Building Scientific Literacy and Concept Achievement of Physics through Inquiry-Based Learning for STEM Education

I. Yuliati1), Parno1), F Yogismawati2), I K Nisa2)
1) Lecture, Physics Department, Universitas Negeri Malang, Indonesia
2) Undergraduate Student, Physics Department, Universitas Negeri Malang, Indonesia

The corresponding author's: lia.yuliati.fmipa@um.ac.id

Abstract. This study aims to determine the effect of inquiry-based learning for STEM Education toward scientific literacy and concept achievement in physics. The study was conducted with a quasi-experiment design toward two group; experimental and control groups. The experimental group had learned by inquiry-based learning for STEM Education and the other by inquiry-based learning only. The sample of this study were 68 students in 10th grade in SMA Negeri 1 Singosari that determined by cluster random sampling. The instrument used multiple choice with the open-ended question (r = 0.70). The data were analyzed qualitatively and quantitatively (Mann Whitney U-Test). The result showed that concept achievement in Newton's Law was a significant difference in the experiment group (mean=63.5) and the control group (mean=53.8). The student's concept of achievement influenced their scientific literacy. These results indicate that inquiry-based learning for STEM education influences the scientific literacy and concept achievement of physics, especially on Newton's Law subject.

1. Introduction

Newton's law has an important role to explain physical phenomena in real life and these laws have been taught at various levels of education, such as in primary, high school and university [1]. Newton's Law is one of the subjects that considered difficult. Students have not achieved the concept well [2]. The cause of poor achievement of Newton's Law concepts because students are not used to finding the direction of forces acting on moving objects when changes in motion are provided [3]. Students also have difficulties in determining the acceleration of moving objects [4]. To learn the Newton's Law, it is not enough to use scientific inquiry, but it requires the consolidation of concept achievement [5].

Concept achievement in physics is used as a person's ability to understand the process of science and obtain meaningful scientific information. In addition, it also reflects a broad and functional of science [6]. Aspects of concept achievement appropriate to the level of the cognitive process dimension, namely; remembering, understanding, applying, analyzing, evaluating, and creating [7]. Concept achievement able to describe the ability of one's thinking in strategizing. Strategy preparation can improve the scientific literacy of students[8] [9]. Scientific literacy can identify students' ability to use scientific knowledge, identify problems, draw conclusions and changes that occur in nature [8]. Scientific literacy can be measured through four aspects, namely; scientific content, scientific context and scientific competence and scientific attitude[10].

Some aspects of knowledge can develop if balanced with a supportive learning model. A learning model provides a framework for interaction between teachers and students [11]. One of them is the inquiry-based learning model. Inquiry-based learning emphasizes students to conduct investigations in
the construction of science [12]. However, in this XXI century, this inquiry-based learning has been developed as a form of educational reform in some developed countries [5].

Learning is designed to include 21st-century skills that include collaboration, creativity and imagination, critical thinking, and problem-solving [13]. In addition, according to some research, problem-based learning and project-based learning should also be emphasized as a collaboration to find solutions to real problems [13] [14]. Both models are available on STEM (Science, Technology, Engineering, and Mathematics) education. STEM education provides opportunities for teachers to show students how the concepts, principles, and techniques of science, technology, engineering, and mathematics are used in an integrated way in the development of products, processes, and systems used in everyday life.

STEM Education develops students’ skills into better problem solvers, independent, innovators, inventors, creators, logical thinkers, and technology literate [15]. STEM Education will connect schools, the world of work, and the global world so that the development of STEM literacy in schools enables learners to compete in a new era of knowledge-based. The teacher should prepare carefully what is needed in the teaching process of the STEM [16]. STEM Education’s main goal is to develop a new generation of multi-talents that can integrate various fields of science education to solve practical problems [17]. STEM Education enables students to gain experience in finding answers to questions, conduct scientific investigations, design techniques related to STEM discipline, so students can develop their own identity as STEM learners through science, math, technology, and engineering. STEM education can link scientific inquiry, by formulating questions answered through investigation to inform the student before they engage in the engineering design process to solve problems [18].

The advantages of STEM education have not been fully utilized by teachers in schools. Physics material is taught as a product, not as a process and skills. Some teachers have linked STEM but have not been integrated. STEM aspects are still partially taught. Some developed countries are developing STEM (science, technology, engineering, and mathematics) education as a solution to the challenges of the XXI century [19]. Inquiry-based learning in STEM gives influence to the students' concept achievement as well as the scientific literacy of the students [20]. The purpose of this study is to know the influence of inquiry-based learning in STEM education toward scientific literacy and concept achievement of the student, especially in Newton's Laws.

2. Method

This study was conducted with pretest-posttest control group design in two groups; experimental group and control group. The experimental group studied with inquiry-based learning in STEM education and the control group of studied with inquiry-based learning. The sample of this study was 68 students of 10th grade SMA Negeri 1 Singosari which was set by cluster random sampling technique. The study instrument used 10 open-ended multiple-choice questions with high reliability with a value of $r = 0.70$. The question instrument consists of 3 questions in the easy category, 4 questions in the medium category, and 3 questions in the difficult category. The learning used lesson plan of inquiry-based learning with STEM education, and self-study activity unit. The pre-test and post-test results were analyzed by the prerequisite analysis test, initial ability equality test, and hypothesis test. The prerequisite analysis test showed that the nonparametric data so that the initial equality test and hypothesis test using the Mann Whitney U Test.

The experimental group used inquiry-based learning for STEM Education in Newton's law material by integration of science, technology, engineering, and mathematics. This learning involves actively the role of students. Students construct inquiry of science into technology and engineering. Students have to understand of science through inquiry process will be able to solve physics problems using mathematics. Inquiry-based learning focused the students on planning the learning process, problem presentation, formulation of hypotheses, data collection, making the explanation, making the conclusion, and reflection. In the data collection, students made a demonstration design which implemented as an engineering phase in STEM education. At one of the meetings, students create a product is three dimension clipping about the application of Newton’s law. At the end of the learning, students described the application of Newton law in technology and its simple design

3. Result and Discussion
The results showed that concept achievement in the experimental group was high rather than the control group. This is supported by the Mann Whitney U Test which yields that $p(0.036) < \alpha (0.05)$. There is a significant difference between the concepts achievement of the two groups. The hypothesis test is done by comparing the mean posttest value between the two groups. The result is the average of the experimental group value is 63.2 higher than the control group which gets the average value of 53.8. These data are presented in Figure 1.

The graph shows that cognitive domain of students in the experimental group are the C1 (remember) = 62%, C2 (understand) = 72%, C6 (create) = 56%. This result is higher rather than the control group, i.e C1 (remember) = 44%, C2 (understand) = 64%, and C6 (create) = 15%. At C3 level (apply), students in both groups achieve 100%. At C5 level (evaluate), the control group achieve 53% while the experiment group was only 3%. In the control group, students had difficulties to conduct evaluation activities because students had not mastered the concept well. The learning experience of students did not yet support the development of concepts of Physics. Overall, the concept achievement of student cognitive domain of the experiment group achieves a 60%, while the control group only 46%.

![FIGURE 1. Concept Achievement of experimental and control groups](image1)

The degree of student’s concept achievement was analyzed from the posttest answers of open-ended multiple choice questions. Student answers are classified into six sections, namely No Response (NR), No Understanding (NU), Specific Misconception (SM), Partial Understanding with Specific Misconceptions (PU with SM), Partial Understanding (PU), and Sound Understanding (SU) [21] [22]. The results of data analysis classification can be seen in Figure 2.

![FIGURE 2. Level of concept achievement in experimental and control groups](image2)
The result of the study showed that the concept achievement of experiment group (26%) is higher than the control group (9%). Engineering process in STEM education allows students to conduct sequential investigations and design their own experiments to investigate their ideas so as to achieve higher science concepts. The results of this study support previous research which state that the engineering approach in STEM education to teach the concept of science is better than compared with inquiry learning [23].

Integration of STEM learning enables the use of various methods of learning [24]. STEM education in inquiry-based learning is done by combining science, technology, engineering, and mathematics which is implemented by the syntax of inquiry learning. This integration involves the active role of the students. The students construct inquiry into science, technology, and engineering [25]. Students who have understood the material through the inquiry process will be able to solve physics problems using mathematics [26].

Students' experiences in the experimental group go beyond the traditional boundaries of science, technology, engineering, and mathematical disciplines so that they can be useful in the future [19]. Students more active in the learning process. Such learning becomes more meaningful. Students connect their prior knowledge with new knowledge and apply it in the real world [27]. The research findings showed that inquiry-based learning in STEM education is more meaningful because they have better in developing knowledge to the technology and engineering [28]. The results of other studies showed that STEM education has a positive effect on learning, especially in improving students' learning interests and achievement of student concepts [29]. Inquiry-based learning in STEM Education emphasizes how students learn through cognitive processes so that students achieve the concept of science [30]. The involvement of cognitive aspects directs the attention and motivation to learn concepts and skills [31]. The engineering approach in STEM education taught the concept of science better when compared to inquiry learning [23].

The results showed that students recognize the context of the problem at the time of recognizing the problems given. Students have scientific literacy on the dimensions of the scientific context because students have been able to analyze the relationship of the problem with the knowledge it has [10]. This means that students have been able to apply their knowledge in the appropriate learning model [11]. Scientific literacy students are based on the learning experience with inquiry learning in STEM education. This learning is a learning innovation that can improve the scientific literacy of students [32].

The analysis of scientific literacy is presented in Figure 3.

**FIGURE 3.** Analysis of student's scientific literacy

At the beginning of the learning activity, students are asked to write down their initial knowledge. Students analyze the initial information to find its relationship with observational data, either individually or in groups. This collaboration develops students' thinking skills [33]. In scientific content, students analyze the problem so students can explain the phenomenon by using the previous theory [34].
Students become more understanding of how the knowledge acquired, may explain natural phenomena scientifically [10], and more skillful in mastering the scientific content [35].

4. Conclusion

The concept achievement of the physics in 10th-grade senior high school students in Newton’s law matter that obtains inquiry-based learning in STEM education is higher than that of senior high school 10th students receiving inquiry-based learning is indicated by p-value (0.036) < α (0.05). Students who have good concept achievement tend to have a good scientific literacy as well. This is evidenced by the significant correlation (r = 0.88) between the two. Significant correlations of concept achievement and scientific literacy are supported by inquiry-based learning in STEM education. Students who have concept achievement properly according to the principles of science have a good scientific literacy. Students who have high concept achievement can explain the reason according to scientific literacy in detail, whereas students who have the ability to concept achievement of low solve problems intuitively and verbal. It indicates that the influence of exploration concept achievement of scientific literacy good. This study recommends for future researchers to explore student misconceptions about Newton’s laws and its application in daily life. Some students that experience misconception on Newton’s Laws in this study.

References
[1] Srisawasdi N and Sornkhatha P 2014 International Journal of Mobile Learning and Organization, 8(1) 28-49
[2] Obaidat I and Malkawi E 2009 International Journal for the Scholarship of Teaching and Learning 3(1) 19
[3] Lee H S and Park J 2013 International Journal of Science and Mathematics Education 11 1391–1414
[4] Sutopo, Liliansari, Waldrib B, and Rusdiana D 2012 Jurnal Pendidikan Fisika 8 161-173
[5] Rustaman N Y 2005 Proceeding of National Seminar II Himpunan Ikat Sarjana dan Pemerhati Pendidikan IPA Indonesia with FPMIPA Universitas Pendidikan Indonesia, Bandung, pp. 22-23
[6] Hurd P D and Gallagher J J 1996 Goals Related to The Social Aspect of Science. Cleveland: Educational Research Council
[7] Anderson L W and Krathwohl D R 2001 A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. A bridged Version. New York: Longman
[8] Fang Z and Wei Y 2010 The Journal of Educational Research 103 262-273
[9] Holbrook J and Rannikmae M 2007 International Journal of Science Education 29 (11) 1347-1362
[10] OECD. PISA 2012 Assesment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy, OECD Publishing
[11] Wenning C J 2010 Journal of Physics Teacher Education Online 5 11-20
[12] Ngertini N W and Sandia M Y 2013 E-Jurnal PP Undiksha 4
[13] McKinney C T S and Berube C 2017 K-12 STEM Education 3 (2) 179-191
[14] Hong M, and Kang N 2010 International Journal of Science and Mathematics Education 8 (5) 821–843
[15] Morrison J S 2006 TIES STEM Education Monograph Series
[16] Nadelson L S, Callahan J, Pyke P, Hay A, Dance M, and Pfiester J 2013 The Journal of Educational Research 106 157–168
[17] Wang H, Moore T J, Roehrig G H 2011 Journal of Pre-College Engineering Education Research 1(2) 1–13
[18] Kennedy T, and Odell M 2014 Science Education International 25(3) 246–258
[19] Bybee R W 2013 The case for STEM education: Challenges and opportunities. United States Of America: NSTA press
[20] Suwarmi I R, Astuti P, Endah N E 2015 Proceeding of Simposium Nasional Inovasi dan Pembelajaran Sains
[21] Renner J W, Brumby M & Shepherd D L 1981 The Science Teacher 48(9) 135-143
[22] Marek E A 1986 The American Biology Teacher 48(1) 37-40
[23] Mehalik M M, Doppelt Y and Sichuan C D 2008 Journal of Engineering Education 97(1) 71-85
[24] Permanasari A 2016 Proceeding of Seminar Nasional Pendidikan Sains 3 23-34
[25] Rush D L 2011 Integrated STEM education through project-based learning Learning.com
[26] Reeve E M 2013 The Science Teacher 48(9) 135-143
[27] Brooks J G, Brooks M G and Alexandria 1993 Association for Supervision and Curriculum Development. ERIC Document Reproduction Service ED 366 428
[28] Stohmann M S, Moore T J, and Cramer K 2013 Journal of Mathematical and Application. 1(8) 18-31
[29] Becker K, Park K 2011 Journal of STEM Education: Innovations and Research 12 23
[30] Bransford J D and Donovan M S 2005 Scientific inquiry and how people learn. How students learn: History, mathematics, and science in the classroom 397-420
[31] Chi M T, and Wylie R 2014 Educational Psychologist 49(4) 219-243
[32] Guzzetti J, Barbara and Eunjin B 2010 Literacy Research and Instruction
[33] Arends R I 2012 Learning to teach Central Connecticut State University: McGraw-Hill Companies
[34] Pantiwati Y 2013 Jurnal Edukasi Matematika dan Sains 1 (1) 18-27
[35] Meltzer D E 2002 American Journal of Physics 70 (12) 1259-1268