The effectiveness of implementing project-based learning (PjBL) model in STEM education: A literature review

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Abstract. STEM education is one of the latest learning approaches, particularly in Indonesia. STEM integrates four scopes of studies including Science, Technology, Engineering, and Mathematics. STEM approach requires an appropriate learning model in order to achieve the effectiveness of learning objectives. Therefore, the aim of this study is to explore the effectiveness aspects of implementing PjBL learning model in STEM education. This study was conducted by analysing journals examined the effectiveness of the application of PjBL learning model in STEM education. The syntax in the PjBL which includes planning, creating, processing, and evaluating has similarities with the steps in implementing STEM learning. As a form of integration of the four fields of study or a combination of several fields, STEM learning was applied to overcome contextual problems through designing, executing (processing), and evaluating. The effectiveness of using the PjBL learning model in STEM education is generally supported by its characteristics. Based on the review of seven journals that link PjBL and STEM, it is known that PjBL is one of the learning models which is significantly appropriate to be implemented in STEM education to increase the effectiveness of this approach.

1. Introduction

The learning process that allows students to construct their own knowledge into a learning concept has attracted attention in the field of education in recent decades. Various innovations in strategies and approaches in learning have been adjusted continuously, both for the needs of students during the school period and for the future provisions that will be faced by students. Constructivist philosophy changes the learning paradigm from teacher-centered learning to student-centered learning. Therefore, constructivists become an educational philosophy that is very influential of education in the 21st century [1].

Constructivism is a learning process that requires students to construct their own understanding through a series of activities. This approach forces students to compare rather than receive knowledge from the teacher. Thus, the special feature of constructivist is student – centered learning. However, the concept of constructivism is also defined variously by each person, including teachers [2]. Various methods, strategies, and approaches are used to apply constructivist learning to become an innovation in learning process. Furthermore, based on the visual classification system or also known as Dale’s Cone of Experience about the learning pyramid, students will also absorb a lot of knowledge gained through direct experiences [3]. One of learning models that requires students to directly compile their knowledge through their experiences is project-based learning (PjBL). This learning model is appropriate with constructivist philosophy since the learning process puts the students as the central in learning [4].
Project based learning (PjBL) is a learning model that requires students to solve a problem together in a particular group. The problems presented are usually authentic, in accordance with the curriculum and sometimes consist of various fields of study[5]. In PjBL, students are required to follow certain learning steps, known as syntax, in order to solve the problems given in detail. The stages in PjBL include (1) the observation and questioning stage, (2) the trial stage, (3) the associating stage, (4) the simplifying stage and (5) the reconstructing stage [6]. The simpler steps of PjBL can also be summarized into the stage of gathering information from various sources, analysing and synthesizing concepts based on the two previous steps [5]. This shows that PjBL is a learning process pursued through a series of experiences. Therefore, this learning model directly makes the students ready to construct their own knowledge through collaborative learning. Furthermore, PjBL is also a learning model that is highly recommended in the current curriculum in Indonesia, namely the 2013 curriculum[6].

The situation in the education sector in the 21st century is increasingly dynamic and demands innovation in education. In line with this, PjBL comes as an innovation in learning considered to facilitate the development of students in acquiring knowledge and strengthen the skills needed by students such as self-confidence, communication skills, flexibility, the ability to work with other students and being able to motivate themselves[7]. Aside of being appropriate with the current general educational needs, PjBL is also a model which is suitable to be used in mathematics learning. The positive impact of PjBL in various fields of study includes increasing mathematical representation skills [8], increasing higher-order thinking skills [9][10], increasing mathematical communication skills[11], and increasing academic accuracy (academic rigor) [12].

Furthermore, the STEM approach is an innovation in education that integrates four fields of study, namely Science, Technology, Engineering, and Mathematics. STEM was first initiated by the National Science Foundation around the 1990s [13]. Because it integrates four fields of study or at least two fields of knowledge in a learning process, it is intended that the learning becomes more meaningful and does not create boredom [14]. In line with that, the advantage of STEM compared with separate learning is that it can increase interaction which forms certain experiences for students in constructing their learning experiences [15].

PjBL model combined with STEM approach is an innovative step in learning to provide opportunities for students to plan the learning process collaboratively and produce a specific product which can be used as a learning resource [16]. The combination of PjBL and STEM is also an effort to increase the effectiveness and the meaning in the learning process [17]. Aspects that enhance the positive relationship between the application of PjBL and STEM are aspects of content knowledge and collaborative learning [18]. Thus, STEM taught by using PjBL approach allows students to act or carry out certain activities which allow them to create a learning project.

In detail, the effectiveness of PjBL learning model application in STEM learning is supported by the similarities between the steps. In PjBL implementation as described above, the PjBL implementation has been detailed on how to obtain productive competence from students. The seven steps are (1) determining the learning objectives to be achieved, (2) understanding the required learning concepts, (3) preparing the skills needed, (4) determining the theme of the project to be carried out, (5) making a proposal for steps implementation, (6) working on projects that have been compiled and (7) reporting the results obtained from project implementation[19].

As an approach which is part of constructivism that emphasizes student involvement in various aspects, STEM has become the attention of many education experts in various parts of the world. The United States as the initiator of the course has developed STEM as an innovation in education, especially in the fields that compose STEM. Furthermore, other countries also continue to develop STEM because of the growing assumptions on the potential and expectations of a paradigm shift in education carried out with the STEM approach[20]. Some studies continue to be carried out to assess the effectiveness of the application of STEM in learning, including findings stating that STEM is more effective than conventional learning[21]. However, currently Indonesia needs clearer regulations in the curriculum related to the follow-up of the application of STEM in learning[22]. Furthermore, STEM with the Project-based Learning model has the potential to be applied at different levels of education, for example
at the elementary school level. The application of STEM in elementary schools can improve creative thinking skills[23], students' critical thinking skills, problem-solving skills [24] and can improve their ability to communicate well [25]. In higher education, STEM also has a positive impact on students' cognitive, affective and psychomotor abilities [26].

The syntax in the PjBL, which includes planning, creating, processing, and evaluating has similarities to the steps in implementing STEM learning. As a form of integration of the four fields of study at once or a combination of several fields, STEM learning applied to overcome contextual problems through designing, executing (processing), and evaluating. The effectiveness of using the PjBL learning model in STEM education is generally supported by its characteristics. The learning approach continues to change with particular innovation, including in learning and teaching of mathematics. The positive impact of implementing PjBL in STEM prompted the writing of this article to further examine the effectiveness of the application of PjBL in STEM for junior high school level

2. Methods

This article was conducted by exploring the effectiveness of STEM implementation through the Project-based Learning (PjBL) learning model. The purpose of writing is to examine the factors that influence the effectiveness of the PjBL implementation in STEM learning. The articles analysed were obtained from Google Scholar and indexed nationally and internationally in the last five years. The articles obtained are based on the category of PjBL application in STEM for junior high school level. All of analysed articles have the core subject of mathematics and science research. The seven articles reviewed were Afriana, Permanasari and Fitriani (2016)[27], Octaviyani, Kusumah and Hasanah (2020) [28], Prabaningrum and Waluya (2020) [29], Mustikasari, Yulianti, Pratiwi, Hidayat, Pryadiani and Phang (2020) [30], Indriani (2020) [31], Susanti and Kurniawan (2020) [32] and Mukaromah and Wusqo (2020) [33].

Furthermore, this literature study was carried out by doing the following steps (1) identifying articles related to PjBL and STEM for junior high school level with a focus on learning science and mathematics, (2) analysing the effectiveness of the application of PjBL in STEM, (3) describing the factors which supports the effectiveness of the application of PjBL in STEM, (4) classifying the increased ability in applying STEM into cognitive, affective and psychomotor categories, and (5) summarizing the general effectiveness of the application of PjBL in STEM.

3. Result and Discussion

The effectiveness of the application of PjBL in STEM learning can improve students' abilities, both cognitive, affective and psychomotor. These three abilities are important requirements which students must have, so they can be categorized as students who have adequate mastery of learning. The learning process that takes place also has a significant influence on the students' mastery of learning. The effectiveness of the application of PjBL in STEM learning is described as follows.

Based on the first literature (Afriana, et al, 2016) [27], the application of PjBL in STEM learning can improve scientific literacy skills. This scientific literacy skill is supported by aspects of knowledge, competence and scientific attitudes during practicum. Furthermore, based on students' responses observed in the implementation of learning, it is known that students are very excited in learning. Students also have memorable experiences and show an interest in learning. In the implementation, PjBL and STEM allow students to solve contextual problems in everyday life by following the steps as follows (1) planning a project, (2) developing solutions and (3) communicating the results of their findings. Based on this description, the three aspects of knowledge have been successfully achieved through integrated learning PjBL and STEM even though they are in different categories.

Furthermore, based on the second literature (Octaviyani, et al, 2020)[28], the PjBL learning model in learning with STEM is proved to improve students' mathematical creative thinking skills. This is supported by the constructivism aspect which allows students to construct new ideas or concepts based on their current or previous knowledge. The next aspect that also improves students' creative thinking
skills is the discovery stage which allows students to solve problems, collaborate, and develop steps to design a project. In addition, an aspect that also determines students’ creative thinking abilities is the research stage because students are required to find information, design and develop conceptual understanding based on the projects that have been compiled at this stage.

In the third literature (Prabaningrum dan Waluya, 2020) [29], students’ mathematical communication skills are increased through the PjBL learning model with a STEM approach strategy. Students’ mathematical communication skills have similarities with students’ initiative skills. The combination of PjBL and STEM also allows students to experience solving technology and engineering related problems. This experience also enhances students’ interaction, collaboration, communication and independence. Furthermore, the combination of PjBL and STEM also has a very positive impact on student academic achievement. Due to PjBL and STEM can improve students’ mathematical communication skills, it can be assumed that this combination is highly relevant to the latest skills demands in the 21st century.

Meanwhile, in the fourth literature (Mustikasari, et al, 2020) [30] also found that the implementation of PjBL in STEM has a very significant effect on developing students’ scientific literacy skills. This ability is obtained based on the pre-test and post-test scores which was carried out. The level of scientific literacy is divided into five parts. Based on the research results, most students have mastered level two literacy, namely students are able to explain phenomena that occur in life with a scientific approach because they have adequate knowledge during the learning process with the PjBL and STEM models was implemented. Students also have mastered level five of literacy skills, namely being able to explain well each discovery process they have gone through, connect knowledge well and able to think critically about complex problems. Students can master this level five because they are familiar with conducting investigations and are able to connect facts with the knowledge that they have in which turns out the learning becomes more meaningful. In addition, with a cooperative learning process, students can discuss to find solutions to the problems given.

Based on the fifth literature (Indriani, 2020) [31], the PjBL learning model integrated in STEM learning can improve students’ mathematical thinking skills, in this case related to the topic of flat wakes. In an action research through two cycles, it is known that there is an increasing in student involvement from the first cycle to the second cycle. Students are also increasingly familiar with applied learning. This is also in line with the improvement in mathematical skills which are also getting better in the second cycle.

In the sixth literature (Susanti dan Kurniawan, 2020) [32] compiled a learning trajectory with the PjBL learning model and the STEM approach. Based on this research, it is known that the learning process using the PjBL learning model and the STEM approach can increase student involvement and enthusiasm in the learning process. Furthermore, students are also encouraged to be more creative, active in discussions and also have good abilities to complete projects given to their groups. As the final stage, students also have good communication skills when presenting their findings through the learning trajectories that have been arranged, especially problems related to everyday life.

In the last literature (Mukaromah dan Wusqo, 2020) [33], it is concluded that the implementation of the PjBL learning model and the STEM approach has a very significant effect on students’ creativity and communication skills. Students’ creativity can be seen from the post-test results and also from the posters they put together after learning. Two aspects of creativity that include originality are shown by students through learning activities. Furthermore, the second aspect is elaboration which is shown by the serious efforts of students to solve the problems given by following the detailed learning steps. Because of many positive impacts and the increasing effectiveness of learning when combining the PjBL learning model in STEM learning, this learning process becomes a learning innovation which is very important to be developed at this time.

4. Conclusion
The syntax in the PjBL which includes planning, creating, processing, and evaluating has similarities to the steps in implementing STEM learning. As a form of integration of the four fields of study at once
or a combination of several fields, STEM learning is applied to overcome contextual problems through designing, executing (processing), and evaluating. The effectiveness of using the PjBL learning model in STEM education is generally supported by its characteristics. Based on a review of seven journals that link PjBL and STEM, it is known that PjBL is one of the learning models that promote the effectiveness of learning.

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