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The impact of STEM-based guided inquiry learning on students' scientific literacy in the topic of fluid statics

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Abstract. The learning in 21st century needs literacy skill, but the study regarding the application of Science, Technology, Engineering, and Mathematics (STEM)-based Guided Inquiry (GI) to develop students' scientific literacy is limited. This study aimed to know the impact of STEM-based GI learning on students' scientific literacy in the topic of fluid statics. Using Pre- and Posttest design in a quasi experiment research, students in grade XI of Senior High School 7 Malang, Indonesia, were placed in two classes called Experiment (STEM-GI) and Control (conventional) classes. STEM-GI class made two engineering products, which are a small-scale hydraulic robot and hydraulic lift based on Pascal Law. The Fluid Statics Scientific Literacy Test was used to measure students' scientific literacy with Cronbach's alpha reliability of 0.741. Data analysis with Mann-Whitney, N-gain, and Cohen's effect size was conducted. The result showed two classes had significantly different scientific literacy. Scientific literacy of STEM-GI was higher than conventional class. The improvement of both Experiment and Control classes belonged in medium category. The effect of operational implementation of Experiment-Control pair yielded "large" category in the enhancement of scientific literacy. From the final questionnaire, it's revealed that students had more positive response towards STEM-based GI than conventional learning.

1. Introduction

Mastering Newton's first and third law and mathematical equations is the foundation in learning the theory of pressure, density, Archimedes' principle, and Pascal's law in the topic of Fluid Statics [1]. Daily activities such as swimming, breathing, and drinking, and technological devices such as barometer, hydraulic lift, car's hydraulic brake, and ships are related with Fluid Statics [2]. However, the topic of Fluids is considered very difficult amongst students [3]. Students often have misconceptions in the topic of Fluid Statics such as buoyant force and hydrostatic pressure [4], and also the phenomenon of sinking and floating [5]. Students thought that the shape of container [6] or the volume of fluid [7] affect hydrostatic pressure. Students had difficulties to understand the application of Pascal's law in car's hydraulic brake using brake fluid, and Archimedes' principle in ships made of iron or steel [8]. It's plain that this topic requires mathematical equations and has many applications in technology, even though it's considered hard for students. This may cause students to have low scientific literacy.

In order to be competitive in global era, people should equip themselves with scientific literacy [9]. Scientific literacy is a very important skill to have to tackle the rapid evolution of the knowledge of science and technology, which includes ethnical, moral, and global issue [10]. Programme for

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International Student Assessment (PISA) in 2015 showed that the scientific literacy in the domain competence has three indicators [11]. The domain of the competence of scientific literacy refers to how to deal with the means to obtain scientific information of certain phenomena and explain it scientifically; produce and evaluate opinions on the matter such as the experiments, technology, and engineering; and draw or interprete the conclusion based on the scientific evidence data collection [12]. For students, scientific literacy is one of the important skills to have or master [13] so that it can be used to solve problems in the topic of fluid statics. However, students' scientific literacy skill all around the world is still categorized in very low level [14]. Initial study showed that students still have relatively low score in scientific literacy indicators: 30,87% in explaining scientific phenomena, 40,20% in interpreting data and evidence scientifically, and 24,90% in evaluating and designing scientific inquiry [15]. Students still have 27.68% scientific literacy [16]. Students' scientific literacy skill score are still dominated by scores in poor category [17]. This is caused by students' tendency to solve physics problems by merely using mathematical equations without understanding the meaning behind the problem itself so that misconceptions occured [18]. Learnings which strive to use mathematical equations with emphasize on knowledge retreival from the discussed topic are still rare, therefore students are still struggling with such misconceptions.

One of the focuses of education in 21st century is the scientific literacy skill [19]. Scientific literacy in the topic of fluid statics demands an understanding of difficult concept, requires mathematical equations, and involves various technological applications in daily lives. There have been research efforts about the advance in scientific literation. In the topic of global warming, the competence of evaluating and designing scientific investigation had not seen any improvement in inquiry learning [20]. In the topic of temperature, students' scientific literacy increased through problem-based STEM [21]. In the topic of Newton's law, STEM-Inquiry based learning had an impact on students' scientific literacy [22]. In the topic of fluid statics, problem-based STEM learning was only able to improve students' literacy in low category [8]. In the topic of Geology-Physics learning with laboratory experiment was successful in honing students' scientific literacy skill [23]. Science, Technology, and Society (STS) model was proved to be effective in enhancing students' scientific literacy in the topic of buffer solution [24]. In the topic of dynamic electricity, the use of scientific approach could also increase students' scientific literacy [25]. From these studies, it's evident that there hasn't been enough research about scientific literacy in the topic of fluid statics. Aside from that, research using integrated science, technology, engineering, and mathematics is still limited. It can be said that there's still opportunity to study the enhancement of scientific literacy in the topic of fluid statics with STEM integration.

The development of students' literacy skill is one of the focused aims in today's learning trend. Literacy is one of the skills needed in Physics learning [26] and learning the 21st century [27]. In Physics learning, students are required to understand the concepts with scientific processing skill and to apply the concepts or facts acquired from class in contextual daily activities [28]. Therefore, scientific literacy skill is paramount in solving the problems in real world. Meanwhile, problem solving process also needs STEM approach for students to work on unsolved tasks to be complete and refined outcome through team effort [29]. STEM is an integration of the aspects of Science, technology, Engineering, and Mathematicsas a whole [30] and therefore it compliments the characteristics of scientific literacy in the topic of fluid statics really well in the hope to equip students with better and more thorough knowledge and skill in the learning process [31]. In STEM learning, students can improve their three areas of learning domain: affective, cognitive, and psychomotor. Also, students can utilize those learning domain to design, develop, and make use of the technology in optimal way [32]. STEM can be used to prepare students to be independent learner, better problem solver, logical thinker, and innovator [33]. In other words, the STEM approach is suitable to make a meaningful learning context [34] and able to improve the quality of learning process [35]. It's evident that STEM has large potential to improve students' scientific literacy skill.

As stated before, physics learning is expected to be able to enhance students' scientific literacy. It can be achieved with the use of active learning which makes the students as the center of the learning. Such learning is satisfied with Guided Inquiry (GI) leaning model where students are involved actively in groups in investigating about a problem, forming hypotheses, designing suitable experiment, gathering and processing the data, and drawing conclusions [36]. Activities in GI learning are in line with scientific literacy indicators. However, the problems posed in GI learning are often less contextual in nature so that students cannot fully understand scientific knowledge through the lacking inquiry process [37]. In other words, inquiry learning is capable only to convey the concepts in general terms without providing deep understanding about related concepts [38]. For this reason, presenting students with contextual real world problems are mandatory in learning. It can be done with relating those problems with Science, Technology, Engineering, and Mathematics so that product engineering activity can be created in the STEM integration in learning [39]. The integration of GI and STEM is called STEM-Based Guided Inquiry Learning (STEM-GI). It's expected that STEM-GI will prove to be the proper and suitable learning to enhance scientific literacy of students in the topic of fluid statics.

The integrated STEM-GI could be a learning model which can enhance students' scientific literacy. This study will investigate the impact, improvement, and effect category as the result of learning process, and also gather students' response towards STEM-GI in improving scientific literacy of students in the topic of fluid statics.

2. Method

This study used Pre- and Posttest Design in a quasi experimental research environment [40]. The subject of the research was 68 students of SMAN 7 Malang Indonesia in grade XI which were distributed equally to two classes called Experiment class (STEM-GI) and Control class (Conventional). The GI learning had 5 phases [41], and the STEM integration was done as follows. Two aspects of STEM, which are science and technology, were integrated into the first phase (the confrontation with the problem) and second phase (the gathering and verification of data). Three aspects of STEM, which are science, mathematics, and engineering, were integrated into the third phase (the gathering of data in experiment). All aspects in STEM, which are science, technology, engineering, and mathematics, were integrated into the fourth phase (to organize and formulate the explanation) and fifth phase (to analize the inquiry process). In STEM, students' activities were mostly dominated in the engineering aspect. The Engineering had 7 steps, which are problem identification, information gathering to find as many solutions as possible, best solution selection, product design and construction, product test, product modification or improvement, and complete product rating [42]. The Experiment class made two products: a small-scale hydraulic robot and hydraulic lift based on Pascal's Law. Students also worked on the posters of the two products and presented them in class. Lastly, students finished on the written report about the whole process. Both Experiment and Control class had conducted experiment on their own, but the students in Experiment class designed on the project independently while students in Control class only followed the given instructions by the teacher. Other activities in the conventional class was generic in nature, such as observing a demonstration, listening to teacher's verbal explanation about the concepts in the topic, solving written problems, conducting discussions, and presenting their findings in class.

This study used the fluid statics scientific literacy test instrument which consisted of 10 essay items with Cronbach's alpha reliability of 0.741. As the instrument was composed, the question item was developed based on the topic of fluid statics which was adapted to fit scientific literacy indicators in PISA question items. The data from this study was analysed with Mann-Whitney (to know the impact from the learning treatment on students' scientific literacy), Cohen's effect size (to assess the strength of practical learning implementation) [43], and N-gain (to measure the improvement of students' score) [44].

3. Result and Discussion

The pre-test result showed that students in Experiment and Control class still had scientific literacy with average and standard deviation (in brackets) of, respectively, 42.43 (21.70) and 40.96 (22.15). It's evident that both had rather similar score. This shows that, at the initial stage before learning began, students in Experiment class had relatively similar scientific literacy skill with students in Control class.

The result of Kolmogorov-Smirnov normality assumption test of the scientific literacy of pre-test data was Sig. 0.000 and Sig. 0.030, each for Experiment and Control class. This indicates that data of pre-test in all classes did not satisfy normality assumption. The result of Levene Statistic test for homogeneity assumption showed that Based on Mean had value of Sig. 0.674. This indicates that the variant group in this study satisfied the homogeneity assumption. Due to the rejected normality assumption and accepted homogeneity assumption, the initial condition similarity test with pre-test data can be done with non-parametric statistical test of Mann-Whitney. The result of the similarity test was Asymp. Sig. (2-tailed) 0.790. This indicates that the initial condition (pre-test score) of both classes wasn't significantly diffierent. As the consequence of this, if there's significant difference of scientific literacy in both classes at the end of the learning, it occurs only due to the differing treatments in both classes during the study.

The post-test result showed that students in Experiment and Control class still had scientific literacy with average and standard deviation (in brackets) of, respectively, 80.07 (6.38) dan 76.18 (2.06). It can be seen that the Experiment class acquired higher scientific literacy score than Control class. This showed that the STEM-GI learning in Experiment class can improve students' scientific literacy better than the conventional approach in Control class in the topic of fluid statics.

The result of Kolmogorov-Smirnov normality assumption test of the scientific literacy of post-test data was Sig. 0.001 for Experiment class and Sig. 0.000 for Control class. This indicates that the post-test data of both classes didn't satisfy normality assumption. The result of Levene Statistic test for homogeneity assumption showed that Based on Mean had value of Sig. 0.000. This indicates that the varian group of this research didn't satisfy homogeneity assumption. Due to the rejected normality and homogeneity assumptions, the end condition similarity test with post-test data can be done with non-parametric statistical test of Mann-Whitney.The result of the similarity test was Asymp. Sig. (2-tailed) 0.001. This indicates that both classes had significantly different end condition (post-test score). Students in Experiment class gained higher average post-test score than Control class. This means that STEM-GI learning in Experiment class can improve students' scientific literacy significantly better than the conventional approach in Control class in the topic of fluid statics.

STEM-GI learning was able to increase scientific literacy higher than conventional class. In the first and second phase of STEM-GI, students were challenged with contextual daily problems. In both phases students can have an exercise to recognize the scientific concepts and also to verify the technological application related to the problem. Both processes are important part in STEM learning because they can help students in honing their understanding about the discussed topic, and this can trigger STEM professional activity and remove the border across disciplines in STEM work field [45]. In this case, students are trained to improve the "explaining phenomena indicator"of the problem.In the third phase of STEM-GI, students tried to apply the initial Physics concepts and supporting mathematical equations related to the problem into engineering steps. Students were taught to design the experiment and/or project to make product and to gather data. In this phase, students can train to improve the indicator of evaluate and design scientific investigation. These steps were aimed to obtain the concepts which can be used to answer related questions about the problem. Such things can influence students' scientific literacy. The design and evaluate scientific inquiry is a competence needed in scientific literacy [46]. In the fourth and fifth phase of STEM-GI, students analized the data and drew the conclusion and/or test the product of the project, modify, and conduct an evaluation. In both phases, all aspects of STEM were involved so that students can improve the indicator of intrepreting the data and scientific evidence. The project of engineering product is the implementation of the concepts which were acquired in the learning. The students in STEM-GI class made 2 products, which werea small-scale hydraulic robot and hydraulic lift, as the realization of the engineering aspect to solve the problem posed at the beginning of the learning. In relation to the product, students had to make posters, present them in class, and made written report about the project. The engineering product was able to make students to be active in communicating their comprehension about the related concepts through STEM education [47]. It's clear that STEM learning can awaken students' ability in identifying concepts or knowledge relating to the problem [48]. In STEM learning, such concepts or knowledge can be implemented or applied in daily activities as part of students' relevant experience so that they're motivated to learn more [49]. Therefore, the integration of STEM in learning can affect students' learning process positively [50]. In conventional class, very contrasting thing happened where students used most of their time in doing written exercise to solve problem in worksheet under domination of teacher. This caused the conceptual understanding of Experiment class to be better than Control class. This is in accordance to the finding in a study that students' conceptual understanding of static fluid can increase as a result of the treatment with guided inquiry [51,52]. In the end, this conceptual understanding resulted in students' literacy score of the Experiment class to be significantly better than Control class. This finding is confirmed with other study which concluded that GI instruction was able to increase students' scientific literacy better than conventional learning in basic concept of biology [53], that GI learning is suitable for increasing scientific literacy of students in fluid dynamics [54], and that subject-specific pedagogy based on guided inquiry can improve students' scientific literacy ability in Newton's law [55].

The scientific literacy analysis with N-gain in pre-test and post-test data resulted in 0.654 of medium category in Experiment class, which is higher than 0.597 of medium category in the Control class. It can be interpreted that STEM-GI is more superior to conventional approach in improving scientific literacy of students. This result is in line with previous difference test in post-test data with Mann-Whitney test. With the help of STEM-GI learning, students can practice to obtain the knowledge or concepts of the topic by conducting experiment and therefore they can learn to find multiple solutions to tackle specific task or problem. STEM education can still be improved to help people train their literacy skill in the world of technology and scientific knowledge [56]. From the analysis, it can be seen from the difference of post-test data and the increase in average post-test score that the proposed STEM-GI approach had an impact in students' scientific literacy.

The difference in the increase of scientific literacy as mentioned above may have been caused as a result of STEM aspects being integrated, especially the engineering aspect, in the GI learning. Mathematics and science aspects have a role in applying the learned concepts in such a way to make sense of certain phenomenon with the use of scientific process, such as problem analysis, investigation of the origin, communication with fellow peers, formulation of the solution, and interpreting the result with the help of mathematical operation of the data [57]. The engineering aspect is useful in transforming the understanding of the knowledge into practical technology which can help to solve further similar problem [58]. The process of engineering puts an upmost importance to the designing phase where the subject of learning attempts to provide solution to a problem by devising a real product or technology and execute the construction in methodical step-by-step procedure [59]. Students, which were divided in groups, discussed and chose the best solution from amongst many possible alternatives. The detail of the construction process, including the estimation of the costs in making the product, was also discussed. As the groups have their own design and plan on their products, each presented their ideas in class as the means to share their work with others. In this session, each group received comments from others about their proposal and as the result, improvements or revision could be made to better suit the group's needs. These set of activities differ with the Conventional class where students were set to do certain tasks in an experiment which were given by the teacher. Although the students also presented their findings of the experiment in groups, the feedbacks gained from the presentation were not as useful because there were limitations about the boundary of the experiment. This differing treatments and level of freedom to create caused differing result in students' final scientific literacy score in both classes. This is in line with the result of a study that STEM learning is able to increase STEM literacy in the topic of electicity [60], and that Inquiry Based Learning for STEM Education is able to increase students' scientific literacy [22]. From this illustration, it's evident that STEM integration is really useful to enrich students' experience with the application of practical concept implementation [61].

The N-gain score in Experiment and Control classes both have surpassed the threshold of learning involving active students with averageof N-gain of 0.48 [62]. This was caused by the experiments conducted by students during the learning. Students in Experiment class designed their own procedure for the experiment, while the students in Control class did not. However, the experiment in Control class was also useful to train students in conducting an investigation in the laboratory. As stated in other study,

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the activity of investigation in learning can be the source of motivation to learn and acquire the concepts with one's own effort [63]. From this activity, students' analytical skill will undergo an exercise in finding the knowledge from the result or conclusion of their experiment [64].

The result of pre-test and post-test data with N-gain analysis in relating to scientific literacy in the subtopics of fluid statics can be seen in Table 1.

Table 1. N-gain score of fluid statics in each subtopic

Subtopics	N-gain Classes (category)	
	Experiment (n=34)	Control (n=34)
Hydrostatic pressure	0.663 (Medium)	0.648 (Medium)
Pascal's Law	0.619 (Medium)	0.557 (Medium)
Archimides' Principle	0.707 (Medium)	0.586 (Medium)

Table 1 shows that both classes acquired medium category of N-gain in all subtopics of fluid statics. However, the Experiment class had higher N-gain than the Control class. In the subtopic of Pascal's Law, both class had significant difference in their N-gain score. This was caused by the activity in Experiment class in making two engineering products, while such activity didn't happen at Control class. The biggest difference of N-gain score of both classes occured in the subtopic of Archimides' Principle. This was caused by the impact of 2 engineering product of Pascal's Law which was discussed in previous meetings during learning. Students in Experiment class also worked on additional experiment in the form of PhET virtual lab.

The result of pre-test and post-test score of N-gain analysis in 3 indicators of scientific literacy is written in Table 2.

Table 2. N-gain score of scientific literacy indicators in all classes

Indicators	N-gain Classes (category)	
	Experiment (n=34)	Control (n=34)
Explaining phenomena scientifically	0.654 (Medium)	0.626(Medium)
Evaluate anddesign scientific inquiry	0.685 (Medium)	0.578 (Medium)
Interpret data and scientific evidence	0.633 (Medium)	0.564 (Medium)

Table2 shows that both classes acquired medium category of N-gain score in all indicators of scientific literacy. However, the Experiment class had higher N-gain score than Control class. Also, both classes were inclined to have high N-gain score in the indicator of explaining phenomena and low N-gain score in the indicator of interpret data and scientific evidence. This may have been caused by the ranking of Indonesian students from the year 2000 until 2015 which placed them in the last 10 positions. In this position, most of Indonesian students only have inadequate scientific knowledge to be implemented in daily lives with the indication of being able to present scientific explanation from the clearly and explicitly given facts, and only few of the students only have enough scientific knowledge to form proper conclusion from simple observation with the indication of being able to provide reasons spontanously and to scientifically interpret the data [11].

The effect size of scientific literacy of students in Experiment-Control pair resulted in d = 0.822 in "Large" category. It shows that the practical implementation of STEM-GI has the influence in "Large" category compared with conventional approach in terms of the increase of scientific literacy in the topic fluid statics. Therefore, it's recommended for educators to use STEM-GI learning in their class setting in order to improve scientific literacy of students.

The students' response towards the learning acivity was gathered through questionnaire. The result showed that the received "agree" and "strongly agree" response was 78.94% for Experiment class and 66.59% for Control class. It is apparent that the response Experiment class was more favorable than

Control class. Also, the "strongly agree" response in Experiment class (19.88%) is significantly higher than the Control class (9.41%). This indicates that students felt more comfortable in Experiment class than in Control class. This discovery is in line with another finding which stated that Physic STEM Education Learning can provide students with more satisfaction than conventional learning method [65].

4. Conclusion

From the result and discussions above, a conclusion can be drawn regarding the scientific literacy of students. Scientific literacy in Experiment class was significantly different with Control class. Students in Experiment class acquired final average score of 80.07 for scientific literacy, which was higher than Control class with the score of 76.18. This means that STEM-GI learning had an impact in increasing students' scientific literacy. N-gain score of Experiment class was 0.654 in medium category. This score is higher than the Control class, which is 0.597 in medium category. This shows that STEM-GI method is more superior to conventional approach to improve scientific literacy of students. The effect size of students' scientific literacy in Experiment-Control pair resulted in d = 0.822 in "Large" category. This shows that the practical implementation of STEM-GI has the influence in "Large" category compared with conventional approach in terms of the increase of scientific literacy in the topic fluid statics. The response of students regarding the activities in the learning process showed that the "agree" and "strongly agree" response reached 78.94% for Experiment class, which was higher than 66.59% for Control class. This response means that students felt more comfortable in Experiment class than Control class.

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