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The effectiveness of experiential learning – STEM model with formative assessment in building students' mastery on fluid dynamics

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Abstract. Fluid dynamics is related to science, technology, and daily lives, but students' understanding of the topic is considered not optimal yet. This study aims to investigate the effectiveness of experiential learning (EL) – STEM model with formative assessment (FA) in building the mastery of fluid dynamics and explore students' difficulties. This is a mixed-methods research with an embedded experimental design with 34 grade XI students of high school in Malang, Indonesia, as subjects, which were chosen with purposive sampling. This research used dynamics mastering test instrument in the form of 18 reasoned multiple-choice question items with a reliability of 0.65. The data were analyzed with Wilcoxon Signed Ranks test, N-gain, and the description of students' answers. The result showed that EL-STEM with FA is effective to build the mastery of fluid dynamics with the effectiveness of the subtopic of Bernoulli's law is higher than the subtopic of Continuity. Before learning, students had difficulties to understand almost all material of fluid dynamics. However, after learning, students only had difficulties to understand certain things, which are the relationship between physical quantities in Bernoulli's law, the distance between the water reservoir and the water jet, the speed of air under or above the wing of an aeroplane, and the shape of aeroplane's wing design.

1. Introduction

The wings of an aeroplane, mosquito spray, and carburetor are a few of the technologies which apply the concept of fluid dynamics [1]. However, the relations between concepts and the solutions to the problems in daily lives which correlate to fluid dynamics are still considered difficult to learn by students [2]. In addition, students think that force is the same as pressure and that pressure is proportional to its velocity [3], and that fluid mechanics is almost the same as solid mechanics [4]. These difficulties were tackled with the Grup Investigation learning with the know, want, and learn strategy [5], however, the active role of students is still felt as lacking during learning. Also, learnings based on digital technology have been implemented before, such as blended learning [6], epistemic games [7], and virtual learning [4]. However, the use of digital content makes some students feel tired [6]. Meanwhile, more interactive learning content can be fulfilled with the field of science, technology, engineering, and mathematics (STEM) [4]. The increase of understanding can be achieved by students if the learning of the topic of fluid dynamics guarantees two things, which are (1) the



active role of students' activity, and (2) the association with the field of STEM. Besides that, the previous research above still hadn't focused on the feedbacks during learning.

The active role of students can appear in the process of observation and reflection. This is filled by the holistic learning Experiential learning which focuses on direct experiences and concrete in nature as a foundation for observation and reflection [8, 9]. The experience of design and the concept gain is two important experiences for students in the implementation of learning and teaching activity of Experiential learning which is innovative [8]. The result of a study showed that Experiential learning can increase students' conceptual mastery [10]. Meanwhile, with the activities of product engineering which involve science, technology, and mathematics in the field of STEM which becomes a foundation of Experiential learning (EL), students can achieve the skills of critical thinking, problem-solving, creativity, and collaborating. The achievement of these four skills and concept mastery is the demands of learning in the 21st century [11]. In the STEM approach, students can gain meaningful learning experience [12], build deep concept mastery [13], and work together in a group to apply their knowledge to solve daily problems [12, 14].

Experiential learning with the STEM approach needs the presence of feedback in the form of Formative Assessment (FA) during the learning process. Formative assessment involves the student-teacher interaction during learning and aims to increase students' achievements in learning [15]. Meanwhile, students' active involvements during learning can be encouraged through collaborative activity, feedbacks, and self-assessment [16]. The class environment which is compatible with science procedure can be created in learning in which it contains formative assessment [17]. Learning with formative assessment is more focused to the improvement of students' learning instead of only aims to evaluate what they have learned [16, 18].

Based on the text above, Experiential learning with the STEM approach with formative assessment (EL-STEM with FA) has a big potential to increase the concept mastery of fluid dynamics. Therefore, the purpose of this research is to test the effectiveness of Experiential learning - STEM model with formative assessment in improving students' mastery of fluid dynamics.

2. Method

This is a mixed-methods research with an embedded experimental design [19] with 34 grade XI students of high school in Malang, Indonesia, as subjects, which were chosen with purposive sampling. To increase EL syntaxes [9], the aspects of STEM [4], and the components of FA [16] are combined to increase the concept mastery (C1: remembering, C2: understanding, C3: implementing, C4: analysing, C5: evaluating, and C6: creating) [20] with the following learning design. The first syntax, concrete experience, is inserted with the aspects of science, technology, and mathematics, and the components of higher-order questioning techniques, use of problem-solving techniques, and discussions, jot time, group work, and pair work to train C1 and C2. The second syntax, reflective observation, is inserted with the aspects of science and mathematics and the components of discussions and collaborative goal setting to train C1, C2, and C4. The third syntax, abstract conceptualization, is inserted with the aspects of science and technology, and the components of feedback as comments and not grades, oral feedback to train C2, C3, C4, and C5. The fourth syntax, active experimentation, covers the aspects of science, technology, engineering, and mathematics, and the components of redrafting of work, use of problem-solving techniques, discussions and collaborative goal setting, feedback as comments and not grade, oral feedback, reflective learning, peer-assessment, self-assessment to train C5 and C6. In this research, students endeavor to make 3 products, which are water jet free energy, venturimeter, and hurricane-proof roof.

This research used dynamics mastering test instrument in the form of 18 reasoned multiple-choice question items with a reliability of 0.65. The test items cover the sub material of the fluid continuity principle and Bernoulli's principle. The quantitative data is analyzed with the Wilcoxon Signed Ranks test [21], and N-gain [22]. EL-STEM with FA model can be said to be effective in building mastery on fluid dynamics if the average post-test score is significantly higher than the average pre-test score and if the N-gain score is in the medium category. The qualitative data in the form of description of

students' answer is analyzed with the use of Coding, Data Reduction, Data Display, and Conclusion Drawing/Verification [23]. Students are considered to have difficulties to understand the concept on the topic of fluid dynamics if the total number of students who chose the wrong answer is more than 10% of all students.

3. Results and Discussion

The data of the research shows that the average score and standard deviation of pre-test and post-test data are, respectively, 83.497 and 7.039, and 18.954 and 7.871. The normality test of Kolmogorov-Smirnov shows that the Sig. a score of pre-test and post-test are, respectively, 0.003 and 0.004, so that both data do not satisfy the normal distribution. As the pre-test and post-test data do not satisfy the normality requirement, the difference test on the pre-test and post-test data pair uses the Wilcoxon Signed-Ranks Test. The result of Asymp. Sig. (2-tailed) test results in the value of 0.000, which means that the pre-test and post-test scores of students are significantly different. As the average score of the post-test is higher than the average score of the pre-test, it means that EL-STEM with the FA model can increase students' understanding of the topic of fluid dynamics. The analysis of the increase of concept mastery yields the result of N-gain score of 0,796 (high category). Therefore, the result of this research shows that EL-STEM with FA model is effective to build students' mastery of fluid dynamics.

The mastery of fluid dynamics with EL-STEM with FA can be explained as follows. The result of previous research showed that Experiential learning, STEM, and FA can increase students' concept mastery if used separately or together. Experiential learning is able to improve concept mastery better than the conventional methods [24]. In Experiential learning, pedagogical skills and innovative learning can be built by the teacher so constructivist learning can be realized [25]. The aspect of engineering in STEM is students' concrete action in solving contextual problems. As students do the concrete actions in real life, their concept mastery will also improve [26, 27]. Indeed, the STEM approach can increase students' concept mastery [28]. Meanwhile, FA depends on all obstacles and students' ideas in learning so the quality of science learning can improve [29]. Self-assessment and peer-assessment in FA can be a reference to fix and improve concept mastery on the topic of fluid dynamics of students [30, 31]. With the feedback elements in FA, students' conceptual understanding can improve [32, 33]. Syntax of a model with FA has been proven to be able to enhance students' science concept mastery [34]. Experiential learning with FA causes learning to have better quality so students can store information in a longer duration [35].

Fluid dynamics covers two subtopics, which are the continuity principle and Bernoulli's principle. For the subtopic of continuity, the average score and standard deviation of pre-test and post-test, are, respectively, 80.000 and 14.771, and 32.353 and 19.079. While the average score and standard deviation of pre-test and post-test of the subtopic of Bernoulli's principle are, respectively, 84.842 and 8.778, and 13.801 and 9.235. Four of the data are not normally distributed. The result of the Wilcoxon Signed-Ranks Test shows that there is a significant difference between pre-test data and post-test data. The result of N-gain yields the value of 0.704 (high category) and 0.824 (high category). Therefore, EL-STEM with FA model is effective to build the mastery of both subtopics, although the effectiveness of the subtopic of Bernoulli's law is higher than the subtopic of Continuity. It's apparent that students understands more about Bernoulli's principle than the continuity principle.

Students' difficulties are known from the analysis of students' reasons for the wrong answer. Before learning, the difficulties experienced by students can be seen in Table 1. It's apparent that before learning, students had difficulties to understand almost all material of fluid dynamics. In Table 1, it can be seen that almost 27% of the students think that the volume flow rate of fluid flow is not constant because of the size of the pipe's surface area changes. In this case, students have difficulty understanding that the changes in radius or diameter of surface area don't cause the volume flow rate of fluid flow to decrease or increase [4]. It's also possible that the difference between the volume flow rate and velocity is difficult to understand by students [3]. The result of this research supports the

finding of a previous study which showed that the mass conservation principle on fluid flow in pipes is difficult to understand by students [36].

Table 1. Summary of Wrong Reason on the distractor on few items in pre-test.

Cognitive level/Item Indicator	Wrong reason on distractor in pre-test (%)
C2/ Explain the action of someone who waters the flowers with hose based on the concept of continuity principle	Volume flow rate of water which goes into the hose is more than the volume of water which goes out of the hose (26.47)
C3/ Make a decision about pipe with increasingly smaller surface area based on the implementation of continuity principle	The speed of flow is proportional with the surface area of the pipe (88.24)
C3/ Determine the variable which affects the blood flow of someone with Arteriosclerosis	Someone with Arteriosclerosis has enlarging blood vein (32.36)
C1/ With few basic concepts of Bernoulli's principle presented, students are expected to determine the suitable concept which applies in certain technology	Bernoulli's principle fulfills that pressure is proportional with velocity (23.53), or fluid pressure is atau tekanan fluida berbanding terbalik dengan kecepatan aliran fluida (29.41)
C3/ Calculate the velocity of bloodstream in a clogged vein by applying Bernoulli's equation	It's difficult to apply Bernoulli's equation on the case of clogged vein (91.18)
C3/ Determine the horizontal distance of the drop of the water from the faucet which flows water from a water reservoir	It's difficult to determine the spot where water drops from the flowing water reservoir (79.42)
C3/ Determine one of variables based on variable analysis which are related to the lift of aeroplanes	It's difficult to determine the speed of air flow above the wings of an aeroplane (88.24)
C4/ With a picture of venturimeter is presented with various diameters, students are expected to analyze the speed of each pipe correctly	It's difficult to determine the relation between the speed of flow, pressure, and the height of water in an venturimeter (82.35)
C6/ Choose the design of an aeroplane with reasons of the choosing based on the Bernoulli's principle	It's difficult to determine the design and reason regarding the wings of an aeroplane (88.23)

Almost 90% of students think that the speed of flow is proportional to the cross-sectional area of the pipe. This is caused by the ability of students which is still poor in understanding the mathematical formula of continuity. The result of previous research showed that students can build mathematical proof correctly if they understand the mathematical concept and definition correctly [37, 38]. The mathematical ability of a student will affect his ability to solve physics problems [39, 40]. Students with low mathematical ability will fail to build the meaning of physics problem statement [41].

Around 25% of students think that a bigger speed of flow will cause bigger or smaller pressure. It seems that students still have difficulty to understand the relation between the units of pressure and speed in Bernoulli's principle. The result of a previous study showed that students still considered that the speed of fluid flow is proportional to the pressure of the fluid on the container [3, 4]. Therefore, students' understanding of mass conservation on Bernoulli's principle is still very poor [36].

In Table 1, it can be seen that more than 80% of students still have difficulties in determining or applying Bernoulli's equation in the case of clogged bloodstream, leaky water reservoir, and wings of aeroplane. Students have known about the mathematical equation of Bernoulli. However, students don't fully understand the meaning of each component of the equation [42]. As a result, students apply the equation in a less than the correct way, or even in the wrong way or don't use the equation at all [43]. After the learning, students have the difficulties to understand the concept which can be seen on Table 2.

Table 2. Summary of Wrong Reason on the distractor on few items in post-test

Cognitive level/Item Indicator	Wrong reason on distractor in post-test (%)
C1/ With few basic concept of Bernoulli's principle presented, students are expected to determine the suitable concept which applies in certain technology	Bernoulli's principle fulfills that pressure is proportional to height (14.71)
C3/ Determine the horizontal distance of the drop of the water from the faucet which flows water from a water reservoir	It's difficult to determine the spot where water drops from the flowing water reservoir (29.41)
C3/ Determine one of variables based on variable analysis which are related to the lift of aeroplanes	It's difficult to determine the speed of air flow above the wings of an aeroplane (48.23)
C6/ Choose the design of an aeroplane with reasons of the choosing based on the Bernoulli's principle	It's difficult to determine the design and reason regarding the wings of an aeroplane (48.23)

From Table 2, it can be seen that after learning, students only had difficulties to understand certain things, which are the relationship between physical quantities in Bernoulli's law, the distance between the water reservoir and water jet, the speed of air under or above the wing of an aeroplane, and the shape of aeroplane's wing design. All these difficulties had been present since before learning as seen from Table 1. This shows that misconceptions are difficult to reduce or remove it. The result of a previous study showed that misconceptions are truly formed from hard effort and a long time so that they can be deeply rooted in students' minds [44]. Besides, when faced with a problem, students in truth know the correct answer or solution, but misconceptions persist although there are efforts to change them [45,46]. Also, students find it difficult to connect the ability which they own before with the contextual problems which they are learning at the present [4].

4. Conclusions

This research has several following conclusions. The post-test score of students is higher than their pre-test scores and both are significantly different. The analysis of the increase of concept mastery resulted in the N-gain score in the high category. This means that EL-STEM with FA is effective to build the mastery of fluid dynamics of students. It can be seen from the sub materials of Continuity and Bernoulli that EL-STEM with FA model is effective to build the mastery of both subtopics, with the effectiveness of the subtopic of Bernoulli's principle is higher than the subtopic of Continuity. Before learning, students had difficulties to understand almost all material of fluid dynamics. However, after learning, students only had difficulties to understand certain things, which are the relationship between physical quantities in Bernoulli's law, the distance between the water reservoir and water jet, the speed of air under or above the wing of an aeroplane, and the shape of aeroplane's wing design. It's recommended for future research to add the aspects of religion and art in the STREAM approach and use it in other topics in physics other than fluid dynamics.

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