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Project-based learning in science education: A comprehensive literature review

Gozde Kurt [1*], Kemal Akoglu [1]

[1] Department of Mathematics and Science Education, Faculty of Education, Bogazici University, Istanbul, TÜRKİYE
***Corresponding Author:** gozde.kurt@boun.edu.tr

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ABSTRACT

Scientific literacy is significant to follow the advancements in the 21st century. Science education enables raising scientifically literate individuals with educational approaches. One of the approaches that is used in science education is project-based learning (PBL). The aim of the study is to present the studies on PBL in terms of science education by using a comprehensive literature review. The studies between the years 2013 and 2023 were reviewed based on the determined keywords and a total of 25 journal articles were included in the study. The findings of the reviewed articles were categorized as PBL's effects on students, PBL's effects on teachers, and PBL's implementations with opportunities, and challenges. Mostly, there was found a statistically significant effect of PBL on students and teachers. The opportunities and challenges of PBL during the implementation were presented in the study. The study also provides some recommendations for stakeholders.

Keywords: project-based learning, science education, comprehensive literature

INTRODUCTION

Scientific and technological improvements are the touchstones of the 21st century. These improvements are changing rapidly at the same time (Korkmaz & Kaptan, 2002). People of 21st century face global issues that require becoming scientifically and technologically literate individuals (Krajcik & Shin, 2014). Therefore, one of the main aims of countries is to grow up scientifically literate citizens who have the abilities of critical thinking, science process, problem-solving, metacognitive thinking, decision-making and etc. (Korkmaz & Kaptan, 2001; Koseoglu et al., 2008). According to Korkmaz and Kaptan (2002), the individual is no longer the passive receiver of knowledge, but the creator and active user of development and change. This means that the individuals should be responsible from their own learning and teaching processes. Thus, it is necessary to make changes in the education system. In other words, change in education system is inevitable to make the students prepared for 21st century (Krajcik & Shin, 2014).

There are some attempts to meet the needs by new educational changes. There has been a transformation from teacher-centered education approaches to student-centered approaches in the century we live in (Baysura et al., 2016). One of the student-centered approaches is constructivism. Project-based learning (PBL) is a type of learning approach reflecting constructivism. Learning in constructivism includes the generation of mental structures actively (Nathan & Sawyer, 2014) through direct interaction with the environment (Sfard & Cobb, 2014). On the other hand, PBL comprises challenging questions, sustained inquiry, reflection and critique on work, and production (Grossman et al., 2019). Bell (2010) sees PBL as a key that makes students successful in front of rapid improvements of the 21st century. Additionally, it is thought that PBL empowers students to become global citizens (Alrajeh, 2021).

PBL was laid by the ideas of John Dewey, an American philosopher, psychologist, and educational reformer (Krajcik & Blumenfeld, 2006; Krajcik & Shin, 2014). Dewey (1916) said that "give the pupils something to do, not something to learn; and the doing is of such a nature as to demand thinking, or the intentional noting of connections; learning naturally results" (p. 191). He claimed that real-life experiences are effective to gain knowledge by proposing the idea of "learning by doing" (Hamidah et al., 2020). Then, William Heard Kilpatrick, a successor of Dewey, introduced the term project to the progressive education movement with "the project method" (Peterson, 2012). Kilpatrick's ideas were given importance by teachers and administrators during the progressive education movement even though it has been revised continuously (Condliffe, 2017). On the other hand, "discovery learning" introduced by Jerome Bruner and "group investigation model" proposed by Herbert Thelen caused the birth of PBL (Korkmaz & Kaptan, 2001).

One of the application points of PBL to cope with the challenges in the global world is science education. A possible reason could be that most of the countries' science standards emphasized the importance of science literacy (e.g., MEB, 2018). Furthermore, next generation science standards emphasized similar aims with PBL's aims (Condliffe, 2017). Therefore, PBL is an appropriate and applicable approach to science education (Korkmaz & Kaptan, 2001). In this respect, this comprehensive literature review aims to present the current literature about PBL in science education. The research is guided by the following research question:

What is the literature between the years of 2013 and 2023 on science education with PBL?

LITERATURE REVIEW

Project-Based Learning

Even though the supporters of PBL do not use a common definition for PBL, they agree on the basic characteristics of PBL (Grossman et al., 2019). According to Grossman et al. (2019), the characteristics of PBL are "giving students opportunities to study a challenging problem, engage in sustained inquiry, find answers to authentic questions, help choose the project, reflect on the process, critique and revise the work, and create a public product" (p. 44). Blumenfeld et al. (1991) see a question or problem that leads to make activities, and artifacts or products that serve the question or problem as fundamental components of the projects. PBL also makes a project the center of learning (Thomas, 2000). In other words, PBL uses a project to teach concepts in a curriculum (Bell, 2010). However, all projects should not be categorized as PBL (Hamidah et al., 2020). This means that the projects in PBL and in the end of the learning are different from each other. Mayer (2016) differentiated the term project and PBL according to the experienced process and the arrived result. For instance, in PBL, inquiry process is experienced with teacher's guidance and results are presented to the public (Mayer, 2016). Thomas (2000, p. 3-4) presented five criteria that assume a project as an example of PBL and these are:

1. "PBL projects are central, not peripheral to the curriculum.
2. PBL projects are focused on questions or problems that 'drive' students to encounter the central concepts and principles of a discipline.
3. Projects involve students in a constructive investigation.
4. Projects are student-driven to a significant degree.
5. Projects are realistic, not school-like."

Furthermore, PBL is grounded on some key ideas from learning sciences, which are "active construction", "situated learning", "social interactions", and "cognitive tools" (Krajcik & Shin, 2014). There are also some main stages that should be followed during PBL, which are planning, implementation, and reporting (Stoller, 2006). In the planning stage of PBL, determination of the project topic, making pre-communicative activities, asking questions, planning the project, and creating timeline are practiced (Hamidah et al., 2020). In the implementation stage, it is aimed to finish the project. Lastly, in the reporting stage of PBL, an assessment and evaluation of the project are conducted (Hamidah et al., 2020).

Project-Based Learning in Science Education

The aim of science education is to raise individuals realizing daily life problems, looking from scientific viewpoints, making observations, thinking analytically, and transferring their knowledge to daily life (Kilinc et al., 2022). However, motivation and understanding of students to the science education has been decreased in the early 1990s (Krajcik & Blumenfeld, 2006; Krajcik & Shin, 2014). To cope with this decline in students' scientific understanding, project-based science that students engage in real problems and follow the processes scientists do was seen as a solution (Krajcik & Blumenfeld, 2006; Krajcik & Shin, 2014). This means that PBL has been used to increase students' motivation and understanding towards science.

METHODOLOGY

Research Design

The comprehensive literature review was used in this study to examine the studies about PBL in science education. The comprehensive literature review was defined as "a methodology, conducted either to stand alone or to inform primary research at multiple stages of the research process, which optimally involves the use of mixed method research techniques" (Onwuegbuzie & Frels, 2016, p. 18). According to these authors (2016), seven steps were proposed, which are "exploring beliefs and topics", "initiating the search", "storing and organizing information", "selecting/deselecting information", "analyzing and synthesizing information", and "presenting the report". In the present study, these steps were followed.

Data Source

The data source of the study consists of 25 journal articles that were conducted between 2013 and 2023. The studies were reached by scanning the databases of Google Scholar, ERIC, ProQuest, Taylor & Francis Online, Wiley Online Library, Dergipark, and TRDizin. The abstract papers of conferences, books, reports, and theses were not included in the comprehensive literature review. The using keywords during the scanning are "project-based learning", "science education", "science teachers", "students", and "implementations". Both Turkish and English journal articles that can be accessible in the databases were included in this study if the keywords compromise with determined keywords.

Data Analysis

The journal articles that were included in this study were collected between December 2022 and January 2023. The journal articles were scanned by using the keywords in different combinations in Turkish and English. These keywords are "project-based learning", "science education", "science teachers", "students", and "implementations". By using Excel, a synthesis matrix was created. The numbers were

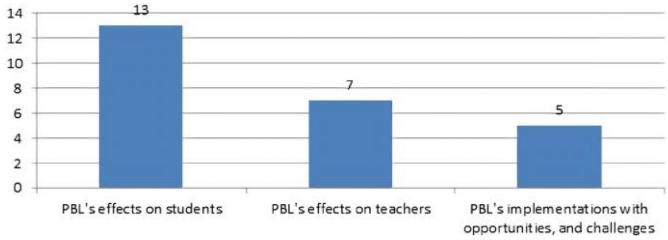

Figure 1. Distribution & number of studies (Source: Authors' own elaboration)

assigned to the journal articles and the aims of studies were written to the synthesis matrix under the main ideas. In other words, based on the aims of the studies, the main ideas, which are "project-based learning effects on students", "project-based learning's effects on teachers", and "project-based learning's implementations with opportunities, and challenges" were formed. With the help of this synthesis matrix, the categorization and synthesis of the studies get easy. Finally, findings of the studies were presented.

FINDINGS

The comprehensive literature review was conducted to examine the recent research about PBL in science education. The main ideas were categorized under the headings of "project-based learning's effects on students", "project-based learning's effects on teachers", and "project-based learning's implementations with opportunities, and challenges". The distribution and number of the reviewed studies under these headings were shown in **Figure 1**. The findings of the studies related to each main idea were synthesized and presented respectively.

Project-Based Learning's Effects on Students

In the literature, PBL's effects on students were examined from various dimensions, which are achievement, critical thinking, metacognition, classroom climate perception, engagement, scientific process skills, and attitude in the context of science education. The reviewed studies and their main ideas were collected in **Table 1**.

Table 1. Articles & their main ideas related to PBL's effects on students

Articles	Main ideas of article
Cakici and Turkmen (2013)	Achievement & attitude
Ergul and Kargin (2014)	Achievement
Karacalli and Korur (2014)	Achievement & attitude
Khaliq et al. (2014)	Achievement
Basche et al. (2016)	Engagement & attitude
Hugerat (2016)	Classroom climate perception
Can et al. (2017)	Scientific process skills
Lukitasari et al. (2020)	Metacognition
Afifin et al. (2021)	Achievement & scientific process skills
Issa and Khataibeh (2021)	Critical thinking
Juuti et al. (2021)	Engagement
Santyasa et al. (2021)	Critical thinking & achievement
Ilma et al. (2022)	Achievement & metacognition

One of the attractive topics is related to how students' achievement increases by PBL. The studies used the terms achievement, learning, success, and learning outcome interchangeably. Much research examined the effect of PBL on students' science achievement and found a similar result that PBL increases science achievement (e.g., Afifin et al., 2021; Cakici & Turkmen, 2013; Ergul & Kargin, 2014; Ilma et al., 2022; Karacalli & Korur, 2014; Khaliq et al., 2014; Santyasa et al., 2021). These studies focused on the success of students at different grade levels in different science-related units. Ergül and Kargin (2014) who conducted a study with 6th grade students in the unit of "electricity in life" found a statistically significant difference between treatment and control groups. Similarly, in the study conducted with 4th grade students, a statistically significant effect of PBL in terms of achievement in the science unit, "electricity in our lives", was concluded (Karacalli & Korur, 2014). Another study that investigated the effectiveness of PBL on 5th grade students' success at the unit of "sound" reached a same result with the previous studies (Cakici & Turkmen, 2013). Furthermore, the study working with 10th grade students for their cognitive biology learning outcomes indicated that students experiencing PBL instruction have higher mean scores than the conventional instruction (Ilma et al., 2022). Afifin et al. (2021) also reached a conclusion that PBL method causes an increase on the learning science outcomes. Different from the previous studies' designs, Khaliq et al. (2014) found significant achievement scores for PBL by conducting one group pretest-posttest design to 8th graders in the unit of "environment".

In addition to the achievement of students, the relationship between PBL and critical thinking, which is seen as one of the important aspects of this century was evaluated by some researchers. "Critical thinking has been called one of the most important attributes for success in the 21st century and has been defined as the process of reasonably deciding what to believe and do" (Kim & Han, 2016, p. 37). Issa and Khataibeh (2021) and Santyasa et al. (2021) emphasized that there are differences in the students' critical thinking skills among groups in favor of PBL strategy in their studies. Unlike the study of Issa and Khataibeh (2021), Santyasa et al. (2021) conducted their study based on the project based e-learning model due to the coronavirus pandemic.

According to Lukitasari et al. (2020), it is not enough to focus on only the learning outcomes of students. Metacognitive abilities should be paid attention to gain students the ability to plan, implement, and evaluate their own learning (Lukitasari et al., 2020). The results of the study showed that students' metacognitive abilities especially for science learning develop by using PBL with an e-portfolio (Lukitasari et al., 2020). Furthermore, Ilma et al. (2022) who investigated the impact of PBL on metacognitive awareness of students found significant differences between conventional learning and PBL in biology learning.

Another research was interested in how PBL affects perceptions of students about science classroom climate (Hugerat, 2016), where 458 9th grade students participated, and an adapted questionnaire was used. The differences between control and treatment groups came up in the factors of "satisfaction, enjoyment, and teacher supportiveness" and "teacher–student relationships" positively for PBL, but no

Table 2. Articles & their main ideas related to PBL's effects on teachers

Articles	Main ideas of article
Ozer and Ozkan (2013)	Scientific process skills
Bilgin et al. (2015)	Self-efficacy
Pitiporntapin and Kuhapensang (2015)	Attitude
Yildiz-Fidan and Mutlu (2018)	Self-efficacy
Mirici and Uzel (2019)	Self-efficacy
Karaer et al. (2020)	Self-efficacy
Dincol-Ozgur and Yilmaz (2020)	Self-efficacy

difference came up in the factors of "student-student relationships" and "competitiveness" (Hugerat, 2016).

Juuti et al. (2021) investigated the engagement of students in science classes while implementing different PBL units. The study, which is a part of an international project between the countries of the US and Finland, found an increase in the engagement of interest, skill, and challenge (Juuti et al., 2021). Basche et al. (2016) also supported the result of the previous study by finding significantly greater levels of engagement in PBL group. Can et al.'s (2017) study differs from the previous studies. They combined project-based science education, active learning, scientific process skills, and the nature of science in the same study. In this study conducted with preschool children, children's scientific process skills scores about the nature of science in the program of PBL and active learning were higher than the children in the program of PBL only (Can et al., 2017). The effect of PBL on the science process skills of students was also examined in another study and concluded that there is a significant effect (Afifin et al., 2021).

In contrast to the previous research that found significant effects on different variables in favor of PBL, some researchers did not find an effect on students' attitudes toward science as a result of PBL approach (e.g., Cakici & Turkmen, 2013; Karaçalli & Korur, 2014). Whereas a positive attitude is one of the main indicators for learning science based on the meta-analysis results of Weinburgh (1995). Karacalli and Korur (2014) indicated the reason for the non-significant result that to change attitudes, there is needed enough time, thus experimental studies cannot increase the attitude in a short time. On the other hand, Basche et al. (2016) indicated that attitudes towards science of the students in the group of PBL are more positive by emphasizing the sub-dimensions of enjoyment, liking, and fun.

To sum up, the current literature related to the effect of PBL in science education on students focused on students' achievement, critical thinking, metacognition, classroom climate perception, engagement, scientific process skills, and attitude. The findings of the studies are parallel with each other and found mostly a statistically significant difference in favor of PBL group.

Project-Based Learning's Effects on Teachers

Teacher education is one of the primary considerations for education. Both in-service and pre-service teacher education should be given attention because their competencies are directly related to students' development. Therefore, in-service teachers and pre-service teachers' self-efficacies, scientific process skills, and attitudes in the context of PBL have significance for science education. The reviewed studies and their main ideas were collected in **Table 2**.

According to Cyprian (2014), teachers' self-efficacy is critical for the success of the implementation of PBL. In the study that science teachers and primary school teachers attended, it was found that the teachers' self-efficacy beliefs on PBL applications are at a good level, but science teachers' mean self-efficacy scores are higher than primary school teachers (Yildiz-Fidan & Mutlu, 2018). Additionally, Mirici and Uzel (2019) examined the changes in teachers' self-efficacy toward PBL after the training and found a significant increase in the post-test scores of the teachers. In these studies, it was also not found significant differences in the general of scales in terms of gender and branch (Mirici & Uzel, 2019; Yildiz-Fidan & Mutlu, 2018).

Furthermore, pre-service teachers' self-efficacies were assessed by implementing PBL approach in some research (e.g., Bilgin et al., 2015; Dincol-Ozgur & Yilmaz, 2020; Karaer et al., 2020). These studies reached a common result that PBL implementation has significant effects on pre-service teachers' self-efficacy. For example, Bilgin et al.'s (2015) study that was conducted with 66 primary school teacher candidates as a treatment and control group obtained higher scores in the treatment group who were instructed with PBL at the context of self-efficacy towards science teaching. The study that used a scale with five subscales found significant effects on subscales of "domination guidance on the project process", "feedback, alternative evaluation", and "group process and high-level learning", but the study did not find significant effects on subscales of "planning, preparation and reflection" and "implementation and evaluation" (Dincol-Ozgur & Yilmaz, 2020). Furthermore, Karaer et al. (2020) indicated in their study that the number of teacher candidates who feel sufficient in laboratory applications increases while the number of teacher candidates who feel non-sufficient in laboratory applications decreases after the applied PBL implementation activities.

The effect of PBL approach on the scientific process skills of pre-service teachers is a topic that draws relatively little attention in the literature. Even though Ozer and Ozkan (2013) did not find a significant difference in the total scientific process scores of pre-service teachers, they found that the test group became more successful in some scientific process skills such as "hypothesizing and examining", "data recording", "measuring" and "test designing".

Positive attitude toward science that teachers have is important to teach science to students (Pitiporntapin & Kuhapensang, 2015). Therefore, Pitiporntapin and Kuhapensang (2015) conducted a study to develop pre-service science teachers' attitudes by using PBL. As a result of this study's findings, providing science project example, making role playing as a scientists, making connection with real life, and providing a safe discussion environment were seen as best implementations for increasing attitude toward science.

In conclusion, the effects of PBL on both in-service teachers and pre-service teachers were investigated in the science education literature. The researchers were specifically interested in the self-efficacies of the teachers after PBL.

Table 3. Articles & their main ideas related to PBL's implementations with opportunities & challenges

Articles	Main ideas of article
Aldabbus (2018)	Opportunities & challenges
Baptist and Subali (2019)	Implementations
Viro et al. (2020)	Opportunities & challenges
Haatainen and Aksela (2021)	Opportunities & challenges
Markula and Aksela (2022)	Opportunities & challenges

Additionally, scientific process skills and attitudes of the teachers were examined in the reviewed articles.

Project-Based Learning's Implementations With Opportunities & Challenges

The teacher is the important component that makes a connection between knowledge and students (Mustan, 2002). In this respect, teachers' implementations of PBL were investigated and opportunities and challenges of PBL were noted in the literature. The reviewed studies and their main ideas were collected in **Table 3**.

How often teachers prefer PBL as a teaching strategy can be a main topic before investigating implementations of the teachers. Baptist and Subali (2019) conducted with 21 biology teachers indicated that 71.4% (15) of the biology teachers used PBL frequently. In the same study, it was also found that most of the teachers see guiding students relatively easy during project designing (59.4%), project implementation (76.9%), and presenting project results (56.4%) (Baptist & Subali, 2019).Teachers presented a lot of views related to the opportunities and challenges of PBL during implementation in some studies (e.g., Aldabbus, 2018; Haatainen & Aksela, 2021; Markula & Aksela, 2022; Viro et al., 2020). For instance, science teachers viewed learning outcomes, collaboration, motivation, student-centeredness, and versatility for education as opportunities for PBL (Haatainen & Aksela, 2021). Collaboration, artefacts, technology, problem-centredness, and scientific practices were shown as opportunities of PBL (Markula & Aksela, 2022).

On the other hand, facilitating PBL (e.g., time management, project facilitation), structural issues (e.g., technical, resources), and interactional issues (e.g., student-related, collaboration) were seen as challenges that teachers experience during PBL (Haatainen & Aksela, 2021). Some studies also emphasized that teachers see a lack of resources as a challenge to PBL (e.g., Aldabbus, 2018; Viro et al., 2020). An inflexible schedule, a lack of teachers' professional skills and motivation are other hindrances that were presented by teachers (Viro et al, 2020). In addition to the previous PBL challenges, Aldabbus (2018) that categorized challenges of PBL as related to teachers, students, curriculum, school, and parents mentioned that some students can dominate their group mates in their works, or some parents can do the projects instead of the students.

To sum up, the studies showed that PBL has some opportunities and challenges during its implementation. Learning outcomes, student-centeredness, and collaboration are examples of opportunities of PBL while resources, time management, and professional skills are examples of challenges of PBL.

DISCUSSION AND CONCLUSIONS

In the present study, 25 journal articles related to PBL, and science education were reviewed, and the findings of these articles are synthesized by emphasizing differences and similarities. The reviewed articles focused on different grade levels and different science education branches such as biology, chemistry, and environment. The journal articles mostly focused on the effects of PBL on students' achievement and found effects on students' achievement (e.g., Ilma et al., 2022; Karacalli & Korur, 2014).

Moreover, the effects of PBL on the self-efficacy of in-service and pre-service teachers were investigated frequently. Similar to findings about students' achievement, the self-efficacies of teachers also were affected positively by PBL approach according to the literature (e.g., Bilgin et al., 2015). Lastly, opportunities and challenges of PBL implementation took place in the selected articles (e.g., Markula & Aksela, 2022; Viro et al., 2020).

As limitations, the number of reviewed journal articles and the number of using database sources can be shown. Their numbers can be increased in future studies to reach more journal articles and to show the findings in a larger spectrum. In the study, the journal articles that were published in the last ten years (2013-2023) were selected as data sources. However, further studies can widen the range of the time or include theses in the review.

The study has some recommendations for the stakeholders who are teachers, parents, schools, and decision-makers in the context of PBL. It can be recommended to teachers that they attend in-service training related to PBL to understand and implement it. When they have competency about how they implement PBL, they can prepare lesson plans or activities based on PBL.

Additionally, teachers can collaborate with colleagues to improve their PBL applications. Secondly, schools have a great responsibility to be able to implement PBL. For instance, schools can allocate a budget for PBL activities or in-service training. Schools can organize seminars about PBL to spread the culture of PBL to the school. Thirdly, decision-makers should create textbook and curriculum content including PBL's objectives, activities, guidance, examples, and assessments. Lastly, parents can be explained the importance of PBL to support their children.

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