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Developing Students' Mathematical Literacy through Problem Based Learning

Junianto¹, A Wijaya²

^{1,2}Graduate Program, Yogyakarta State University, Indonesia

Corresponding author: 1antojun93@gmail.com

Abstract. The modern era requires more than just conceptual and procedural knowledge. Many studies such as the Program for International Student Assessment (PISA) emphasize the importance of individual's ability to apply their conceptual and procedural knowledge. Such competence in mathematics is referred to as mathematical literacy. With this respect, the present study is aimed to explore the possibility of Problem Based Learning (PBL) as a means to develop students' mathematical literacy. For this aim, a literature review was used for which 11 research articles on the effectiveness of Problem Based Learning (PBL) in learning several mathematical competences were selected and reviewed. By focusing on the common characteristics between the mathematical competences reported in the 11 articles and the characteristics of mathematical literacy, the literature review show that PBL has a potential to develop students' mathematical literacy. Variables in the 11 articles like critical thinking, creative thinking, students' understanding, and mathematical communication are related to fundamental capabilities in mathematical literacy. The result of this studies prove that the use of PBL from elementary school to university level can improve students' mathematical literacy skills.

1. Introduction

The 21st century is a century where that requires massive transformations in various sectors of life. Agrarian society began to shift into an industrial society which then continued to be a knowledgeable society [1]. This modern era demands more than conceptual knowledge. The ability to apply conceptual knowledge and critical thinking are crucial to cope with the demands of modern society. In the modern era, any information needs to be processed intelligently and critically with the knowledge an individual has.

A knowledge that must be possessed in dealing with the global era is the ability in terms of abstraction, problem analysis, and logical reasoning where these three things are taught in mathematics [2]. At the world level, students' mathematical abilities are measured through surveys conducted by the OECD through the Program for International Student Assessment (PISA). The capabilities measured in this survey are mathematical literacy from students around the world. Mathematical literacy is the capacity of individuals to formulate, use, and interpret mathematics in various contexts [3]. Meanwhile, according to Ojose [4], mathematical literacy is knowledge in using the basics of mathematics to solve problems in daily life. Despite the growing attention towards mathematical literacy, the Indonesian students' mathematical literacy is still relatively low when viewed from the PISA survey. Based on the PISA survey, in 2006 Indonesia was ranked 50 out of 57 countries. In 2009 Indonesian students' performance decreased to 61 of 65 participants with an average score of 371, which was lower than the



average international score of 496. In 2012 Indonesia's score rose to 375 and increased again in 2015, namely 386 [5].

The results of PISA survey indicate that Indonesian students' mathematical literacy still needs to be improved. Moreover, the aim of mathematical literacy is to train students to use relevant abilities in an unstructured context, where instructions are not so clear [4]. Considering the Indonesian students' low mathematical literacy, improving students' mathematical literacy is very important thing. One of the fundamental capabilities of of mathematical literacy is problem solving [6]. Therefore, a possible learning strategy that has a potential to support such competence is Problem Based Learning (PBL) that will be analyse in this study.

PBL is a teaching method using problem solving and integration and application in real world context to encourages learning and developing 21st century competencies and skills [7]. PBL was started at the McMaster School of Medicine in Canada in 1965 [2]. Later, Barrows revised the learning strategy and process approach [2]. The learning approach is developed for two reasons. The first objective is to help graduating students bridge the theory and practice in the field. The second objective is to prepare students to face challenges due to technological developments [8]. After going through this revision, PBL was later adopted by several medical schools, nursing and midwifery programs, and other health curricula in many countries [9] [10]. According to Karacalli and Korur [11], PBL is learning that focuses on problem solving in real life situations. The characteristics of the concept of Problem Based Learning (PBL) functional curriculum design include:

- a. Engagement. The problems presented to students are explained along with their roles.
- b. Inquiry/Investigation. It include what concept that students know before, students' need and how best to gain the concept/information.
- c. Problem Resolution. Students determine their choices and make decisions to take action.
- d. Debriefing. The important thing is students are able to understand the problem solving process, in addition to their discussion of content and how to use it in dealing with new situations [12].

PBL has several benefits including: 1) determining the problem, 2) investigating the cause of a problem, 3) hypothesizing, testing hypotheses, obtaining information, determining learning targets, developing problem solving skills, and using the information obtained for life [11]. PBL also has several advantages including: student-centered learning, helping students to develop various points of view; do deep, active and meaningful learning and develop problems of ability to solve, research, creative and think critically [13]. Based on the understanding of mathematical literacy and the PBL approach, there are similarities between the problems presented, namely the problems that are close to everyday life. Cindy and Hmelo-Silver [14] emphasized that PBL is also designed with several objectives, i.e. to help students in:

- a. building a broad and flexible knowledge base
- b. develop their skills to solve problem effectively
- c. develop independent and lifelong learning skills
- d. be an effective collaborator
- e. being motivated intrinsically to learn.

Based on the understanding and description above, there is a possibility of a positive relationship between mathematical literacy and problem based learning. Therefore, this literature review attempts to examine the concepts, characteristics and advantages of the PBL. In addition, the present study will also examine the relationship between the PBL approach and mathematical literacy so that it can be known how PBL could develop students' mathematical literacy. The results of this studies could be a reference for education practitioners in implementing PBL to improve students' mathematical literacy skills.

2. Method

2.1. Search Procedure

Before searching for research articles, the literature analyzed was limited to several types of research. The main research analyzed is empirical research to find out more about the effectiveness of PBL. The

empirical article and the review literature were selected as relevant research but were not included in the analysis.

The formulation of the problem that has been compiled is then searched for by several methods that have been selected. The search procedure is done by finding as many as possible previous studies. The research sought is about the problem based learning approach and the effectiveness of PBL on learning. In addition, studies on mathematical literacy are also sought through tracing in several journals. To find some literature studies, the search procedure used is to search the database from Google Scholar, Springer, the Educational Resources Information Center (ERIC) and tracking citations from a study for further study. Some reference search keywords include problem based learning, problem based learning in mathematics, mathematical literacy, characteristic of problem based learning, advantages and benefits of PBL, etc.

Some journals from search results also become references in this literature review. Part of the journal is an empirical study that examines the effectiveness of PBL on students' mathematical abilities. The journal that became the reference was the journal of mathematics education, the Journal for the Australian Nursing Profession, the Journal of Elementary Science Education, the American Journal of Pharmaceutical Education, etc. In addition to journals, the book is also a reference for this research such as the OECD published book about PISA which examines PISA and mathematical literacy. The study used in this literature review is in the span of time between years 2005-2017.

2.2. Selection Criteria

Based on the search results in several journals with keywords that have been defined in the article search procedure, several articles about PBL were obtained. Then, from the article sorted by topic tested. Of the PBL articles obtained, there were articles that were not related to mathematics so that this article was not included in the analysis. In addition, there are also several articles that are literature reviews. The article produced by literature review is used as a relevant research and is a source of study. However, the literature review article was not analyzed.

Furthermore, there were several criteria in choosing the articles that have been searched according to the established procedures. The first criterion was this literature review focusing on articles with empirical research that includes information on research subjects. This focus is limited to empirical research because the main intention of the study was the level of effectiveness of PBL on research subjects. Therefore, literature review articles obtained from search results were used as relevant research and theoretical sources, because these articles were empirical studies aiming to know the effectiveness of PBL. The second criterion was the limitation of research subjects, namely at the level of primary education to higher education. This was done so that research can be more comprehensive and come from various levels of education. The college level was chosen because it referred to the history of PBL where it was first tested. While students at the primary and secondary education levels were chosen because mathematical literacy was tested at these levels. The third criterion was the publication period which was limited to the period from 2000 to 2018. This was intended to make the study reviewed more recently so that it is expected to be more valid. However, theoretical studies are not limited by the year of publication of an article, because PBL was initiated since 1965. Therefore, theoretical studies in this study are not limited to the time since PBL first began to be studied.

Based on the aforementioned four criteria, the relevant articles obtained 11 articles of empirical research with various kinds of dependent variables. The differences in the dependent variable also refers to the components in mathematical literacy that will be studied.

2.3. Coding Strategies

Based on the questions in the problem formulation, then the main characteristics of several articles will be defined. Articles about the effectiveness of PBL are then selected and grouped in table form. The information entered in the table regarding the selected article contains the following content.

- Author and year of publication
- Number of authors

- Independent variable
- Research design
- Research subject

The coding strategy is then used as a means to analyze articles that have been traced so as to facilitate categorization.

3. Result

Based on the results of the search for journal articles, 11 articles were selected according to the needs of the analysis. Information on these 11 articles can be observed in Table 1.

Table 1. Overview of studies on PBL

Author	Year	Teaching Strategies	Dependent variables	Research design	Subject
R.D. Padmavathy & Mareesh. K	2013	PBL	Students understanding	Control group pretest posttest experimental design	Two groups of 30 samples equal for both.
Rattanatumma, T & Vichian Puncreobutr	2016	STAD	Learning achievement and problem solving ability	Quasi experimental research	25 students chosen by cluster random sampling method.
Indah, N., Mania, S & Nursalam	2016	PBL	Mathematical literacy	Quasi experimen one group pretest-posttest design	One group of Junior High School 7 th grade
El-Shaer A & Gaber, H	2014	PBL	Critical thinking disposition, knowledge acquisition and retention	Quasi experimental design	3 rd year nursing students (200) which divided into two groups
Ersoy, E & Baser, N	2013	PBL	Creative thinking	Pretest-posttest design	First grade student's (n=73) in higher education
Wardono, Waluya, SB., Mariani, S & Candra, S., D	2014	PMRI	Mathematics literacy	Mix method	7 th grade of Junior High School (2 groups)
Firianawati, M & Hartono, H	2016	TGT	Learning achievement, creative thinking ability and tolerance	Quasi experimen pretest posttest non-equivalent comparison-group design	8 th grade of Junior High School (2 groups)
Hidayati, R	2017	TPS	Learning achievement, mathematics communication and interpersonal students' skill	Quasi-experimental design	8 th grade of Junior High School students.
Gijbels, D., Dochy, F., Bossche, P, V., & Segers, M	2005	PBL	Problem solving skill	Meta-analysis	Relevant studies to PBL
Widyaningtyas, R., Kusumah, YS., Sumarmo, U., & Sabandar, J.	2015	Cooperatively in small groups	Students' mathematical critical thinking ability	Posttest control group research design	140 of 10 th Senior High School Students
Firdaus, F. M., Wahyudin & Herman, T	2017	PBL	Mathematical literacy	Quasi-experimental method non equivalent pretest-posttest group design	5 th grade school students

There are seven fundamental capabilities in mathematical literacy including communication, mathematizing, representation, reasoning and argumentation, devising strategies for solving problems, using symbolic, formal, and technical language and operations, using mathematical tools [6]. The abilities tested in PISA are grouped into 3 mathematical process components, namely 1) formulating situations mathematically, 2) employing mathematical concepts, facts, procedures and reasoning, 3) interpreting, applying and evaluating mathematical outcomes [6]. While in the Trends International Mathematics and Science Study (TIMSS), the ability of the tested literacy is grouped in the cognitive dimension of knowing the fact and concept, applying concept and procedure, and problem solving and reasoning ability [15] [16].

Several studies reveal show the effectiveness of PBL that discuss in the eleven articles. Research of Padmavathy and Mareesh [17] has a major finding that in teaching mathematics, PBL method is more effective to improve students' understanding. Findings of the study revealed that problem based learning have impact in teaching mathematics and develop students understanding, skills to use concepts in daily life. Understanding and skills to use concept in daily life is one aspect of mathematical literacy, namely formulating situation mathematically and mathematizing. In addition to students' understanding, also tested how the ability to use concepts in real life. This is also part of mathematical literacy, namely using mathematical tools, devising strategies for solving problems and communication.

In the second literature, research by Rattanutumma and Puncreobutr [18] shows that PBL is useful in improving the students' mathematics learning achievement and problem solving abilities. In addition, when compared between the control class and the experimental class with PBL, the PBL class has higher achievement and problem solving scores. So, it can be concluded that the application of PBL has an important role in improving students' abilities and problem solving. Problem solving is including in three aspect of fundamental mathematics capabilities that are matheatising, representation, reasoning and argument and devising strategies for problem solving.

Research by Indah and Nursalam [19] shows that the use of Problem Based Learning approaches can develop mathematical literacy of Junior High School 7th grade students. Then, El-Shaer and Gaber [20] prove that there are statistically significant improvements in students' critical thinking disposition, knowledge acquisition and retention after implementing PBL approach. There are four indicators to investigate critical thinking, i.e. clarification, assessment, inference and strategy [21]. In clarification phase, student has played the objective to provide problem formulation of the given problem accurately and correctly. This stage includes the basic abilities of mathematical literacy, namely mathematizing (transforming a problem defined in the world to a strictly mathematical form) and including the first aspect of the mathematical process, namely formulating mathematically situations. Assessment phase is also including in communication aspect of fundamental mathematics capabilities of mathematical literacy. Inference phase is including in reasoning and argument, then strategy include in using symbolic, formal, and technical language and operations aspect.

Wardono, Waluya, Mariani and Candra [22] show that students' mathematical literacy ability are improved after implementing PBL approach. Studies by Firianawati and Hartono [23] prove that PBL can develop creative thinking ability, mathematics learning achievement, and tolerance. There are four phase in creative thinking that are fluency, flexibility, originality, and elaboration. Fluency include in mathematizing, flexibility in devising strategies for solving problems, originality in reasoning and argument, elaboration in communication aspect of fundamental mathematics capabilities of mathematical literacy. Based on studies by Hidayati [24] learning achievement, mathematical communication skills, and interpersonal skills of the students increase after the using of PBL approaches. Mathematical communication skills are also same with one of seven basic mathematical literacy abilities, i.e. communication. Ersoy and Baser [25] also show that PBL is effective to improve problem solving ability.

Problem Based Learning has positive effects on problem solving especially in the level of understanding principles that link concepts. The research conducted by Gijbels, Dochy, Bossche and Segers [26] show that there are variable linkages with mathematical literacy, namely problem solving variables are also one of the basic abilities of mathematical literacy and include the second stage in the

mathematical process. Then, studies by Widyaningtyas, Kusumah, Sumarmo and Sabandar [27] show that students' critical thinking in terms of school level and students' prior mathematical abilities to be better after implementing PBL. Similar to the previous variables, the clarification phase on critical thinking is included in mathematising abilities and the first stage in mathematical processes. Studies by Firdaus, Wahyudin and Herman [28] prove that there is a significant effect of PBL toward mathematical literacy and PBL more effective than Discovery Learning (DL).

Based on the analyses, creative thinking, critical thinking, and problem solving ability is the most important component that have impact on mathematical literacy. It can be known that the three components are related to four component of fundamental capabilities among seven capabilities in mathematical literacy. Then, based on some of the research results, it can be presented in the following chart.

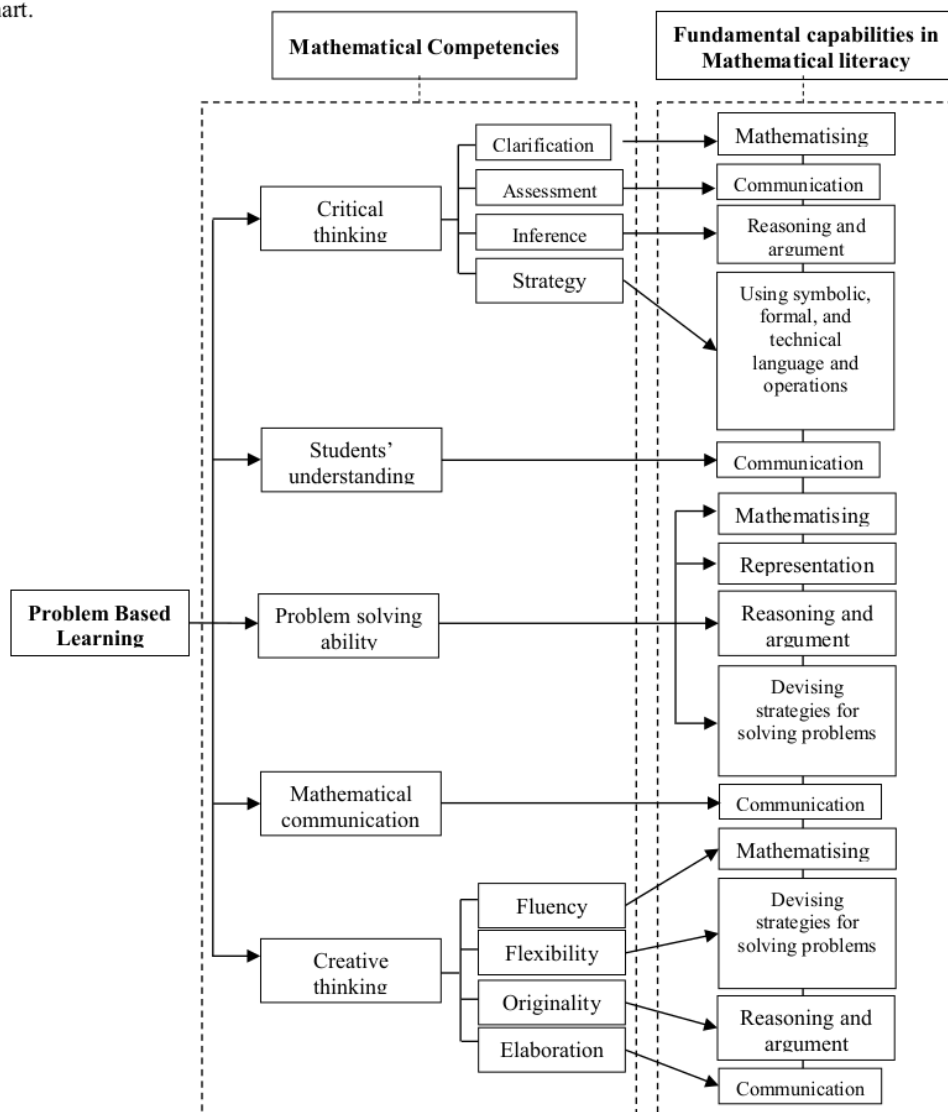


Figure 1. Relationships between PBL, variable and mathematical literacy

4. Conclusion

Based on the analysis of the selected literature, there are relationships between the characteristics of the mathematical competences studied in the 11 articles with the fundamental capabilities in mathematical literacy. It has been proven that the use of Problem Based Learning can improve several variables tested in the selected literature (studies). For example Celik, Onder and Silay say that the advantages of PBL include: student-centered learning, helping students to develop various points of view; do deep, active and meaningful learning and develop problems of ability to solve, research, creative and think critically [14]. Furthermore, some variables in the 11 articles like critical thinking, creative thinking, students' understanding, and mathematical communication are related to fundamental capabilities in mathematical literacy. So, it can be concluded that the use of PBL from elementary school to university level can improve students' mathematical literacy skills.

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