Journal of Physics: Conference Series

The effect of the STEM approach with the formative assessment in PBL on students' problem solving skills on fluid static topic

To cite this article: Parno *et al* 2021 *J. Phys.: Conf. Ser.* **2098** 012025

View the article online for updates and enhancements.

The effect of the STEM approach with the formative assessment in PBL on students' problem solving skills on fluid static topic

Parno[1*], S Kusairi[1], D R Wahyuni[1], and M Ali[2]

[1]Physics Education, Universitas Negeri Malang, Indonesia
[2]School Education, Universiti Teknologi Malaysia, Malaysia

*parno.fmipa@um.ac.id

Abstract. The use of problem-based learning with STEM and formative assessment (PBL-STEM-FA) to overcome the weakness in students' problem solving skills (PSS) is still limited. This research investigates the effect of PBL-STEM-FA in students' PSS in the topic of fluid static. This research uses the pretest-posttest non-equivalent group design, and involves the research subject of class XI high school students in Malang, Indonesia. Experiment class' students make engineering products in the form of miniature boats. The PSS test instrument with 0.799 reliability were used in this study. The data were analyzed by independent t-test, Hake-gain, and Cohen-effect. The results showed that students of PBL-STEM-FA class had significantly higher PSS and N-gain than students of PBL class. The highest raise occurred in the Useful Description indicator and hydrostatic pressure subtopic for the Experiment class; and Useful Description indicator and surface tension subtopic for Comparison class. But, the two classes had the same lowest raise, namely in the Mathematical Procedures indicator and capillaries subtopic. The effect size at 0.651-medium category implies that the implementation of PBL-STEM-FA is recommended to be carried out in the field to increase students' PSS. It is recommended that future studies add an "Art" aspect to the STEM approach.

1. Introduction

Students still have some misconceptions about static fluids. In the hydrostatic material, students still think that pressure is influenced by volume and container [1], and it is still difficult to understand that at the same depth there will be the same hydrostatic pressure [2]. Most students have not been able to apply Pascal's law correctly [1]. In the Archimedes law material, most students still do not understand the concepts of neutral buoyancy, floating and sinking [3] so that they assume that the buoyant force on a floating object is greater than the gravitational force. The wrong understanding of the concept is because students only memorize the equations without interpreting them, resulting in low problem-solving skills (PSS) [4].

PSS is part of 4C in the 2013 Curriculum, and competencies that should be mastered in the 21st century so that it is a very significant skill in physics meaningful learning [5]. PSS is the ability to apply previous knowledge in certain situations [6] to improve conceptual abilities and develop problem-solving strategies anywhere and anytime [7]. This is useful for training students to be skilled in gathering information, analyzing information to take action [6]. However, students still have a low PSS of 48.88%, and about 21% of students have difficulty solving problems with static fluid material [8]. This difficulty is because students still have a lack of understanding of the concept [4], and they only memorize the equations without interpreting them [4].

Several studies have been conducted to improve students' PSS. In the static fluid material the inquiry training model still produces 30% of students who have PSS scores below 70 [9]. However, this model is mostly investigated in the lab. In static fluid material, problem-based learning with thinking maps is still difficult for most students to represent graphs so very few students exceed their passing grade. Problem based learning (PBL) is able to improve PSS [10]. However, PBL is felt to only be able to improve authentic PSS in theory but is still lacking in practice that produces products. Also, these studies looked only at baseline and final results without paying attention to assessments during the learning process [11].

Meanwhile, static fluid material is closely related to everyday contextual problems and technology. Therefore, understanding this static fluid material requires a PBL solution, but it must be integrated with the STEM approach and formative assessment. PBL requires teachers to present authentic and meaningful problems as stepping stones for investigation [12] and PBL allows students to gain independent learning experience [13]. The STEM approach requires students to become experts in solving problems by applying theory in the practice of making technology miniatures through engineering design products [14]. The application of formative assessment in learning can improve student learning outcomes [15]. It is clear that the STEM approach with formative assessment in PBL has the opportunity to optimize student PSS acquisition. However, the implementation of the STEM-FA in PBL to increase students' PSS is still rare. Based on this reasoning, the purpose of this study is to find out the comparison between PBL-STEM-FA and PBL in optimizing the building of students' PSS in static fluid material.

2. Method

This study used a quasi-experimental design: the pretest-posttest non-equivalent group design [16]. The subjects of this study were students of class XI Senior High School in Malang, Indonesia. The research subjects were chosen with cluster random sampling. The Experimental (Exp) class with PBL-STEM-FA has 26 students (M = 8, F = 18) and And the Comparison (Comp) class with PBL has 30 students (M = 12, F = 18). This study is intended to improve students' PSS with 5 indicators, namely the useful description (UD), physics approach (PA), specific application of physics (SAP), mathematical procedures (MP), and logical progression (LP) [17] on fluid static material, namely hydrostatic pressure, Archimedes' law, surface tension, viscosities, and capillaries.

The comparison class used PBL with 5 phases, namely students' problem orientation (F1), students' organization for study (F2), assistance of investigation (independent and group) (F3), Developing and presenting of artifacts and exhibits (F4), and analyzed and evaluated the process of the problem-solving (F5) [12]. The experiment class also uses 5 PBL phases, but with embedded 4 aspects of STEM, namely Science (A1), Technology (A2), Engineering (A3), and Mathematics (A4) [18] and 5 key strategies of formative assessment, namely Developing Classroom Talk and Questioning (KS1), Giving Appropriate Feedback (KS2), Sharing Criteria with Learners (KS3), Self-assessment and Peer assessment (KS4), and Thoughtful and Active Learners (KS5) [19]. The following is how the learning using the STEM approach with formative assessment in PBL is done in building students' PSS. The first phase of F1 involves aspects of A1, and the KS1 strategy to facilitate the UD indicator. The second phase of F2 involves aspects A1 and A2, and the KS2 strategy to facilitate the PA indicator. The third phase of F3 involves aspects of A1, A2, and A3, and the KS 3 and KS4 strategies to facilitate PA and MP indicators. The fourth phase of F4 involves aspects of A2, A3, and A4, and the KS3 and KS5 strategies to facilitate SAP and MP indicators. The fifth phase F5 involves all aspects of STEM, and the KS3, KS4, and KS5 strategies to facilitate the LP indicator. Experiment class' students make engineering products in the form of miniature boats.

This study used the PSS test instrument in the form of 7 essay items. This instrument includes 5 PSS indicators [34], and a static fluid subtopic [2]. Construct and content validation was carried out by an expert college teacher in physics education, and empirical validation by 53 senior high school students of class XII who had taken static fluid material. The result of validation analysis was 0.799 in Cronbach alpha reliability. The research data were analyzed by independent t-test [20], Hake's N-gain [21], and Cohen's d-effect size [20].

3. Result and Discussion

The average and standard deviation (in brackets) of pretest data for the Exp and Comp classes are, 14.286 (4.902) and 12.400 (6.116), respectively. It appears that the two classes show almost the same pretest score mean data. This means that the two of them started this research with the same initial ability conditions. The average and standard deviation of posttest data for the Exp and Comp classes are, 49.033 (19.182) and 39.181 (15.062), respectively. The experimental class showed that the average posttest score data was higher than the comparison class. This shows that the STEM approach with formative assessment has an impact on improving students' PSS.

The result of prerequisite analysis shows that the experimental and comparison classes had normal distribution of pretest and posttest data. In addition, the pretest and posttest data showed homogeneity. Because the normal and homogeneous properties were fulfilled, the difference test with the independent t-test was carried out. The pretest data of the two classes (sig. 0.213) not significantly different, but the posttest data of the two classes (sig. 0.036) were significantly different. It appears that the initial conditions for the two classes are the same, but at the end of the lesson it is evident that the STEM approach with formative assessment has a significant impact on the building of students' PSS. The results of this study support previous research, namely, although in experiential learning, the STEM-FA was able to improve students' PSS on fluid static material [22].

In this study, PBL was carried out in the comparison class. However, solving problems in PBL is only theoretical so that it is lacking in practice that produces products. This drawback requires an embed STEM approach. The STEM approach in PBL requires students to become experts in solving problems through the application of theory into practice making miniature technologies through engineering design products [14]. This causes the STEM approach in PBL to be able to lead to better student PSS development than in PBL without a STEM approach.

In this study the PSS in the experimental class using STEM was higher than the comparison class that did not use STEM. This is supported by previous research that STEM learning has a positive effect on students' PSS [23], and students in PBL-STEM classes obtain much higher PSS than students in PBL classes [11]. This happens because STEM focuses on solving problems that have several solutions with their respective limitations and demands students' creativity and innovation in solving problems [14]. PBL starts by looking for the cause of the problem that occurs, while the PBL with STEM approach begins by asking how to solve the problem. This has an impact on the data obtained in PBL learning which is used to find concepts to find solutions, while in PBL-STEM the data is used as a support to determine the solution design.

Formative assessment in the experimental class can improve the quality of learning in the classroom. Formative assessment includes ongoing guidance and feedback from the start to the end of learning, and reflection at the end of learning [24]. Guidance is carried out to reduce students who lag behind in learning. Feedback is intended to adjust the learning that is taking place in order to improve student achievement [12]. Reflection is intended to determine the shortcomings of learning that has been done. This study conducted 5 key strategies formative assessment throughout the learning process. Thus the application of formative assessment in learning can increase learning outcomes of student [25].

The results of the increase in the PSS of the students of both classes in N-gain are 0.404 (medium) and 0.306 (medium) for the Exp class and Comp class, respectively. These results support previous study that the use of PBL in learning can increase problem solving abilities of student [26]. However, the increase in the PSS of the experimental class students was higher than the comparison class. The increase in experimental class students was closer to the average increase in the active class value of 0.48 [27], while the increase in comparison class was closer to the low level limit. This happens because the STEM approach in the experimental class can improve the learning experience of solving students' problems by applying theory through practice of making products [14]. In addition, solving problems in PBL is indeed related to STEM aspects [11]. Thus, this reinforces the results of the research that has been stated above that the existence of the STEM-FA resulted in an increase in the PSS of the Exp class students better than the Comp class. The results of the increase in each PSS indicator are written in the following Table 1.

Table 1. Summary of data analysis on the improvement of each PSS indicator.

Class	N-gain (category)				
	UD	PA	SAP	MP	LP
Exp	0.660 (M)	0.529 (M)	0.327 (M)	0.315 (M)	0.356 (M)
Comp	0.907 (H)	0.308 (M)	0.173 (L)	0.148 (L)	0.164 (L)

Note: H=high category; M=medium category; L=low category; UD=useful description; PA=physics approach, SAP=specific application of physics; MP=mathematical procedures; LP=logical progression

It appears that for both classes the highest increase occurred in the UD indicator. These results support previous research that the STEM approach with formative assessment obtained the highest percentage of the UD indicator [22], and that students were able to complete the stages maximally only on the UD indicator because they only mastered fluid static knowledge partially [28]. Both classes have the lowest increase in the MP indicator. This shows that students have understood the equations used to solve problems in the SAP stage, but failed to continue in the MP stage [22]. It is clear that students don't quite understand the concept, but must also be proficient in using mathematical procedures in the problem solving process [29]. Meanwhile, it also appears that the improvement of all PSS indicators, except UD, in the experimental class is higher than the comparison class. This happens because the experimental class students focus more on problem solving so they tend to write incompletely the information obtained at the beginning. The increase in the Exp class SAP, MP, and LP indicators is one level higher than the Comp class. This is the direct experience that students get through the STEM engineering product design and feedback and self-assessment in the formative assessment [22]. The results of PSS increase in each subtopic of static fluid in both classes are written in Table 2.

Table 2. Summary of data analysis of PSS increase for each subtopic of static fluids

Class	Hake's N-gain (category)				
	Hydrostatic pressure	Archimedes' law	Surface tension	Viscosities	Capillaries
Exp	0.532 (M)	0.341 (M)	0.503 (M)	0.364 (M)	0.247 (L)
Comp	0.398 (M)	0.254 (L)	0.420 (M)	0.259 (L)	0.239 (L)

It appears that the improvement of all subtopics in the experimental class is better than the comparison class. In fact, the increase in the subtopics of Archimedes' law and Viscosities increase in experimental class one level better than the comparison class. This happened because the experimental class with the STEM approach made a miniature boats. The practice of making this product involves 7 steps of product design engineering [29]. The highest increase occurred in subtopic hydrostatic pressure for the Experiment class; and subtopic surface tension for Comparison class. But, the Exp and Comp classes had the same lowest improvement, namely in the capillaries subtopic. It seems that the students of both classes still have trouble in carrying out the stages of problem solving on the capillaries subtopic. Capillaries items have a fairly high cognitive level and are in the form of qualitative and symbolic. Problem solving involving numeric is easier than symbols [29].

The highest increase in Hake's N-gain for the Exp class occurred in the subtopic of hydrostatic pressure. This is represented by question number 01 with cognitive level C4 and the indicator "If data is presented on the difference in pressure that can be held by a snorkel's lungs, students can determine the maximum but safe depth that can be reached to dive properly". To solve this problem students must understand the formula $p = \rho gh$. In this case the increase in the indicators of UD, PA, SAP, MP, and LP is 0.378 (M), 0.773 (H), 0.647 (M), 0.672 (M), and 0.672 (M) for the experimental class, and 0.667 (M), 0.667 (M), 0.425 (M), 0.437 (M), and 0.487 (M) for comparison class. In this item, students make a picture representation of people diving so that it is easier to make mathematical equations. An expert solver will use non-mathematical representation to get to mathematical calculations [30], or use multiple representation in problem solving [31]. In the above improvement, it appears that only on the first indicator, the comparison class students have a higher increase than the experimental class. This means that the comparison class students only excel in determining the symbols and data variable physics, and not in other cases [28]. Whereas in four other indicators the experimental class has a significant difference in improvement than the comparison class. This shows that the STEM approach with formative assessment can enable students to take better problem-solving steps.

The highest N-gain increase for Comp class occurs on the subtopic of surface tension. This subtopic is represented by question number 05 with cognitive level C4 and the indicator "If data on the size of an insect's leg floating on the water surface is presented, students can determine the maximum mass of the insect so that it does not enter the water". To solve this problem students must understand the relationship between the formulas $F = L\gamma$, $w = mg$, and $K = 2\pi r$. In this case, the increase in indicators for UD, PA, SAP, MP, and LP is 0.846 (H), 0.554 (M), 0.385 (M), 0.392 (M), and 0.508 (M) for the experimental class, and, and 0.978 (H), 0.420 (M), 0.287 (L), 0.247 (L), and 0.227 (L) for comparison class. Overall the results of the improvement in this question are in line with the previous discussion. Comparison class students only excel in determining symbols and physics variable data, and not in any other case [28]. The increase in this problem is smaller than the previous problem. This means that students have difficulty regarding the surface tension subtopic higher than the hydrostatic pressure subtopic. Many students consider the variable length of circumference L to be the surface area of the insect's legs and/or the diameter of the circle. This means that students have used the variable information they have, but then they are wrong in applying mathematical equations [29]. Meanwhile, the difference in one level increase between the experimental class and the comparison on the last three indicators shows that the STEM approach with formative assessment can make students better able to take problem-solving steps.

The lowest N-gain increase for the Exp and Comp classes occurred in the subtopic of capillaries. This subtopic is represented by question number 07 with a C5 cognitive level and the indicator "If data on changes in the surface height of water and mercury are presented in a capillary tube, students can choose between the two fluids which have a greater surface tension." To solve this problem students must understand the formula $h = (\rho g r) / (2\gamma \cos \theta)$. In this case the increase in the indicators of UD, PA, SAP, MP, and LP is 0.561 (M), 0.369 (M), 0.162 (L), 0.139 (L), and 0.162 (L) for the experimental class, and, 0.860 (H), 0.140 (L), 0.067 (L), 0.067 (L), and 0.060 (L) for the comparison class. It appears that most of the troubleshooting steps are in the low category. This means that students of Exp and Comp classes have the highest trouble in working on this problem. Perhaps, this happened because this item involved quite a lot of physics variables and had a higher cognitive level than the previous problem. Also, the question in this item is "Which liquid has the greater surface tension?" qualitative and symbolic. This proves that solving problems involving symbols is more difficult than numeric [29]. However, overall in this matter the increase in the Exp class was higher than the Comp class. This means also showing that the STEM-FA can enable students to take better problem-solving steps.

The effect of the practical field implementation of STEM-FA learning approach in developing students' PSS can be shown in the value of d-effect size of 0.651 (medium category). This happened because the experimental class students made miniature boats through 7 steps of engineering design product [29], while the comparison class students did not make them. The result of this effect size implies that the practice field implementation of PBL-STEM-FA is recommended to be carried out in the field to increase students' PSS.

4. Conclusion

Based on the description above, it can be seen that experiment class students (PBL-STEM-FA) had a significantly higher PSS than students in the comparison class (PBL). The increase in N-gain in the experimental class is better than the comparison class. Measurements on each PSS indicator and fluid static subtopic show that the experimental class has the highest improvement in PSS on the Useful Description indicator and subtopic of hydrostatic pressure, while the comparison class has the highest increase on the Useful Description indicators and subtopic of surface tension. But, the Exp and Comp classes had the same lowest improvement, namely in the Mathematical Procedures indicators and capillaries subtopics. The treatment impact implies that the practice implementation of PBL-STEM-FA is recommended to be carried out in the field to increase students' PSS. It is recommended that future studies to add an "Art" aspect to the STEM approach.

5. References

[1] Widodo L Yuliati L and Parno 2017 Exploration of Students' Initial Concept Mastery in Static Fluids *Pros Semnas Pend IPA Pascasarjana UM* **2** pp 206–211
[2] Ashadarini W Yuliati L and Supriana E 2017 Mastery of the Concept of Static Fluids for Students of SMAN 3 Blitar *Pros Semnas Pend IPA Pascasarjana UM* **2** pp 340–344
[3] Dewi I N K Kusairi S and Yuliati L 2016 High School Students' Misconceptions on Archimides' Law Materials *Prosiding Seminar Nasional Pascasarjana Unesa* pp 339-343
[4] Purnamasari I Yuliati L and Diantoro M 2017 Analysis of Physics Problem Solving Ability in Static Fluids *Pros Semnas Pend IPA Pascasarjana UM* **2** pp 191–195
[5] Docktor J L Strand N E Mestre J P and Ross B H 2015 Conceptual problem solving in high school physics *Physical Review Physics Education Research* **20106** pp.1–13
[6] Hertiavi M A Langlang H and Khanafiyah S 2010 *Jurnal Pendidikan Fisika Indonesia* **6** pp.53–57
[7] Steif P S Lobue J M Kara L B and Fay A L 2010 *Journal of Engineering Education* **99** 135
[8] Azizah R and Yuliati L 2015 *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)* **5** 44
[9] Arisa Y and Simamora P 2014 *Jurnal Inpafi* **2** 4 54
[10] Siswanta J, Endang S and Jatmiko B 2018 *Journal of Baltic Science Education* **17** 381
[11] Parno, Yuliati L and Ni'mah B Q A 2019 *Journal of Physics: Conf Series* **1171** 012013
[12] Arends R L 2012 *Learning to Teach 9th* (New York: MCGraw Hill)
[13] Cate Th J T, Kusurkar R A and Williams G J 2012 *Medical Teacher* **33** 961
[14] Roberts A 2012 A Justification for STEM Education *TECHNOLOGY AND ENGINEERING TEACHERe* **May/June** pp.1–5
[15] Nikat R F, Munfarikha N, Henukh A and Samritin 2019 *IOP Conf Series: Earth And Environmental Science* **343** 012214
[16] Cohen L, Manion L and Morrison K 2018 *Research Methods in Education 8th Edition* (New York: Routledge-Taylor & Francis Group)
[17] Docktor J L, Dornfeld J, Frodermann E, Heller K, Hsu L, Jackson K A and Yang J 2016 *Physical Review Phyisics Education Research* **10130** 1
[18] Bybee R W 2013 The case for STEM education: Challenges and opportunities (Arlington VA: NSTA Press)
[19] James M 2017 *Embedding Formative Assessment in Classroom Practice in: Maclean R (Ed) Life in Schools and Classrooms* (Singapore: Springer pp.509–525)
[20] Morgan G A, Leech N L, Gloeckner G W and Barrett K C 2004 *SPSS for Introductory Statistics Use and Interpretation* (London: Lawrence Erlbaum Associates)
[21] Hake R R 1998 *Am J Phys* **66** 64
[22] Parno, Estianinur and Latifah E 201 *American Institute of Physics Conference Proceedings (AIP Conf Proc)* **2331** 030021
[23] Cooper R and Haeverlo C 2013 *American Journal of Engineering Education* **4** 27
[24] Michael & Susan Dell Foundation 2016 *Formative Assessment In The Classroom* (United State: Michael & Susan Dell Foundation)
[25] Pahlevi T, Rosy B and Ranu E M 2018 *International Journal of Educational Research Review* **3** 29
[26] Gunantara G, Suarjana M and Riastini P N 2014 *Jurnal Mimbar PGSD Universitas Pendidikan Ganesha* **2** 1
[27] Jackson J, Dukerich L and Hestenes D 2008 *Science Educator* **17** 10
[28] Mulyastuti H, Sutopo and Taufiq A 2019 *J Phys Conf Ser* **1171** 012028
[29] Balta N, Mason AJ and Singh C 2016 *Phys Rev Phys Educ Res* **12** 1 010129
[30] Harper K A 2006 Student Problem-Solving Behaviors *Phys Teach* **44** 250
[31] Kohl P B, Finkelstein N D, Hsu L, Henderson C and McCullough L 2007 *AIP Conference Proceedings* **951** 132