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Improving Students Understanding on Fluid Dynamics through IBL-STEM Model with Formative Assessment

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Improving Students Understanding on Fluid Dynamics through IBL-STEM Model with Formative Assessment

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Abstract. Fluid dynamics is related to science and technology in everyday's life, but students still have low understanding about it. This research aims to correct the understanding and describe students' difficulties on the topic of fluid dynamics after Inquiry-Based Learning integrated STEM with Formative Assessment. This mixed methods with an embedded experimental design made use of research subject of 34 students (M=14 and F=20) of grade XI in a high school at Jombang, Indonesia, which were selected with purposive sampling. The research instrument used was the fluid dynamics understanding test instrument in the form of reasoned multiple-choice questions with a reliability of 0.774. The data analysis was done with Wilcoxon Signed-Rank test, N-gain, d-effect, and and the analysis of the description of students' answer. The result of the study shows that the learning process was able to significantly improve students' conceptual understanding with the N-gain value of 0.628 (medium category) and d-effect size of 3.645 (very large category). After the learning process, students still have great difficulty in learning two things, which are flow rate with constant magnitude and the relation between pressure, surface area of the space, and the flow speed. Other than that, students still feel some difficulty to analyze (1) the relation between speed of flow and radius of space, (2) the construction of the proof of constant debut, (3) aerodynamic lift of two wings of an aeroplane, and (4) the phenomena of someone standing near a moving train, and (5) the relation between the height of water reservoir and the flow rate.

1. Introduction

The concept of fluid dynamics is a basic of few phenomena and technology in daily life, such as the concept of aerodynamic lift on aeroplanes, venturimeter, carburator, perfume spray and other more complicated concepts such as turbulency and the phenomenon of the flow of whirlwind [1]. However, students still have difficulty on the topic of fluid dynamics. Students still find it difficult to understand the difference between the fluid mechanics and the concept of solid mechanics which they learned earlier [2]. Students assume that the bigger the speed of fluid, the bigger its pressure, and that pressure is equal with force [3]. Students still struggle to connect the concept of fluid dynamics and to determine the solution from the problem in daily lives [4].

Some of learning strategy which make use of digital technology has been done to teach the topic of fluid dynamics to minimalize students' difficulties, for example online learning and feedback activities [2], epistemic games [5], blended learning [6], and virtual learning [2]. However, some students feel tired with the themes in the digital content [6] so, there is a need to make the content to be more interactive in nature which is then related to the field of STEM (science, technology, engineering, and mathematics) [2]. Also, (model Grup Investigation) has been done with combination of know, want, and learn method [7]. However, there's still difficulties on the management of students' active role. These previous studies recommend that the learning of fluid dynamics need two important aspects, which are (1) the active role of students in retrieving the concept of fluid dynamics, and (2) the attribution of the topic of fluid dynamics with the field of STEM.

In relation to the active role of students' participation in retrieving the concept of fluid dynamics, it is recommended that students act the role of scientists in a process to a concept discovery such as in project-based learning, problem-based learning, or inquiry-based learning [8]. However, to teach fluid dynamics, even though project-based learning was successful in improving students' problem-solving ability, students still have difficulties to connect the concept to solution taking [9]. On the other hand, problem-based learning which is combined with STEM was able to improve students' concept understanding and scientific literacy in the topic of fluid dynamics [10]. Therefore, inquiry-based learning with the integration to STEM has a potential to improve students' concept understanding.

Inquiry Based Learning (IBL) is one of learning models which puts students as researchers. Students will be guided to think deductively and inductively through formulation of questions [11]. The result of the research showed that inquiry-based learning was able to increase students' learning achievement [12] and concept understanding [13]. Fluid dynamics learning needs a contextual learning which has strong connection with the field of science and technology and is based on experimentation without taking away the essence of Physics learning, the process, and the product [14]. This is in accordance to the research about inquiry-based learning which suggested the integration with STEM approach [15].

The implementation of inquiry-based learning with STEM integration is a combination which is expected to increase students' conceptual understanding in Physics. STEM is a learning approach which integrates the fields of science, technology, engineering, and mathematics into a whole learning which is intended to develop students' knowledge and skill in a comprehensive manner [16]. The research about inquiry-based learning with STEM has been done to improve conceptual understanding and scientific literation on the topic of Newton Laws [13]. The result of that research showed that conceptual understanding was able to be improved higher with STEM-integrated inquiry-based learning than with inquiry-based learning without STEM integration [13,17]. On the other hand, STEM integration into learning needs time to make the students get accustomed to complex phases [4]. Therefore, IBL-STEM needs formative assessment which has been tested to help students achieve the goals of learning effectively.

The combination of Formative assessment with IBL-STEM is a combination which is expected to improve students' conceptual understanding. Formative Assessment (FA) is an assessment which not only put the assessment stage as a process to determine the result of students' learning, but also help students to reach the goals of the learning [18,19]. The result of the research showed that the use of formative assessment also helped the teachers immensely to develop their professional skill [19] and to get quick feedback [8,20]. With the quick feedback, students get the necessary help to gain conceptual understanding quickly and teachers get necessary help to find the difficulties faced by students to be handled with quickly [20]. Similar research revealed that formative assessment can improve conceptual understanding and lower the level of students' misconceptions on the topic of fluid statics [8].

Fluid dynamics learning must take three aspects into accounts, which are students' active role in the learning process, the relation with STEM aspects, and formative assessments. The three aspects were deemed suitable with the characteristics of students' conceptual understanding. The purpose of this research is to improve students' understanding and to describe students' difficulties in the topic of fluid dynamics after the Inquiry-Based Learning integrated STEM with Formative Assessment was implemented.

2. Method

This research implemented mixed methods with embedded experimental pre-posttest model [21]. The subject of this research was 34 grade XI students (L=14; P=20) of a high school in Jombang, Indonesia. The subject was chosen with purposive sampling technique [21]. To increase the concept understanding, namely remembering (C1), understanding (C2), implementing (C3), analysing (C4), evaluating (C5), and creating (C6) [22], IBL syntax [11], STEM aspects [2], and FA component [18] was combined as following design. The first syntax of Orientation was inserted with aspects of Science and Technology and the component of Sharing Learning expectation and Questioning to train C1 and C2. The second syntax of Conceptualization (Questioning, and Hypothesis Generation) was inserted with the aspect of Science and the part of Questioning dan feedback to train C2 and C6. The third syntax of Investigation (Experimentation, and Data Interpretation) was inserted with the aspects of Science and Mathematics and the part of Questioning dan feedback to train C2, C3, C4, C5, and C6. The fourth syntax of Conclusion was inserted with the aspects of Science, Engineering, and Mathematics and the part of Self-Assessment, and Peer assessment to train C4, C5, and C6. The sixth syntax Discussion (Communication, and Reflection) was inserted with the aspects of Science, Engineering, and Mathematics and the part of Self-Assessment, and Peer assessment to train C2, C4, and C6.

This research used fluid dynamics understanding test instrument in the form of 12 multiple-choice questions with reasons with the reliability of 0.774. The scope of the questions includes 6 dimensions of cognitive process, C1 to C6 [22], and covers the submaterial continuity equation for fluids, Bernoulli's Principle, and Implementation of Bernoulli's Principle. The quantitative data was analyzed with difference test of pre-posttest with Wilcoxon Signed-Ranks test [23], the increase of conceptual understanding with N-gain [24], and the effectivity of treatment with d-effect [23]. The qualitative data of students' reasoned answer was analyzed with Coding, Data Reduction, Data Display, and Conclusion Drawing/ Verification [21].

3. Results and Discussion

The descriptive data analysis showed that the average and standard deviation of pre-test and post-test score are, respectively, 40.687 and 10.001, and 77.941 and 10.437. Kolmogorov-Smirnov test showed that the value of Sig. for the pre-test and post-test, respectively, are 0.000 and 0.016. This showed that both data were not normally distributed. Lavene Statistic test showed that the value of Sig. was 0.369, which showed that the variant of pre-test and post-test data fulfilled the homogeneity assumption. As the normality assumption was not fulfilled, the difference test between the pair of pre-test and post-test data was done with Wilcoxon Signed-Ranks Test. The result of this test showed the value of Asymp. Sig. (2-tailed) was 0.000, which means that there is significant difference between students' pre-test and post-test. This means that the model was able to increase students' understanding on the topic of fluid dynamics. The analysis of the improvement of conceptual understanding and the magnitude of model treatment's impact yielded the results of N-gain of 0,628 (medium category) and d-effect size of 3,645 (very large category).

The stages in IBL-STEM with formative assessment make the students' conceptual understanding in the topic of fluid dynamics stronger and direct the concept to solve problems in real world. This supports the result of previous research which showed that IBL-STEM was able to increase students' conceptual understanding [13] and students are able to implement the concept to solve problems [25]. Also, the combination of FA in the syntax was proven to be able to improve students' conceptual understanding of Science [26]. Other than that, teachers can gather all information, including the the obstacles and ideas from students to be used to improve the quality of science learning through FA [27]. In the end, the integration of IBL-STEM with FA is a combination that can increase students' conceptual understanding.

Inquiry Based Learning is able to increase the conceptual understanding in the topic of fluid dynamics because it gives students a chance to have a role to be researcher. Students performed empirical test to investigate the relation between dependent variable with independent variable [11]. In this research, students were faced with how research is determined independently so that students' curiosity was increased [28]. As students were given liberty to choose their own learning, students' active role and cognitive structure would automatically increased as they gained their own cognitive knowledge [29]. This result supports the finding in previous research that showed IBL can effectively increase students' conceptual undertanding [13].

STEM amplify the role of students as engineers as they put their knowledge to use. In this research, conceptual understanding of the topic fluid dynamics was deeper when students are given a chance to apply their knowledge onto the context of concrete solution of a problem. Students can provide solution to the problem of the expensive price of water jet and the rarity of water source in the mountain area. This resulted in the increase of students' conceptual understanding as they progress in making the solution into a reality with a concrete action [15,16]. This finding also supports the result of previous research which showed that STEM can increase students' conceptual understanding [17].

Formative assessment has an important role in the implementation of learning in this research. Students are given a chance to be assessors in the learning process in which they were a part of. The result of the assessment then was utilized as a point of reference to fix or even increase students' conceptual understanding in the concept of fluid dynamics [18,19]. Other result which was related to students' conceptual understanding was that formative assessment gave good result in improving students' conceptual understanding through the element of feedback [8,20].

The analysis of reasons in students' answers described the difficulties which are still experienced after the learning. In the subject of continuity equation, the increase of N-gain in the cognitive area of C2, C4, C5, and C6, yielded the values of, respectively, 0.89 (high), -0.73 (low), 0.89 (high), and 0.58 (medium). It is apparent that in the indicators of understanding the relation of velocity and the radius of space in the continuity equation (C2), determining the speed of fluids (*kecepatan aliran fluida*) in real world problems (C5), and constructing the implementation of continuity equation in the field of engineering (C6) had increased significantly. However, students' conceptual understanding had decreased in the indicator of analyzing the concept of continuity equation in the case of the speed of fluid at the tip of the pipe (C4). In this sub material of continuity equation, students still had difficulties as shown in Table 1.

Table 1. The summary of wrong reason in distractor of sub material of Continuity Equation

Dimension/Form of question	Wrong reason on the post-test of the distractor (%)
C2/As the scheme of horizontal pipe is given in the different radius of space, students can explain the relation between the speed of fluid on two different points	Students assume that the speed of fluid is inversely proportional to the radius of the pipe (24)
C4/Analyzing the concept of continuity equation in the case of difference of flow rate on two ends of the pipe	Students assume that the decrease of the speed is caused by the decrease of radius on the output-end of the pipe (21)
	Students assume that the difference in diameter caused the speed to decrease (21)
C6/Constructing the implementation of continuity equation on the field of engineering	Students tend to choose the least editorial answer (24)

It can be seen that 24% of students still assume that the flow speed of the fluid in the horizontal pipe is inversely proportional to the radius of the pipe. This is caused because of the weak mathematical ability of students so they still assume that the area of space is proportional to its radius. This is in accordance to the finding of a research that students which don't understand the concept and mathematics definition well will have difficulty in constructing correct mathematical proof [30,31]. In relation with the mathematical ability in solving Physics problems [32,33], students fail to build the meaning of Physics problem statement [34] so it obstructs the process to solve Physics problems.

Other than that, in the case of physical changes on the pipe, such as the existence of leak of flow rate, 42% of students assume that the value of flow rate depends on the radius or diameter of the space. This means that students feel difficulties in understanding that the flow rate is constant and doesn't depend on the radius or diameter of the space penampang [2]. Other than that, students still have difficulties in making difference between flow rate and velocity [3]. This finding is supported by the result of other research which said that students have difficulties in understanding the principal of mass conservation in the fluid flow inside the pipe [35]. As many as 24% students also had difficulties in constructing the procedure of the proof of flow rate of city water because they tend to focus on the unit of time so they only utilized stopwatch to measure it when in fact tools of measurement of volume was also needed to determine the flow rate. It can be linked by the difficulties experienced by students to apply procedural knowledge to solve problems [2]. Other than that, students had difficulties to connect their abilities which they gained in the past onto contextual problems [2].

In the sub material of Bernoulli's principle, the increase of N-gain in the cognitive area C1, C4, C5, and C6, are, respectively, 0.89 (high), -1.17 (low), 0.38 (medium), and 0.97 (high). It is apparent that there is an increase in the indicator of showing the assumption of (*penurunan persamaan Bernoulli*) (C1), evaluating the implementation of Bernoulli's equation in daily activities (C5), and developing a set of investigation about the implementation of Bernoulli's principle (C6). In the dimension of C4, there is a decrease of conceptual understanding. In the sub material of Bernoulli's principle, students still have difficulties which are shown in Table 2.

Table 2. The summary of wrong reason in distractor of sub material of Bernoulli's Principle

Dimension/Form of question	Wrong reason on the post-test of the distractor (%)
C4/Analyzing the difference of pressure in the pipe system based on the Bernoulli's principle	Students have difficulties in analyzing the relation between surface area of the space, velocity, and pressure of the fluid which is flowing inside tapered pipe (24)
C5/As the problem in Bernoulli's equation about pipe with different surface area and height of tips is presented, students evaluate how to solve the problem	Students cannot explain in detail about the choice of answers, even as far as to leave it empty for some students (29)

It can be seen that 24% of students had difficulties in analyzing the connection surface area, velocity, and the pressure of the fluid which is flowing inside the tapered pipe. Students were faced with two ways that can be used to obtain large pressure. In this case, students should have had mathematics and analysis ability about the necessity of the problem. Other than that, 29% of students didn't explain in detail about the reason of their choice in determining the way to obtain the big rate of reservoir because they assumed that to increase the pressure then one must increase the height of the reservoir. Other than that, students mostly answered with speculative answer than with result of calculation which can be used to draw the conclusion to answer the question. Students had difficulties to connect the concept which were being learned with previously learned concept [29,35]. Other than that, the misconceptions due to the transision of the topic of Hydristatic towards Hydrodynamics made students struggle to explain the reason why the pressure change at every point of heights [2,36,37].

In the sub material of the implementation of Bernoulli's principle, the increase of N-gain in the cognitive area C3, C4, C5, and C6, are, respectively, 0.47 (medium), 0.69 (medium), 0.67 (medium), and 1.00 (high). It's apparent that there is an increase in the indicators of implementing Bernoulli's equation in the case of areoplanes (C3), analysing the concept of the implementation of Bernoulli's principle on the piping system (C4), evaluating the use of Bernoulli's equation in many areas (C5), and formulating questions in applying the concept of Bernoulli's equation in the field of engineering (C6). In the sub material of the implementation of Bernoulli's principal, students still have difficulties as shown on Table 3.

Table 3. The summary of wrong reason in distractor of sub material of the Implementation of Bernoulli's Principle

Dimension/Form of question	Wrong reason on the post-test of the distractor (%)
C3/Applying the Bernoulli's equation on the case of an aeroplane	Students have difficulties to implement aerodynamic lift on two wings of an aeroplane; students tend to calculate the aerodynamic lift on one wing only (29)
C4/Analyzing the concept of Implementing Bernoulli's Principle on a piping system	Students had calculated correctly, but made the wrong conclusion. Students had difficulties in analyzing the connection between the surface area with pressure (29)
C5/Evaluating the use of Bernoulli's principle on various problems	Students evaluated the cause of a phenomenon of the pull which is felt by a person towards a moving train by assuming that there is a direct proportion between velocity and pressure as the train moves (21)

It can be seen that 29% of students only implement the aerodynamic lift of one wing of an aeroplane during take-off because they were reckless when analyzing the problem. This recklesness can be attributed to the difficulties of students to develop basic knowledge to be able to be implemented on real world problems [2,37]. On the case of water flow on tapered pipe, 29% of students can calculate the difference of pressure between two ends of the pipe with different diameter, but they had difficulties in analyzing (C4) the part of the pipe which has higher pressure. Similar difficulty also arose when students were faced with the problem of why someone feel a pull towards a near moving train. As many as 21 % of students can evaluate (C5) with the argument that the line of air flow around the sides of the train became more dense than the line of air flow which is far from the railway. So, there is difference between the high velocity of air near the railway and the one far from the railway. The pressure near the railway was then less than the pressure of enviroment which is far from the railway. This caused the body of a person to be pushed towards the direction of the moving train [1].

The assumption that bigger the flow speed causes bigger the pressure on the area still arises often. Students assumed that the pull which is experienced by the body towards the mofing train was caused by the high pressure in the area as the consequence of the high velocity of the train. This is caused by the difficulty felt by students in understanding the connection between velocity and pressure in Bernoulli's principle. Naive understanding about mass conservation on Bernoulli's princple is deemed to be very lacking still [35]. In the end, students made a conclusion that the speed of fluid flow will increase the pressure on the area [2,3].

4. Conclusion

The research to increase students' conceptual understanding through the intervention of IBL-STEM learning with Formative Assessment yielded good results. The learning setting of IBL-STEM with formative assessment made it possible for students to have a role as researchers, which will increase their confidence and their conceptual understanding with teachers are facilitators. Students' conceptual understanding on the topic of fluid dynamics increased significantly with the N-gain value of 0,63 (medium category) and d-effect size of 3.645 (very large category). Few difficulties are still encountered by students, such as the concept of flow rate which has constant value on the case of physical changes on the pipe, such as leaking, the relation between the unit of flow speed, diameter of the space, and pressure on the fluid flow, the proportion between velocity and the power of radius of the pipe, aerodynamic lift of the wings of an aeroplane, the phenomenon of the pull someone felt towards a moving train, and the possibility of making the water rate bigger from the reservoir. The limitation of this research is the proposed method is only suitable for the fluid dynamics material. It's recommended to explore about the possibility to broaden the STEM approach to include religious and art aspects to be the STREAM approach in an effort to improve students' understanding in Physics learning.

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