World Transactions on Engineering and Technology Education *© 2022 WIETE*
Vol.20, No.4, 2022

Combining STEAM learning and performance assessment to optimise students' higher-level thinking abilities

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ABSTRACT: This study aimed to determine the difference in the higher-order thinking skills of 41 students (18 males and 23 females) who followed a performance assessment-based STEAM (science, technology, engineering, the arts, mathematics) approach, and 41 students (24 males and 17 females) who were taught in conventional classes. The students were selected from four high schools located in Bali, East Nusa Tenggara (Nusa Tenggara Timur - NTT) and West Nusa Tenggara (Nusa Tenggara Barat - NTB) provinces in Indonesia, in the 2021/2022 year. The sample selection technique used was random sampling and the type of research was quasi-experimental with a non-equivalent control group design. The data obtained were analysed using parametric statistics with a *t*-test and all data analyses were performed using SPSS version 16.0. The analysis revealed that there was a significant difference in the higher-order thinking skills of the students that followed the STEAM approach and those who attended conventional classes. Based on the assessment, the experimental group learned more effectively and demonstrated better outcomes as compared to the control group.

INTRODUCTION

Today, global development is aligned with faster transformations, and the tendency of human interaction has changed towards being more digital. The mastery of science and technology is currently key to helping countries handle challenges posed by this new environment, including the Fourth Industrial Revolution (4IR) [1][2]. The education system plays an important role in addressing these challenges, as the appropriate preparedness of human resources for the demanding labour market and every-day life depends on the quality of education [3]. This acts as a benchmark for national progress. Studies have revealed that education can be a force that initiates and leads to the required or even better than expected changes. It also offers a wider spectrum of life opportunities for those who obtain the sought-after skills and knowledge [4].

Although information and communication technologies have led to development across the globe, due to the constantly increasing demands for change and ever-faster transformations, the problems of education have become increasingly complex. Currently, one of the most crucial problems is the quality of education. In Indonesia, this issue still requires special attention from education experts, because, until now, the quality of the country's education is still low when compared to other countries in the region [5].

In a survey on the quality of education administered by the Program for International Students (PISA), Indonesia ranked 72 out of 77 countries that participated in the survey [6]. The rankings were organised and compiled based on individual variables provided by the OECD and a G20 expert team on data availability and accessibility [6]. According to this data, Indonesia is in the sixth lowest rank, still far from neighbouring countries, such as Malaysia and Brunei Darussalam. For instance, the results of the PISA study showed that Indonesia scored 371, 379 and 396 on reading, mathematics and knowledge (science) respectively [6]. These results reflect a very low quality of education in Indonesia, which is caused by an education system that is too old and shackled, and they also reveal that teacher competencies maybe too low or inadequate [7].

The authors of this article conducted a pilot study in 2020 and established that there was a significant difference in higher-order thinking skills between those students that were taught using a performance assessment-based STEAM (science, technology, engineering, the arts, mathematics) approach compared to those that followed conventional learning in class X of purposively selected high schools in Indonesia. Based on this, the present study aimed to examine closer the differences in higher-order thinking skills of students using the performance assessment-based STEAM approach (experimental group), and those taught with conventional approaches (control group). The population in this study included students from class X of the randomly chosen senior high schools in Bali, East Nusa Tenggara (Nusa Tenggara Timur - NTT) and West Nusa Tenggara (Nusa Tenggara Barat - NTB) for the year 2021/2022. The experimental group was comprised of 41 students (18 male and 23 female) and the control group also 41 (24 male and 17 female). The sample selection technique used was random sampling, with research respondents randomly chosen.

Applying the STEAM (Science, Technology, Engineering, the Arts, Mathematics) Approach for Enhancing Higher-Order Thinking Skills among Students

The use of the STEAM approach to integrate several disciplines, where the disciplinary boundaries are crossed and disciplines merged, is referred to as interdisciplinary integration, and the involvement of several courses at different times is known as multidisciplinary integration. STEAM learning is a strategic approach to honing key competencies, especially critical thinking and problem solving, creativity, and building character, particularly curiosity. Table shows the definitions of STEAM literacy in the five interrelated fields of study, based on Asmuniv [8].

Table 1: Description of STEAM literacy.

Science	Scientific literacy: The ability to use scientific knowledge and processes to understand the world and nature, and the ability to participate in making decisions, and to influence it.
Technology	Technology literacy: Knowledge of how to use new technologies, how new technologies are developed, and the ability to analyse how technology affects individuals, communities, nations and the world.
Engineering	Design literacy: An understanding of how technology can be developed through engineering or design processes using project-based topics and integrating different subjects (interdisciplinary approach).
Arts	Art literacy: The ability to incorporate art and aesthetics into a design project.
Mathematics	Mathematical literacy: Analyse and communicate ideas effectively and in appropriate manner, the ability to formulate, solve and interpret solutions to mathematical problems in different situations.

Source: a modification from Asmuniv [8]

The application of the STEAM approach was divided into three levels. At level I, the projects given to students are short-term, meaning that they are to be completed in two to six learning periods. Level II project completion can take from one to three months, and students are asked to make reports in the form of e-portfolios, posters or videos. At level III, the project is a long-term project that takes up to five-six months. Students are asked to conduct research and come up with findings either individually or in groups. At that time, they are given guidance on the tools that they will make.

Performance Assessment Approach in Mathematics Teaching and Learning

Assessment is a systematic procedure to collect information that can be used to refer to student performance and characteristics [9]. Assessment is not only given to students to check on their performance at a given point of time, but it is a process that can, through different means, guide students to improve their learning competencies [10]. With assessment, students find new learning strategies to improve their competence, while lecturers can apply new learning techniques to address students' learning challenges. Several assessment techniques can be used to collect information, such as formal and informal observations, paper-and-pencil tests, selected response tests, student performance on assignments, research projects and oral questions.

In the world of education, including mathematics, assessment has a long history of development. The assessments and learning activities carried out generally focus on activities related to academic achievement (cognitive) and pay less attention to psychomotor (behavioural) and affective (attitude) aspects [11].

For the case of this research, a scoring system was used in the form of standardised assessment test techniques referred to as conventional assessment. Conventional assessment does not completely describe student learning progress as a whole, because the results obtained from these conventional assessments often tend to be in the form of numbers or abstract letters [12]. Other techniques, such as performance assessments, can be used to complete the picture of progress in learning outcomes. Conventional assessment is often associated with the term *test* (test), while performance assessment is often associated with the term *task* (task). Performance assessment leads students to perform reasoning and acquire skills to complete various interesting and challenging tasks in real-life contexts. Performance assessment is conducted to reflect the actual ability of the students.

The purpose of performance assessment is to evaluate the actual process, in this case, natural sciences and mathematics. This assessment can examine the application of students' abilities in solve real (actual) problem. The difference between the performance assessment and the ordinary (conventional) assessment adopted from Brown [13] for application in this study is presented in Table 2.

Table 2: Differences between performance assessment and ordinary assessment (conventional).

Aspect	Performance assessment	Ordinary assessment (conventional)
Appraisal activities	Doing the task	Choose the answer
Nature of the activity	Created by lecturer	Based on the application
Cognitive level	Knowledge/achievement	Application and analysis
Assessment objectivity	Difficult to achieve	Easy to achieve
Proof of mastery	Direct evidence	Indirect evidence

A performance assessment rubric is often used to discuss the assessment scores. A rubric was used as the scoring guide. The rubric contains criteria that describe what students need to complete the given tasks and measures the level of students' ability to complete the task. The quality of the student work in the classroom was obtained from the rubric. The rubric created by the lecturer must be consistent and uniform for all the students.

Higher-Order Thinking Skills (HOTS)

The higher-order thinking skills (HOTS) is a component of creative and critical thinking skills. Creative and critical thinking can lead a person to be more innovative, creative, ideal and imaginative. The HOTS are defined as a broader use of the mind to identify new challenges. This higher-order thinking ability allows students to apply new information or prior knowledge, and manipulate information to reach possible answers in new situations. Higher-order thinking skills are an important aspect of teaching and learning. People believe that learning can affect learning ability, speed and effectiveness. Therefore, thinking skills are associated with the learning processes. Students trained in thinking have a positive impact on their educational development [14].

Based on these observations, it can be concluded that higher-order thinking skills are thinking activities that do not merely allow to memorise and convey known information. But they are also the ability to construct, understand and transform the knowledge and experience already used in making decisions and solving problems in new situations, which cannot be separated from everyday life. Several principles must be considered in thinking skills:

- Thinking skills are not automatically owned by students.
- Thinking skills are not a direct result of teaching a field of study.
- Students rarely transfer these thinking skills on their own; therefore, guided practice is needed.
- Teaching thinking skills requires a student-centred learning model.

In Bloom's taxonomy, revised by Anderson and Krathwohl, there are three aspects of the cognitive domain that are part of higher-order thinking skills [15]. These three aspects are analysis, evaluation and creation. Three other aspects in the same realm, namely aspects of remembering, aspects of understanding, and aspects of the application, are included in the lower-order thinking section [15][16]. The indicators of higher-order thinking skills used in this study were as follows:

- Analysis refers to the ability to examine and parse, formulate problems and provide appropriate solution steps.
- Evaluation is the ability to assess, refute or support an idea, and provide reasons that can strengthen the answers obtained.
- Creativity is the ability to design a way to solve a problem or combine information into the correct strategy.

RESEARCH METHOD

This study was a quasi-experimental type of research, with a control group, but external variables affecting the implementation of the experiment could not be fully controlled [17]. It aimed to determine the differences in higher-order thinking skills between students that followed performance assessment-oriented STEAM learning and students who were taught with the conventional approach.

This study involved 82 students, using a simple random sampling technique. There were two types of learning approaches examined: the STEAM approach based on performance assessment and the conventional approach that was used as an independent variable. The dependent variable was the students' higher-order thinking ability.

A descriptive test was conducted to collect data on the students' higher-order thinking skills. The collected data were analysed using parametric statistics with a *t*-test; prerequisite tests were carried out in the form of a normality test of data distribution and a homogeneity of variance test. All data analyses were performed using SPSS version 16.0.

A normality test was performed to ensure that the statistical tests used in hypothesis testing could be conducted. This is an important step, because if the data are not normally distributed, a *t*-test, which is a parametric statistic, cannot be performed. The normality tests - Kolmogorov-Smirnov and Shapiro-Wilk – were performed on data for both groups of students' higher-order thinking skills, as shown in Table 3.

Table 3: Tests of normality.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Y_1	0.102	41	0.200*	0.976	41	0.528
Y_2	0.093	41	0.200*	0.979	41	0.640

[a] Lilliefors significance correction
* Lower bound of the true significance

Analysis of the Kolmogorov-Smirnov and Shapiro-Wilk tests showed that sig. > 0.05 for both groups of data; namely, the data on higher-order thinking skills in the experimental group (Y_1) and the control group (Y_2), mean that H_0 is accepted (failed to be rejected) and both sample groups are normally distributed.

RESULTS AND DISCUSSION

The objective of this research was to examine the differences in students' higher-order thinking abilities depending on the learning approach and assessment method. There were two groups involved: experimental that followed the STEM approach, based on performance assessment, and control based on conventional learning and conventional assessment. This study used a non-equivalent control group design with a *t*-test as the data analysis tool.

Thus, the data obtained in this study were clustered according to each group's higher-order thinking skills. The results of the analysis of the central measure (mean, mode and median) and the size of the data spread (variance and standard deviation) on students' higher-order thinking ability scores are shown in Table 4 below.

Table 4: Statistical summary of students' higher order thinking ability scores.

		Y_1	Y_2
N	Valid	41	41
	Missing	41	41
Mean		73.1220	61.1951
Median		74.0000	61.0000
Mode		74.00[a]	60.00
Standard deviation		5.36281	5.24985
Variance		28.760	27.561
Range		22.00	23.00
Minimum		60.00	48.00
Maximum		82.00	71.00
Sum		2998.00	2509.00

[a.] Multiple modes exist. The smallest value is shown

Description:

Y_1 - higher order thinking ability of the experimental group.
Y_2 - higher order thinking ability of the control group.

Variance Homogeneity Test

The homogeneity of variance test was intended to ensure that the differences obtained from the *t*-test came from differences between the groups, not from differences within the groups. From the results of the analysis of the homogeneity of variance test using SPSS 16.0, the following results were obtained.

Table 5: Test of homogeneity of variances (Y - higher-order thinking ability).

Levene's statistic	df_1	df_2	Sig.
0.126	1	80	0.723

From the analysis results, the authors obtained the value of sig. > 0.05 or 0.723 > 0.05; so H_0 is accepted. This means that both groups originated from populations with the same or homogeneous variance. Thus, data on higher-order thinking skills were obtained from a homogeneous population. Based on the results of the prerequisite test; namely, the normality test of the data distribution and the homogeneity of variance test, it can be concluded that the students' higher-order thinking ability data came from a population that is normally distributed and has the same or homogeneous variance.

HYPOTHESIS TESTING

A summary of the data analysis results using parametric *t*-test statistics is presented in Table 6.

Table 6: Summary of the data analysis results using a *t*-test (independent samples test).

		Lavene's test for equality of variances		*t*-test for equality of means						
									95% confidence interval of the difference	
		F	Sig.	*t*	df	Sig. (2-tailed)	Mean difference	Std. error difference	Lower	Upper
Y	Equal variances assumed	0.126	0.723	10.176	80	0.0001	11.92683	1.17204	9.59440	14.25926
	Equal variances not assumed			10.176	79.964	0.0001	11.92683	1.17204	9.59438	14.25928

From the output above, it can be seen that the *t*-count significance for the equal variances assumed for the two-tailed test is 0.001. So, the value of sig. < 0.05 or 0.001 < 0.005. This means that H_0 is rejected, and H_1 is accepted. It can be said that there are differences in higher-order thinking skills between students who followed the STEAM approach based on performance assessment and students who followed the conventional learning approach. The results of the data analysis also showed that the group that followed the STEAM approach had a higher-order thinking ability score of 73.122, whereas the group of students who followed conventional learning had an average higher-order thinking ability score of 61.195. Thus, the average higher-order thinking ability of the experimental group of students was higher than the average of the higher-order thinking ability of the control group of students.

DISCUSSION

The results of data analysis using a *t*-test showed differences in higher-order thinking skills between students who followed the STEAM approach based on performance assessment and those who followed the conventional learning approach. This also shows that it is necessary to improve the quality of learning, especially for students still taught with conventional methods. The superiority of the performance assessment-based STEAM learning approach over the conventional learning approach can be seen in the average higher-order thinking abilities of students. The average higher-order thinking ability of the experimental group was 73.122, which was higher than the average of the control group's higher-order thinking ability of 61.195.

This advantage is not limited to a theoretical description, but has been empirically tested in the field. The application of approaches and assessments in the learning process plays an important role, because it is a conceptual framework in the form of a systematic learning plan. The STEAM approach, based on performance assessment, is a learning approach that can challenge students to actively solve problems by connecting their knowledge and skills to challenging situations. As a learning approach based on interdisciplinarity, it constitutes an interconnected learning model to learn various academic concepts applied and categorised into the following five disciplines: science, mathematics, engineering, art and technology. The advantages of the STEAM approach over conventional approaches can be demonstrated by evidence.

Mathematics is an important subject for many students. Through mathematics learning, students can solve everyday problems rationally. The role of lecturers as educators should be to manage to learn to create interesting learning to foster student learning activities. If students already have an interest in learning, they can improve their activities and learning outcomes.

According to Afriana et al, the advantages of the STEM (STEAM) approach compared to conventional approaches can be further strengthened; namely, STEM (STEAM) can improve scientific literacy and motivate learning, help understand teaching materials and form creative attitudes, also it can make students more aware of the importance of protecting the environment [18]. This approach can provide new experiences for students, so that their motivation and interest in learning will increase through real experiences. In STEAM learning, students are invited to engage in meaningful activity to understand concepts. They are invited to explore project activities, so that they can be actively involved in the process. This encourages students to think critically, creatively and analytically, and improves their higher-order thinking skills [19].

CONCLUSIONS

Based on the findings and discussion, the application of the STEAM approach in the learning process and assessment plays an important role, because it is a conceptual framework in the form of a systematic learning plan. The STEAM approach is a learning model that is expected to challenge students to actively solve problems by connecting their knowledge and skills with challenging situations. It is a learning approach based on interdisciplinarity that constitutes a cohesive learning model for learning various academic concepts from five disciplines; namely, science, mathematics, engineering, arts and technology, while connecting them with the real world. The purpose of the STEAM approach is to provide students with the knowledge and skills required to deal with unexpected changes in the world.

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