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Improving students' cognitive skill: The use of the project-based learning of STEM Model

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Abstract
Science learning emphasises the provision of direct experience to develop students' competencies in exploring and understanding the natural surroundings scientifically. However, the science learning process in SDN 2 Bulusan, Indonesia, remains directed at students' ability to merely remember various information without relating it to their natural surroundings. This impacted students' ability to understand science only to the extent of rote memorisation. There is a need for an approach that improves students' cognitive skills to achieve the desired ability. The objectives of this study are: (1) to explain the procedures of Project-based Learning (PjBL) in teaching Science, Technology, Engineering, and Mathematics (STEM); and (2) to improve scientific attitudes and students' cognitive learning outcomes. This research employed classroom action research (CAR) with two cycles for 13 fifth graders of SDN 2 Bulusan. The data was obtained through interviews, observation, and tests, which were analysed using source triangulation and technique triangulation. The results showed that: (1) PjBL STEM was carried out through reflection, research, discovery, application, and communication; and (2) students' cognitive learning outcomes have increased as shown through minimum completion criteria, which improved from 76.9% to 92.3%. This finding shows that PjBL STEM potentially improves the cognitive learning outcomes of Indonesian fifth-graders.
Keywords: CAR; Cognitive Learning Outcomes; PjBL STEM; Science.

INTRODUCTION

The 21st century requires high-quality human resources with multiple competencies. Lukum in Putriani & Hudaidah (2021) states that the three major competencies needed in the 21st century are the ability to think, act, and live. Education, in this case, is expected to improve the quality of human resources and serve as an investment in a nation's future (Hasibuan & Prastowo, 2019). This is because education comprises materials and teaching materials needed by students, one of which is Science.

Science is compulsory in primary schools because it can provide direct experience, actively involve students, and improve learning outcomes (Musyadad, 2019). This is in line with Dwiyanti et al. (2021), who states that Science embodies the process of obtaining information through logical and systematic investigations, which entails observation and experimentation. Besides its integration of processes, procedures, and products, Science learning in primary schools aims to create a generation with fundamental scientific knowledge, skills, and attitudes. However, this is at odds with the reality that Science learning in Indonesian primary schools practice passive learning due to the teacher-centred method (Fitriani et al., 2019). Teacher-centred learning is prone to students' boredom, which further affects their cognitive skills and their ability to understand the material well (Zamil & Udyaningsih, 2021).

Such a phenomenon is visible in the fifth-graders of SDN 2 Bulusan, Indonesia, where students' activities during Science learning were listening, taking notes, reading, and working on evaluation questions and assignments in the textbook. Apart from that, students' understanding is limited to memorisation with minimum literacy and comprehension ability. Based on our preliminary study, this can be seen from the students' scores below the minimum completion criteria. Only 5 students scored above 70% out of 13 students.

Science learning should emphasise direct methods to develop students' competencies in understanding their natural surroundings, rather than note-taking and memorisation. This notion follows the stage of cognitive development of primary school-age students stated by Piaget, namely, the operational stage. During this stage, the thought process is directed at real events observed by the child. In particular, children can carry out complex problem operations as long as the problem is not abstract (Juwantara, 2019). By targeting students' cognitive development, teachers' ways of teaching should be more effective, efficient, and targeted. Hence teachers need to design innovative learning models that are appropriate to the characteristics of students (Magdalena et al., 2023).

The Project-based Learning (PjBL) learning model is known to help students build knowledge and skills by using a project as the core of learning (Afriana et al., 2016). In PjBL, teachers and students are required to develop questions, so that students can comprehend the material in a meaningful way (Nyihana, 2021). PjBL is essential in improving the quality of student activities by garnering several different learning processes. Astuti et al. (2019) regard that the application of PjBL will increase students' abilities in conceptual learning. In their study, Nurhadiyati et al. (2021) found that PjBL influences the learning outcomes of fourth-graders. Surya et al. (2018) similarly found that the implementation of PjBL improved both learning outcomes and creativity of third-graders in Salatiga.

Besides choosing a learning model, teachers must also be able to select an approach that suits the chosen learning model used (Asih & Halisiana, 2022).

Approaches to Science learning must fit the characteristics of the 21st century to train problem solvers, innovators, and inventors, who can think logically and be independent. In this case, Science, Technology, Engineering, and Mathematics (STEM) is seen to fit that purpose because it teaches practical skills to increase students' interest in learning (Astuti et al., 2019; Kelley & Geoff, 2016). Learning STEM can build a cohesive and active learning system because all four are needed simultaneously to solve problems, in which students can be confident in uniting abstract concepts from each aspect (Khairiyah, 2019). A study by Davidi et al. (2021) shows that learning with a STEM approach has proven effective in improving the thinking skills of elementary school students in Wae Ri'i, Indonesia.

Concurrently, the PjBL STEM learning model is an approach that places students in groups to complete a project that integrates Science, Technology, Engineering, and Mathematics. According to Fazriyah (2019), PjBL learning steps entail 1) *reflection*, which brings the students into problem contexts and ignites investigation; (2) *research,* in which teachers guide students to carry out research; (3) *discovery,* which bridges research and information through the identification of project steps; (4) *application,* which students apply the obtained knowledge to solve problems; and (5) *communication* as the final stage where students present their learning and solutions.

A study by Elisabet et al. (2019) shows that PjBL can increase students' motivation and Science learning outcomes. Another study conducted on the fourth graders of SDN 2 Tahunan, Indonesia, also shows that is effective in increasing students' positive STEM learning experience (Nurul, et.al., 2021). Both studies were quantitative and similarly showed significant improvement in the subjects. As a novelty, this present study attempts to apply Classroom Action Research (CAR) to explore the process of the PjBL STEM model in improving students' learning.

METHODS

This present study employed Classroom Action Research (CAR), which focuses on the learning process that occurs in the classroom and aims to improve the quality of learning (Saputra et al., 2021). This research was carried out at SDN 2 Bulusan, Karangdowo, Klaten with research subjects of fifth graders for the 2022/2023 academic year, totalling 13 people.

The cycle model by Kemmis and McTaggart (Hopkins, 2011) was used, comprising the *planning, implementation, observation,* and *reflection* stages. This cycle does not occur only once, but several times until the expected goal is achieved. The following is the visualisation of the CAR cycle:

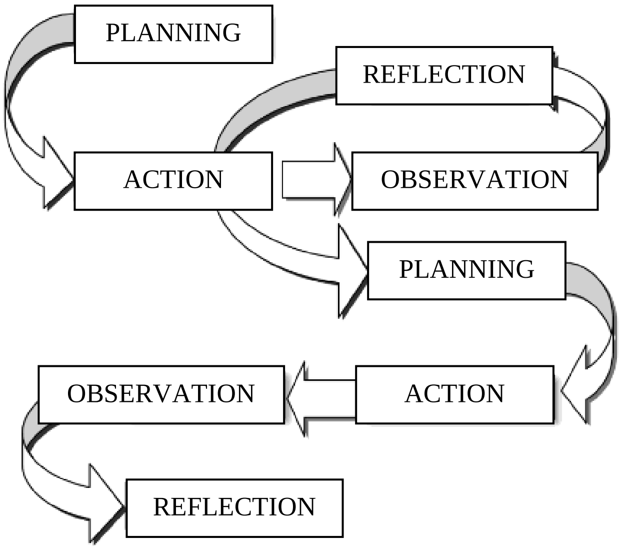

Figure 1. CAR Cycle by Kemmis dan Mc. Taggart

The data collection techniques used in this research included: 1) test and 2) non-test. Tests are used to measure learning outcomes from the PjBL STEM model about the water cycle; while non-test techniques include observation, interviews, and documentation. Observations were carried out to observe the implementation of the PjBL STEM model in improving students' cognitive ability; interviews were used to investigate the shortcomings of the learning process; and documentation included compiling the portfolios, such as students' data and grades. Following the data collection techniques, the research instruments included observation sheets, interview guidelines, and paper tests of multiple-choice questions and short answers.

According to Arikunto et al. (2017), valid data is results from detailed evaluation and corresponds to reality. Therefore, this CAR also employed triangulation in data collection techniques. This follows Sugiyono (2017), who states that validity can be obtained through the combination of various existing data collection techniques and data sources. The triangulation used in this research is source and technique triangulation. Triangulation of sources were the fifth-grade teachers, students, and observers; while the triangulation of technique included observation, interviews, and tests.

In this present study, the obtained data was analysed both quantitatively and qualitatively. Quantitative data was in the value of students' scores, and qualitative data was from the implementation process of PjBL STEM. The qualitative data was analysed through four steps, namely, data reduction, data presentation, data verification and conclusion drawing as developed by Miles and Huberman (Safira et al., 2021).

The effectiveness of this present study is indicated through both process and outcome while carrying out learning in the classroom (Suriani, 2020). Indicators of effective process are measured from teacher activities in implementing PjBL STEM with a target of 85%, and students' scores with a target of 85%. If 85% of the students scored above 70%, it can be said that they have fulfilled the minimum completeness criteria. These criteria followed Agustina (2014) as summarised below:

Table 1. Students' minimum completeness criteria in PjBL STEM

No.	Percentage	Criteria
1.	≤ 49%	Fail
2.	50 – 59%	Poor
3.	60 – 69%	Fair
4.	70 – 79%	Good
5.	≥ 80%	Excellent

Source: Agustina (2014)

RESULTS AND DISCUSSION

The CAR in this present study was carried out in two cycles, each consisting of two meetings. Each meeting comprised four stages *planning, implementation, observation,* and *reflection.* At the *planning* stage, the researchers decided on the learning objectives, drafted lesson plans, tailored working sheets, prepared learning resources and media, and prepared research instruments. The *implementation* stage entailed the classroom application of the PjBL STEM model. During the *observation,* the researcher was assisted by two observers (tutor and colleagues), and the *reflection* stage guided the decision for the further cycle as shown through students' scores.

In particular, five steps comprising *reflection, research, discovery, application* and *communication* were applied during the *implementation* stage as argued earlier in this study. The increase in learning effectiveness is shown through differences in the results of Cycle I and Cycle II as illustrated by the following figure 2.

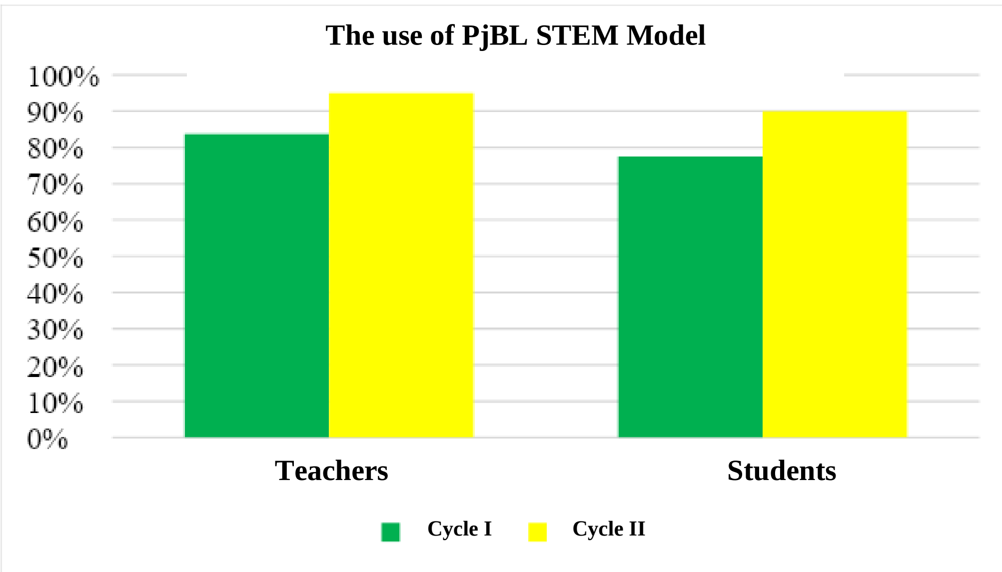

Figure 2. Differences in students' results

Looking at Figure 2 above, an increase (12.5%) in students' scores is readily apparent as also evidenced through observation and interviews with the STEM teacher. In Cycle I, students' scores were categorised as Excellent with an average of 3.3 or 82.5%. However, this number was not enough as it did not achieve the research target. This was partly caused by teachers' domination in the second and third steps, which are *research* and *discovery*, respectively. During the *application*, teachers were not seen to guide students in the task distribution to explore information and problem resolution. Therefore, Cycle II was deemed necessary to improve learning to ultimately achieve the research target of 85% through the implementation of the PjBL STEM model by teachers.

In Cycle II, particular improvements were made to the second and third steps. During the *research*, the teacher was asked to ignite students' critical thinking through questions, in which students were allowed to discuss in groups the form of research that would be carried out. Next, during *discovery*, the teacher provided several references for students to help them search for information. By so doing, the percentage of teachers using the PjBL STEM model increased in Cycle II with an average of 3.8 or 95% in the Excellent category, which reached the research target of 85%. This finding lends strong support to the notion by Handayani & Ayub (2021) who state that the steps in PjBL STEM provide meaningful Science learning. This can help students better acquire knowledge as guided by teacher creativity and scientific literacy (Afriana et al., 2016).

Furthermore, Figure 2 depicts students' responses to the use of the PjBL STEM model. In Cycle I, the average students' responses were 3.1 or 77.5%, categorised as Good, but had not yet reached the research target of 80%. This was because students were used to passively receiving material from the teacher, waiting for orders from the teacher, and getting confused by the distribution of group assignments. This condition was visibly improved in Cycle II where teachers' questions triggered students' motivation and guided their discussion and group work. Cycle II was also improved because teachers gave rewards or points to active students during the learning process. These improvements were also shown through students' responses which were increased to 3.6 or 90% (Excellent), fulfilling the research target of a minimum of 80%. This is in line with research conducted by Fatihah (2023) who found that the implementation of PjBL STEM boosts students' communication and responsive roles within group work. Such collaboration leads to idea production in the form of innovative work, which concurs with the values of PjBL that emphasise the project.

Overall, the findings show that learning using the PjBL STEM model can improve students' cognitive learning outcomes in science learning. Students' achievements in Cycle I and II were also far better than their Pre-cycle achievements. Following is the comparison of students' scores in Pre-cycle, Cycle I and Cycle II:

Table 2. The comparison of students' scores in pre-cycle, cycle i, and cycle ii

No	Category	Pre-cycle		Cycle I		Cycle II	
		No. of students	(%)	No. of students	(%)	No. of students	(%)
1.	Complete	5	38.4	10	76.9	12	92.3
2.	Incomplete	8	61.6	3	23.1	1	7.7

Based on the table, it is readily apparent that students' cognitive learning outcomes improved throughout Pre-cycle learning activities, Cycle I and II by using the PjBL STEM. This is shown through the index of learning completeness (70%), in which eight students scored 61.6% before the treatment. This index much improved in Cycle I to 76.9% with 10 achievers, and only three students scored below the targeted index. Such improvement consistently rose in Cycle II where 12 students achieved 92.3%, leaving only one student scored below the index. This finding is in line with Rahmi et al. (2022) who found that using PjBL STEM potentially improves student learning outcomes.

Figure 3 depicting students' positive changes in cognitive learning outcomes throughout cycles can be seen below:

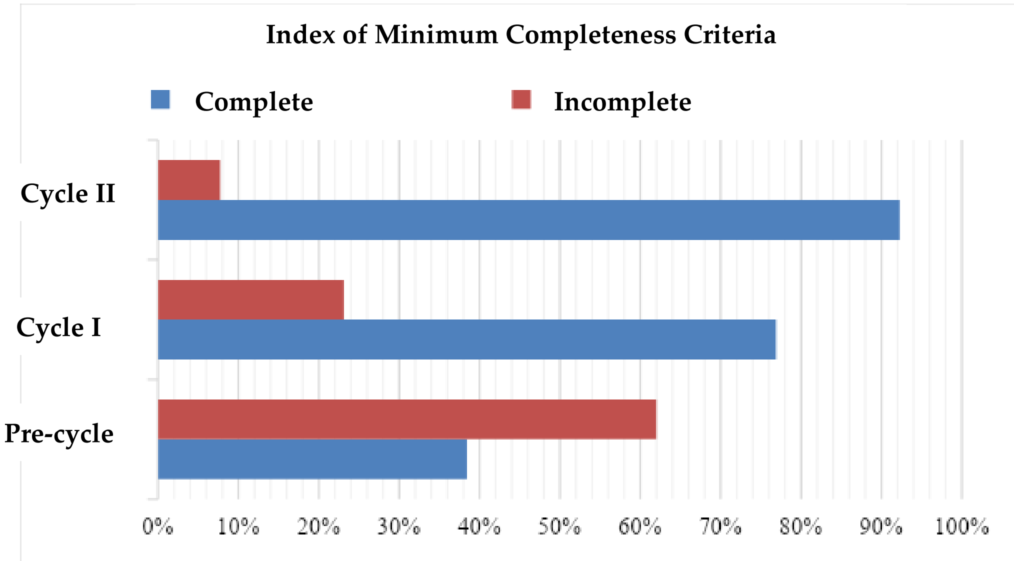

Figure 3. Comparison of students' achievements throughout cycles

Figure 4 illustrating the improvement as seen through classroom observation for teachers and students:

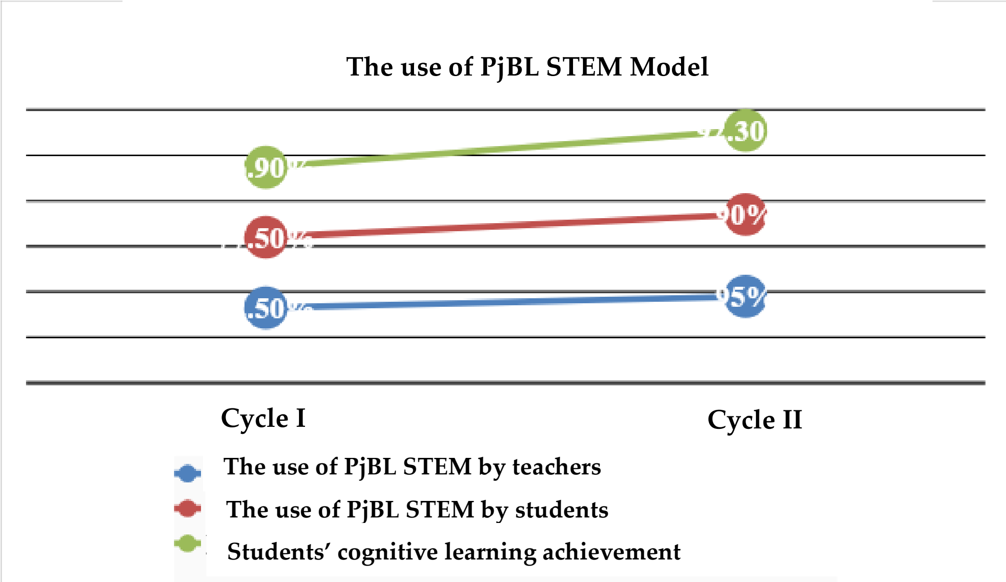

Figure 4. The improvements in teachers and students based on classroom observation

Based on the observation, PjBL STEM for the fifth graders was seen to record numerous advantages. First, it encourages students to learn actively and independently. The researchers observed that students did not receive information passively, but instead were involved in the process of designing, implementing, and evaluating projects related to the learning materials. This increases students' curiosity, creativity, and problem-solving skills.

Second, PjBL STEM was shown to instil a deeper understanding of science concepts. Through projects, students could apply the learnt theory to real situations and see its connection to other STEM fields. This helped them build more complete and meaningful knowledge connections. Third, PjBL STEM supported the development of the 21st-century skills required by students in the future, such as collaboration, communication, critical thinking, and creativity. This was apparent during group work where students learnt to collaborate in teams, communicate clearly, solve problems creatively, and think critically to find the best solutions.

Despite its advantages, PjBL STEM poses several disadvantages to consider. First, it requires careful preparation and planning from the teacher. Developing a project that is interesting, relevant, and appropriate to the level of student development requires extra time and effort. Second, PjBL STEM can be difficult to implement in large classes with limited resources. Limited space, tools, and materials can hinder the maximum implementation of the project.

Third, PjBL STEM calls for adaptations of assessment methods that are different from traditional learning. In the PjBL STEM model, the assessment does not only focus on the results of the project but also the learning process and skills shown by students during project work. This requires teachers to develop more complex and comprehensive assessment instruments.

By observing both advantages and disadvantages, teachers can utilize PjBL STEM effectively to improve the quality of science learning in fifth-grade elementary schools. PjBL STEM can be an interesting and meaningful learning alternative for students, but it needs to be supported by thorough preparation, appropriate implementation, and an effective assessment system.

CONCLUSION

This present study has shown that the PjBL STEM model can improve students' cognitive learning outcomes in science learning for Indonesian fifth-graders. This increase is evidenced by consistent improvement in Cycle I and II with 82.5% and 92.5%, respectively. Most students also scored above the minimum index of completeness criteria and showed learning enthusiasm as observed by the researchers. The findings of this present study offer both practical and theoretical implications as documented through the successful classroom implementation and support of the previous theory about the potential effectiveness of PjBL STEM for primary school students.

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