control group

PROJECT-BASED APPROACH IN STEM EDUCATION

Project-based learning (PjBL) is a type of inquiry learning motivated by students' curiosity (Brassler & Dettmers 2017). It is also a systematic learning approach that is able to effectively enhance students' knowledge and skills as it involves the completion of challenging assignments and is carried out in a planned manner. On the other hand, Aksela and Haatainen (2019) claimed teaching science by using PjBL approach can improve student-teacher relationships and encourage students to learn in a fun environment. These conditions have contributed to a positive learning climate and helped teachers achieve learning objectives thereby improving student achievement in science. Capraro et al. (2013) expressed their view that STEM is suitable to be integrated in PjBL due to the overlapping of science, technology, engineering, and mathematics concepts occurs naturally in daily life. This is because in the real world, solving environmental issues for example not only involves science, but also involves technology, engineering, and mathematics. Thus, the integration of STEM with PjBL will enable students to learn STEM as one discipline.

Most scholars suggested that PjBL can improve students' achievement and performance in STEM subjects. Mutakinati et al. (2018) found that the integration of STEM through PjBL encouraged students to think critically to complete STEM-related projects. Such projects have succeeded in building skills such as leadership skills, creativity, and innovation. Plus, Beier et al. (2019) also found that the use of STEM PjBL module in teaching can improve students' problem-solving skills in real-world contexts, as well as promote career aspirations. In other words, the involvement of students in integrative STEM learning activities can improve HOTS, as their experience and skills in learning will help their problem solving skills and creativity (Hazari et al. 2017; Huang et al. 2016; Lestari et al. 2018). In addition, students' interest in learning Science subjects can also be sustained, which will further enhance students achievement (Hazari et al. 2017).

Capraro et al. (2013) also suggested that the alignment of 5E Model and Engineering design process in Teaching and learning STEM can make STEM PjBL becomes more structured. 5E model (*Engage, Explore, Explain, Elaborate, Evaluate*), encourage students to involve in problem solving activities (Hazari et al. 2017; Lesseig et al. 2015) by conducting research, evaluate and reflect. Then, it will lead to improvement of communication skills (Ridlo 2020; Baihaqi et al. 2020), higher order thinking skills (HOTS) such as creative and critical thinking skills (Mutakinati et al. 2018; Barak 2013), and improvement of STEM knowledge and skills (Lestari 2018) and help students make decisions (Baran et al. 2016).

In short, the steps of the engineering design process were also used by previous researchers in the field of STEM education. Among them suggested teacher to follow the five steps stated by the Museum of Science Boston (2008) namely *Ask, Imagine, Plan, Create* and *Improve* (Edy Hafizan et al. 2016; Moore et al. 2015)

PRO-STEM MODULE

The PRO-STEM module is built to encourage learning through a student-centred approach and encourage active student involvement in Science lesson. It aims to allow students to explore science learning with the guidance of teachers, thus allow them to connect students' existing knowledge with science concept. The teaching and learning activities in the PRO-STEM module employed the project-based learning (PjBL) approach as this approach is claimed to be effective in developing students higher order thinking skills (HOTS).

During teaching and learning, students are also encouraged to communicate, ask questions, and engage in brainstorming activities on challenging assignments given by teachers. In addition, students also need to use problem solving skills and 21st century skills in project learning activities. The term 'PRO-STEM' used in this module is the short form of Project (PRO) and Science, Technology, Engineering, and Mathematics (STEM) integration highlighted in each project. This module covered two topics in the Form Two science syllabus, which are Biodiversity and Ecosystem.

The selection of topics is based on the Secondary School Standard Curriculum and described in the Form Two Science Assessment and Curriculum Document developed by the Ministry of Education of Malaysia. The selected topics are Biodiversity and Ecosystems in the theme of Preservation and Sustainability. The following are the learning standards in the PRO-STEM module:

1. Describe and communicate about biodiversity.
2. Interpret food chains and food webs.
3. Describe and communicate about the role of living things in the oxygen cycle and the carbon cycle in ecosystems.
4. Explain with examples the interdependence between living things and the environment for ecosystem balance.
5. Justify and communicate the fact that human beings need a stable and productive ecosystem for the sake of sustainability.

As presented in a previous paper (Nurul Huda & Che Nidzam 2018), the content validity of the PRO-STEM Module was evaluated by nine STEM education experts, including local universities lecturer and science expert teacher. On the other hand, the experts involved in evaluating the module also have vast experiences in developing STEM teaching module. The content validity is analysed using Content Validiy Index (CVI) and the overall mean for the five domain is 0.93. This showed that the module has a high content validity (Sidek & Jamaludin 2005). The module was piloted on a group of 30 Form Two students, and obtained a Cronbach's Alpha reliability coefficient of 0.92, which shows that the module has an excellent reliability (Sidek & Jamaludin 2005).

METHODOLOGY

RESEARCH DESIGN

This study used quasi-experimental research design to determine the effectiveness of the PRO-STEM module in developing HOTS among students. Non-equivalent control group design was used as intact groups were used and assigned as control and treatments groups. This design was used to avoid validity threats, because the inability to assign individuals to treatments randomly would add validity threats. For example, regression and interactions between selection, maturation, history, and testing.

In this study, the treatment group underwent the teaching and learning of Science using the PRO-STEM module, while the control group underwent the teaching and learning of Science using conventional instruction. This study was conducted for seven weeks. Table 1 shows the research design.

TABLE 1. Research Design

Experimental group	Q_1	X_1	Q_2
Control group	Q_1	X_2	Q_2

Indicators:
X_1 = PRO-STEM module
X_2 = Conventional instruction
Q_1 = Pre-test
Q_2 = Post-test

This study had also obtained ethical approval by the Education Policy Planning and Research Division (Ministry of Education Malaysia). The consent to conduct this study has been obtained from the university, the ministry, and the school administrator where this study was conducted.

RESEARCH PARTICIPANTS

A total of 63 students from moderate achievement backgrounds from rural schools were involved in this study. These students obtained grades C and D in the final examination of the Form One in the year 2017. The division of students is divided into random groups according to the treatment group that goes through learning with the STEM PjBL approach and the control group that goes through learning by conventional approach. This is because researchers use existing classes that have moderately achieving students. A total of 33 students were selected as the treatment group consisting of 14 male students and 19 female students. While 30 students are placed as a control group consisting of 10 male students and 20 female students. Students involved in the control group are taught entirely by a teacher using the PRO-STEM Module developed by the researcher himself.

RESEARCH INSTRUMENT

The effect of the module on HOTS will be assessed cognitively based on tests constructed based on the cognitive level in the revised Bloom's Taxonomy namely the skills of applying, analysing, evaluating, and creating. The HOTS assessment test (pre-test and post-test) was built by the researcher by adapting the actual Form 3 Assessment questions (PT3) and TIMSS questions in related topics. The research instrument used has a good validity and reliability that is appropriate and acceptable and were administered to both treatment and control groups.

DATA ANALYSIS METHOD

Independent sample t-test and paired sample t-test were used to analyse the effectiveness of the PRO-STEM module in developing HOTS on the treatment group. Independent sample t-tests were used to compare the mean of two independent samples and test whether the two samples came from different mean populations with one variable (Ghazali & Sufean 2016; Noraini 2013). In this study, the independent samples t-test was used to analyse the difference in the mean achievement of the treatment group and control group, and the paired samples t-test was used to analyse the mean difference between the pre-test and post-test score among the same groups.

FINDINGS AND DISCUSSIONS

Table 2 shows the pre-test and post-test mean scores for both the treatment and control groups. Results show that the treatment group scored higher on the post-test (M=40.73, SD=13.945) than the pre-test (M=20.12, SD=8.60); and the control group scored higher on the post-test (M=32.27, SD=11.492) than the pre-test (M=19.80, SD=9.057) as well.

Table 3 shows the paired sample t-test results that compared the difference in means between the pre-test and post-test scores. Results show that for the treatment group, there was a significant statistical difference between the pre-test and post-test mean score ($t(32)=-12.367$, $p<.05$). Hence, H_{o1} is rejected. Results also show that for the control group, there was also a significant statistical difference between the pre-test and post-test mean score ($t(29)=-13.884$, $p<.05$). Hence, Hence, H_{o2} is rejected.

To test the effectiveness of the PRO-STEM module in developing HOTS among the students, the post-test mean score of the treatment group (M=40.73, SD=13.945) is tested against the post-test mean score of the control group (M=32.27, SD=11.492) by using independent sample t-test, as in Table 4. Results show that there was a significant difference between the post-test mean score of the treatment group and the post-test mean score control group ($t(61)=-2.613$, $p=0.011$). This result indicates that students that participated in the teaching and learning using PRO-STEM module developed or improved their HOTS significantly compared to students that participated in the conventional teaching and learning.

TABLE 2. HOTS pre-test and post-test score

Group	Test	N	Mean	SD	Std. Error Mean
Treatment	Pre	33	20.12	8.601	1.497
	Post	33	40.73	13.945	2.427
Control	Pre	30	19.80	9.057	1.654
	Post	30	32.27	11.492	2.098

TABLE 3. Paired sample t-test of pre-test and post-test scores

Group	Pair	Paired differences			t	df	Significant (2-tailed)
		Mean	SD	Std. Error Mean			
Treatment	Pre-test – Post-test	-20.606	9.572	1.666	-12.367	32	.000
Control	Pre test-Post test	-12.47	4.92	.898	-13.884	29	.000

TABLE 4. Independent sample t-test of HOTS Post test score for control group and treatment group

	Lavene's Test for Equality of Variances		t-test for Equality of Means		
	F	Sig.	t	df	Significant (2-tailed)
Equal variances assumed	1.042	.311	-2.613	61	.011
Equal variances not assumed			-2.637	60.466	.011

The significant increase in the post-test mean score for the treatment group after undergoing intervention with the PRO-STEM module is likely due to the students have been trained to use HOTS in solving problems in the module, such as the skills of analysing, applying, evaluating, and creating in producing products. As such, the PjBL approach utilised also encouraged the students to use inquiries in generating ideas, selecting product designs as well as incorporating STEM concepts in presenting the products. This argument is supported by Slough and Milam (2013), which states that the activity in STEM PjBL requires HOTS because students are trained using the inquiry process. Through this process the students are encouraged to investigate and argue with a variety of problem-solving methods that ultimately lead to the understanding of the scientific concept emphasized in the projects. The integration of the STEM concept helps to give them an exposure on how scientist and engineer work while show them how STEM concept is applied in daily life. This can lead to meaningful learning by encouraging them to learn in a real-world context. Thus, the student's HOTS can be improved. The students will become more confident in learning the concept of science as it can be applied in everyday life. The process of linking STEM's basic concepts in producing projects related to Biodiversity and Ecosystem issues makes science learning more meaningful.

The findings of this study are also in line with the findings of Nur Fadhila (2016) which examines the effectiveness of the PBM-SC2 module constructed based on an inquiry approach to HOTS for Form two students. The findings show that the inquiry approach in science succeeds in enhancing the level of HOTS from the low to moderate level for the group of students who are following the learning with PBM-SC2 module. The findings also support the findings of Nurashikin (2015), which developed the Bio Three Module (based on PjBL approach) for Biology Form Four students. The finding shows that the HOTS increase from the mean=39 (weak level) to mean=46.96 (moderate level). Overall, the findings also support the findings of previous studies that found that the implementation of the module based on inquiry by applying the inquiry phases (5Es) can increase the students' ability to answer HOTS questions (Lee & Kamisah 2015) as the students able to link the concept of science to real-world situations (Aminah Ayob et al. 2015) and lead to a better understanding of concepts (Nurashikin 2015).

CONCLUSION

This study determined to study the effectiveness of the PRO-STEM module in developing students' Higher Order Thinking Skills (HOTS). Findings show that the treatment group scored significantly higher than the control group, after they underwent the teaching and learning of science using the PRO-STEM module for seven weeks. This implicates that the PRO-STEM module

is effective in developing students' HOTS, whereby their active involvement in the problem-solving activities and projects in the module required them to think creatively and critically, which indirectly developed their HOTS. In addition, STEM project activities in this module can also be used as activities outside the classroom such as activities for the school STEM Club or as an exhibition for the school Science and Technology carnival. Therefore, it will encourage more students from various backgrounds to participate and practice STEM in school. However, this study has some limitations. This study chose to examine the effect of using the PRO-STEM Module for students from moderate achiever students only. Therefore, it is encouraged that other researchers can study the impact of STEM integration on HOTS towards higher-achiever students and low-achiever students. This, in turn, can compare the effects of STEM integration on different achievement background. On the other hand, the PRO-STEM module is limited to two topics (in the Biology discipline) of Secondary School Standard Curriculum for Form Two Science, namely Biodiversity and Ecosystem. Due to time and cost constraints, only those two topics being covered in the module. Thus, it is recommended that further studies to be done so that other researchers will build more modules for other topics in Science. This, in turn, will add a source of reference for teachers and students in increasing and broadening STEM integration in teaching and learning.

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