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STEM LEARNING WITH A SIMPLE HYDRAULIC PUMP PROJECT TO IMPROVE STUDENT COMMUNICATION AND COLLABORATION SKILLS

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ABSTRACT

To succeed in today's era, a person must possess 21st-century skills, which include communication and collaboration. With a Simple Hydraulic Pump project, this study aims to enhance students' communication and collaboration skills through STEM learning at the junior high school level. This quantitative study applied a quasi-experimental approach with a pretest-posttest control group research design. The participants are 38 out of 228 8th-grade students in two junior high schools in Bandung, Indonesia. Statistical analyses using the Wilcoxon Signed Rank tests were done on the data obtained through pretests and posttests. The results indicate a non-significant gain in communication skills of students in the experimental group compared to the control group, with a significance value of 0.67 (sig. >0.05), meaning that there is a non-significant difference between pretest and posttest results. Meanwhile, the collaboration skills of students in the experimental group increased significantly compared to the control group, with a significance value of 0.03 (sig. <0.05), indicating a significant difference between the pretest and posttest results. Using Cohen's d, it is evident that students' collaboration skills experience a medium increase (r=0.22). Furthermore, students' communication and collaboration skills were measured using the Performance Assessment Rubric. The results demonstrate that STEM learning using a simple hydraulic pump project can enhance students' collaboration skills but not their communication skills. This implies that while STEM learning helps students improve their collaboration skills, other methods are needed to assist them in developing their communication skills.

Keywords: stem learning; communication skill; collaboration skill; simple hydraulic pump

INTRODUCTION

The rapid development of science and technological advances in recent years have made STEM learning a highly sought-after research subject. To thrive in the 21st century, people need to acquire a variety of skills, including the ability to gather, analyze, and communicate information, collaborate with others in solving complex problems, and create things with existing technologies (Griffin & Care, 2014). According to Bybee (2013), STEM education should focus on producing solutions for challenges and problems that arise in the real world. Thus, STEM education is introduced to help students solve their problems (Idin, 2018). STEM education is not merely about imparting information; it also applies multidisciplinary knowledge, such as Science and Mathematics, through the integration of engineering and design practices (Hamdu et al., 2020).

In Indonesia, the preparation to implement STEM learning has been underway since the 2013 National Curriculum was put into effect. The low graduate competencies, extremely broad and irrelevant content, and teacher-centered, textbook-oriented learning that uses cognitive-

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focused assessments highlight the importance of implementing STEM education in this country (Suwarma & Kumano, 2019). This is reflected in the Programme for International Student Assessment (PISA) 2018 Results, where Indonesia ranked 71st in the science category with a score of 396, far below the average OECD score of 489. Similarly, Indonesia ranked 72nd (seventh from the bottom) in the mathematics category with a score of 379. Overall, these results place Indonesia in the 74th position or sixth from the bottom (Schleicher, 2018).

The 4Cs, namely critical thinking, creativity, communication, and collaboration, are core competencies that make up the majority of 21st-century skills. Students possessing these learning skills will be better equipped to succeed in the global economy and face the challenges of the 21st century (Soh et al., 2010). Science, Technology, Engineering, and Mathematics (STEM) education is closely linked to the development of 21st-century skills, which also encompass the concepts of active learning, complex problem-solving, and technology creation. In this regard, "21st-century skills demand innovation, persistence, and problem-solving mixed with effective cooperation" (Musa et al., 2013). STEM education helps students acquire these 21st-century skills, enabling them to have the ability to invent technological designs and engage in complex problem-solving (Corlu et al., 2014). According to Akgündüz et al. (2015), there is a growing demand for education systems that provide children with early access to modern information (including information and communication technologies) and assistance in developing critical thinking, entrepreneurial spirit, creativity, sense of responsibility, and problem-solving abilities. STEM education is among the approaches that can be applied at all levels of education to achieve this purpose.

Before applying STEM learning to a particular subject, educators must first understand the materials. In this study, STEM learning was implemented in Physics subject. As a component of the natural sciences discipline, physics focuses on traits commonly associated with phenomena or objects discovered through experimentation, coherent methods, and objectivity that utilize scientific practices and attitudes (Putri et al., 2022). It is also defined as information collected through various means, including experiments, observations, and inferences, to explain a phenomenon accurately (Trianto, 2012). This study applied STEM learning during the "Pressure" discussion, a topic included in the 2013 National Curriculum. Understanding this topic requires visualizing numerous concepts, such as hydrostatic pressure, Archimedes' principle, Pascal's law, and how pressure acts in different media.

In physics, pressure (particularly of fluid), is an essential concept to understand. Fluid pressure is a concept within fluid mechanics (Buyai & Srisawasdi, 2014). Several prior studies have reported that students encounter difficulties in understanding the concept of pressure. For example, Kariotoglou & Psillos (1993) found that students often misunderstand the concept of fluid pressure.

While there is a growing need for the development of STEM learning as a teaching method that enables students to be more involved in the learning processes and thereby develop their learning skills (the 4Cs), studies that focus on the communication and collaboration aspects of the 4Cs remain very limited. In addition, educational institutions still do not realize how important it is for students to develop their collaboration skills, which can ultimately enhance their communication and problem-solving skills (Brownell & Walther-Thomas, 2002; Jackson, 2004; Erozkan, 2013). Meanwhile, it has been proven that individuals with great communication skills generally have high self-confidence, are respectful and open to sharing, and can work together with others (Bilen, 2004), whereas those who lack self-confidence, are fearful, and fail to empathize will have problems communicating (Berscheid, 1994 as cited in Erözkan, 2009)

Several previous studies have examined the implementation of STEM learning in junior high school. In their study, Crippen & Antonenko (2018) investigated collaborative problem-solving in STEM cyberlearning by utilizing cyber technologies. However, their study focused on collaborative problem-solving, not collaborative skills. Lin et al. (2020) also studied junior high school students' attitudes toward technology and technological inquiry ability by using 6E-oriented STEM practical activities, but they did not discuss students' communication and collaboration skills.

Therefore, this study was conducted to fill the existing research gaps. In this study, students were asked to do a project of designing a simple hydraulic pump during the Physics class on the topic of pressure. The research questions of this study are:

a. How can STEM learning through a hydraulic pump project be implemented in class?
b. How does STEM learning through a hydraulic pump project improve students'

communication skills?
c. How does STEM learning through a simple hydraulic pump project improve students' collaboration skills?

METHODS

This study employed a quantitative approach to analyze scores collected on the research instruments to answer the research questions. According to Creswell (2007), quantitative research gathers closed-ended information, such as that found in attitude, behavior, and performance instruments.

A quasi-experimental design was applied to examine whether there is a causal relationship between independent and dependent variables (Rogers & Revesz, 2019). A variable is considered independent when it exerts influence, and dependent when it receives influence (Loewen & Plonsky, 2017).

This study was conducted in two private junior high schools in Bandung, Indonesia. Research participants were selected using purposive sampling, which is a sampling technique. With purposive sampling, researchers do not simply work with available individuals; they use careful judgment to select samples that they consider appropriate based on their prior knowledge (Fraenkel et al., 2011). In this study, participants were chosen among students domiciled in Bandung, Indonesia, who were studying the concept of pressure according to the 2013 National Curriculum and were willing to participate in this study.

A total of 38 participants out of 228 students aged 15-16 years old from both schools were distributed evenly into the experimental class and control class. The performances of students in both groups were evaluated before and after treatment. Data were collected using performance evaluations conducted by 3 expert observers. Table 1 illustrates the quasi-experimental pretest-posttest research design.

Table 1. Quasi-Experimental Pretest-Posttest Design

Group	Pretest (O1)	Treatment	Posttest (O2)
Experimental	O1	X	O2
Control	O1		O2

Notes:
- O1 are pre-tests that examine student's communication and collaborative skills
- X is the treatment (the STEM project-based learning)
- O2 are post-tests that examine student's communication and collaborative skills

The research instrument used to measure students' communication skills was based on The Competent Speaker, a rubric assessment tool adopted by Dunbar et al. (2006). It consists of 6 indicators, i.e.: 1) choosing the right topic and limiting it according to the purpose and the audience; 2) communicating the purpose of the speech in a manner appropriate to the audience and the occasion; 3) utilizing suitable supporting materials to fulfill the purpose of the oral discourse; 4) applying a correct organizational pattern depending on the topic, audience, and occasion; 5) employing proper language for the target audience; and 6) using vocal variation in rate, pitch, and intensity. Meanwhile, the research instrument used to measure students' collaboration skills was based on the rubric assessment adapted by Ofstedal & Dahlberg (2009) from the Collaboration Self-Assessment Tool (CSAT), with 11 indicators tested namely contribution, kaizen (continuous improvement), time management, representation, preparedness, problem-solving, group processes, interaction with others, role flexibility, and reflection.

Prior to the treatment, students took a pretest, and the observers used the rubric for performance assessment to evaluate students' communication and collaboration skills. During the treatment, students were given a worksheet containing the challenges and criteria of the project. Then, a posttest was taken by the students and the results were evaluated using the same rubric for performance assessment applied in the pretest. The performances of students in the experimental group were compared to the control group. The mean (average) results were calculated and analyzed using the SPSS program. First, a normality test was conducted and a statistical test was carried out on the results. Then, the Wilcoxon Signed-Rank tests were performed to discover whether or not the increase in students' communication and collaboration skills was significant. After that, Cohen's d (effect size) test was conducted to measure the effect of the gain and determine the effectiveness of the treatment given. Table 2 describes the categories for Cohen's d effect sizes.

In this study, the participants explored the concept of pressure through a simple hydraulic pump construction project using a STEM approach. For this project, they were divided random-

Table 2. Categories of Cohen's d Effect Sizes

Cohen's d effect size	Category
$1.00 \leq n$	very large
$0.80 \leq n \leq 1.00$	large
$0.20 \leq n \leq 0.80$	medium
$0.00 \leq n \leq 0.20$	small

ly into 5 groups of 4-5 members. Group placement was done by the students themselves using a wheel containing group numbers. Each group was instructed to create a simple hydraulic pump design, where members jointly came up with the ideas, created the design, and evaluated the design they had prepared. Then, they were asked to investigate how the mechanism of Pascal's law is applied in real life. Lastly, they were also required to present the results of their project in front of the class and explain the ideas behind their design as well as the results of their evaluation (whether it needed further improvements or not). A lesson plan related to these processes has been previously prepared, as seen in Table 3 below.

Table 3. STEM Learning Lesson Plan

Meeting	Activity	Implementation	Percentage
Meeting 1	Introduction	Students are introduced to the primary concepts of pressure, such as the principles governing pressure, hydrostatic pressure, Archimedes' principle, and Pascal's law.	100%
Meeting 2	Starting the project (defining problems, exploring ideas, and designing the hydraulic pump)	Students are given a worksheet detailing the tasks to do upon completing their project, where they have to record their progress, document their project, illustrate their design, and describe the results. Students can use existing designs as references but are encouraged to modify them.	100%
Meeting 3	Finalizing the simple hydraulic pump design (testing and evaluating)	Students are given the task of finalizing the design they have created in the previous meeting using the tools and materials they have planned to use. Then, students are requested to demonstrate their product in front of the class and explain their design ideas. Finally, students are asked to evaluate their products to see if there are any improvements they can make.	100%

In the pretest, students did the group work without implementing STEM learning. During this session, students were divided into small groups and asked to perform an experiment on optics. The lesson plan presented in Table 3 was implemented after the pretest. In the first meeting, students were introduced to the main scientific concepts of pressure, such as the principles governing pressure, hydrostatic pressure, Archimedes' principles, and Pascal's law, to give them ideas of the principles applied when they started their hydraulic pump project. Students were also introduced to the real-life uses of these concepts, including in hydraulic pumps, which would be the pretext of their upcoming project. After the introduction session, respondents were informed of the project they had to do in the next meeting to ensure that they got the ideas of what they would learn or do next.

In the second meeting, STEM learning was implemented in the experimental group. In this meeting, students were asked to do a project involving the construction of a simple hydraulic pump. This meeting was divided into 3 steps: a) defining problems, b) exploring ideas, and c) designing the hydraulic pump. STEM learning continued to be applied in the third meeting which comprised the last two steps of the project: 1) testing and evaluation; and 2) communication of results.

RESULTS AND DISCUSSION

Based on the observations made during the pretest, most participants were unwilling to work with their group members. Most of the work was delegated to one or two students in each group, while the rest played a passive role. Most students were also reluctant to present the results of their work. Yet again, they assigned this responsibility to one or two students in the group, who also demonstrated a lack of understanding of their work. In interpreting and describing their own work, these students asked the teacher for help. In addition, their voices were weak and could barely be heard and understood by the audience, indicating that they had not developed the appropriate presentation, communication, and collaboration skills. These findings confirm the statement of Johnson & Johnson (1975) that the skills needed to collaborate have not necessarily been developed even among college students and adults in general because collaboration skills have not been considered important and thus were not taught comprehensively in previous generations.

The first step of the second meeting is defining problems, which is the beginning of the engineering design process (Baydere & Bodur, 2022). In this study, students were presented with the problem of how they could create a tool that would allow them to demonstrate the concept of Pascal's law. The following is an excerpt from the worksheet that provides details of the problem:

"You and your group members are one of the teams taking part in a competition to create an educational demonstration tool. In this competition, you and your group members are tasked with designing and producing a working prototype of a device, which, in this case, can be used to demonstrate the concept of pressure. You are also given several criteria, some of which are that the product is made of affordable materials and can be operated easily."

At this stage, students should imagine competing to make an instrument to demonstrate Pascal's law following the criteria and limitations outlined in the worksheet. The engineering design process helps students create the tool while encouraging them to produce various solutions. This step is vital in making the best decisions (Gencer et al., 2019). Collaboration involves the "mutual engagement of participants in a coordinated effort to solve the problem together". Collaboration is "not about agreement; it is about creation" (Denise, p. 3).

The next step is the exploration of ideas. At this stage, students collected information and inspirational references from existing models that could assist them in designing their pump. To do so, they learned more about the mechanism and concept of hydraulic pumps and were encouraged to ask for their teacher's opinions during the process. According to Han & Shim (2019), students need to sort out the information they gather based on the problem given. Similarly, Baydere & Bodur (2022) stated that students should discuss relevant information and reflect on their past experiences when facing a problem.

These steps are essential to help students improve their communication and collaboration skills. Students shared the ideas they had explored with their group members and discussed them together. This aids students in developing the ability to use supporting materials, including organizational patterns appropriate to the topic, audience, and occasion, to conduct oral discourse more effectively (Dannels, 2001; Dannels, 2002). In this regard, students should be able to select suitable topics and narrow them down according to the given purpose as well as the needs and interests of the audience (Allen, 2002). Thus, their skills in delegating work, collaborating, and interacting with others can be honed simultaneously, as suggested by Ofstedal & Dahlberg (2009).

The final step of the first meeting is designing the pump. In this stage, students planned the design of the hydraulic pump along with illustrations, descriptions, and a brief explanation of how it works and the concept involved. The purpose of this stage is for respondents to exchange and discuss ideas that can help them solve the presented issues, challenges, restrictions, and criteria. Figure 1 displays an illustration created by one of the groups participating in this project.

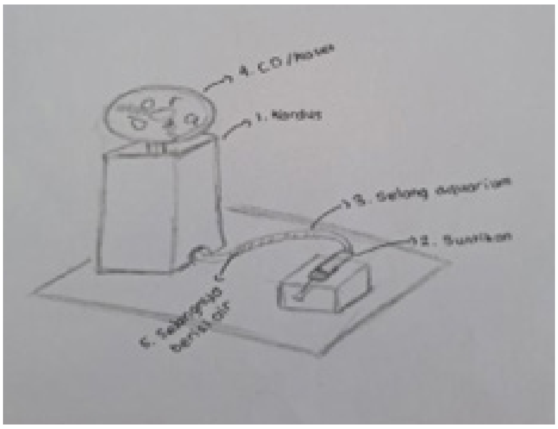

Figure 1. Initial Design of Simple Hydraulic Pump by Group 4

The following is an excerpt attached to the picture.

"Hydraulic pump is a tool that can be used to lift very heavy objects. Examples of objects that can be lifted using this tool are machines and vehicles. It is called a hydraulic pump because this tool uses a special fluid to be able to carry out the process of lifting heavy objects."

The illustration above is a design produced by Group 4 which decided to make a pump from simple ingredients, such as ink-jet syringes, a plastic aquarium hose, cardboard, and a used compact disc (CD). The pump has two ink-jet syringes connected by a plastic tube attached to a cardboard structure (with one end attached to a CD and the other filled with water). The water used must be in the right amount since this system must be waterproof for the hydraulic pump to function properly and water can be pushed to the other syringe.

When designing the pump, students brainstormed about the given problem with their group members and worked collaboratively in choosing and evaluating all possible solutions. By having discussions, students were eventually able to produce more feasible and practical solutions (Han & Shim, 2019).

At this stage, students can also sharpen their communication and collaboration skills, particularly in choosing the most effective modes of communication. Students learn to form and organize messages more effectively, determine the level of receptivity of others to their messages, give appropriate information, and support the messages with facts (Dunbar et al., 2006). Additionally, this stage helps students develop teamwork, time management, self-improvement, problem-solving, and presentation skills, as mentioned by Ofstedal and Dahlberg (2009).

This was the first stage of the last meeting, where student tested the functionality of their project by demonstrating how it worked in front of the class. In this stage, students are asked to test whether or not their pump is functioning as intended. If it fails, students are asked to describe what problems might prevent their pump from working properly and come up with suggestions for improvements they can implement to fix the issues, at least temporarily. This is part of the engineering design process as mentioned by the Accreditation Board for Engineering and Technology (ABET, 2005), which includes the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.

From the tests conducted, the products created by most groups worked perfectly without any problems. However, the pump produced by Group 3 experienced a liquid leak in the connecting tube. Based on the evaluation they made, the members of Group 3 concluded that the loose connection between the tube and the syringe caused the leak. One solution they came up with to fix the problem was to apply waterproof glue to the loose connection and seal it tightly.

The evaluation stage is crucial to improve students' collaboration skills. At this stage, students learn to develop their ability to reflect (Ofstedal & Dahlberg, 2009) and evaluate the strengths and weaknesses of their product, allowing them to work towards possible solutions to improve their results.

At this final stage, students presented the results of their project, where they explained the name of their design, the mechanism, and the results they obtained from their project. Students were encouraged to ask questions to the presenting group and the group members were required to answer those questions.

At this stage, students' communication skills have begun to develop, especially in terms of using language appropriate to the target audience (Erwin, 1991; Dougan, 1996), utilizing vocal variation in rate, pitch, and intensity (Erwin & Sebrell, 2003), and articulating their ideas clearly with correct grammar and pronunciation, thus demonstrating nonverbal behavior that supports the verbal message (Morreale et al., 1993; Morreale et al., 1998).

The results produced in this stage showed that the students have become more communicative. Most of the group members contributed to the presentation and participated actively in the discussions. Most students also enthusiastically asked questions to the presenting group, such as "Why does one end of the pump rise if you push the other end?", or, "Can the liquid be replaced with air?"

It is observed that students' collaboration and communication skills improved significantly by the end of the last meeting. Students are more willing to work together as a group, take initiative, and become more inclined to help each other or share information with their group members.

A rubric for performance assessment called The Competent Speaker adapted by Dunbar et al. (2006) was used to measure students' communication skills. It consists of a performance scale used in the teacher assessment sheet containing 6 indicators rated on a scale of 1-4. The assessment of students' communication skills was conducted before and after treatment using STEM learning. After completing the pretest and posttest, the obtained data were analyzed statistically to find out if there was any improvement in students' communication skills before and after the treatment. The data were compared between the pretest and posttest results as well as between the control and experimental groups. Table 4 presents the results of the descriptive analyses of students' communication skills.

Table 4. Results of Descriptive Analysis of Students' Communication Skills

Group	Test	N	sd	Min.	Max.	x
Experimental	Pre-Test	57	3.9	70.8	87.5	80.3
	Post-Test	57	5.8	79.2	95.8	85.0
	Gain	57	4.3	-4.2	12.5	4.7
Control	Pre-Test	57	4.5	50.0	66.7	57.1
	Post-Test	57	5.7	54.2	70.8	61.8
	Gain	57	4.3	-4.2	12.5	4.6

Meanwhile, the measurement of students' collaboration skills utilized another rubric for performance assessment based on CSAT adopted by Ofstedal & Dahlberg (2009). It comprises a performance scale used in the teacher assessment sheet containing 11 indicators rated on a scale of 1-4. The assessment of students' collaboration skills was also conducted before and after treatment using STEM learning. After completing the pretest and posttest, the obtained data were analyzed statistically to find out if there was any improvement in students' collaboration skills before and after the treatment. The data were compared between the pretest and posttest results as well as between the control and experimental groups. Table 5 describes the results of the data analysis of students' communication skills.

Table 5. Results of Descriptive Analysis of Students' Collaboration Skills

Group	Test	N	sd	Min.	Max.	x
Experimental	Pre-Test	57	6.7	54.5	88.6	78.1
	Post-Test	57	7.3	65.9	100.0	83.8
	Gain	57	4.8	-2.3	18.2	5.6
Control	Pre-Test	57	4.5	47.7	65.9	57.3
	Post-Test	57	5.7	54.5	75.0	61.7
	Gain	57	4.1	0.0	15.9	4.4

Before analyzing the data, it must be determined whether the hypothesis testing uses a parametric test or a non-parametric test. In this study, normality was measured first as the prerequisite for hypothesis testing. The Shapiro-Wilk Test was employed for the normality test on the pretest and posttest results of students in the experimental group. The results of the normality tests for students' communication and collaboration skills can be seen in Tables 6 and 7.

Table 6. Results of Descriptive Analysis of Students' Communication Skills

Group	Test	Statistics	p	Skewness	Kurtosis
Experimental	Pre-Test	0.869	0.000	0.053	0.303
	Post-Test	0.831	0.000	0.701	-0.834
Control	Pre-Test	0.905	0.000	0.090	-0.868
	Post-Test	0.895	0.000	0.167	-1.180

$p > .05$ = normal distribution

Table 7. Results of the Normality Tests for Students' Collaboration Skills

Group	Test	Statistics	p	Skewness	Kurtosis
Experimental	Pre-Test	0.859	0.000	-1.539	3.917
	Post-Test	0.937	0.000	0.535	0.388
Control	Pre-Test	0.956	0.039	0.005	-0.745
	Post-Test	0.904	0.000	0.823	-0.085

$p > .05$ = normal distribution

For students' communication and collaboration skills, the normality scores of the pretest and posttest results in both experimental and control groups were $\partial < 0.05$. This indicates that the data is not normally distributed. Based on the results of the normality tests, a non-parametric test using the Wilcoxon Signed-Rank Test was used to test the hypothesis because the results of the prerequisite test did not meet the requirements of a parametric test.

The Wilcoxon signed-rank tests were done to determine whether there was a significant difference between the scores of the same students who participated in the pretest and posttest in terms of their communication and collaboration skills. This assessment was used to compare the score gains between the experimental and control groups to observe whether the implementation of STEM learning results in a more significant increase in students' communication and collaboration skills compared to the control group. Based on the test results presented in Table 8, there is no significant difference ($p>0.05$) between the score gains of students' communication skills before and after the implementation of STEM learning compared to the control group. Meanwhile, the test results shown in Table 9 indicate a significant difference ($p<0.05$) between the score gains of students' collaboration skills before and after the implementation of STEM learning compared to the control group. Furthermore, the effect size for students' collaboration skills ($r=0.22$) can be considered a medium improvement.

Numerous factors may contribute to students' communication skills not improving noticeably, one of which is that in the implementation of STEM learning, there is a lack of activities that encourage students to exercise their communication skills. It is also suspected that students may have different understandings of the concepts of effective communication. Meanwhile, the increase in students' collaboration skills may be attributed to the fact that STEM learning allows students to collaborate and interact with their peers. The National Science Board (NSB, 2010) stated that in STEM education, students should have the opportunity to experience peer collaboration and interactions. STEM learning can also create a collaborative learning environment that promotes hands-on and mind-building activities (Socratous & Ioannou, 2018; Nugent et al., 2010; Mitnik et al., 2009). All of these factors contribute to improving students' collaboration skills.

The results of this study confirm the finding of a previous study by Latip et al. (2020) which stated that STEM learning positively impacts students' collaborative skills in terms of social regulation. This is because teamwork and collaboration activities during project completion make students understand their roles and the roles of their friends, a condition called transactive memory (Ziaeefard et al., 2017). This also supports the finding of another study which explained that socially shared regulation has a positive effect on the collaboration process among students. Similarly, Anderson (2002) also discovered that students' collaborative problem-solving performance is significantly better in a STEM learning environment. When adaptive domain-specific support (STEM learning environment) is provided, collaborative problem-solving performance can be enhanced (Karakostas & Demetriadis, 2011; Kopp et al., 2014).

However, the findings of this study also contradict the results of several prior studies. Ridlo (2020) found that the application of STEM learning in elementary schools can significantly improve students' communication skills. The finding of their study is in line with the result of another study by Mukaromah & Wusqo (2020) which stated that the STEM approach has an extremely significant effect on students' creativity and communication skills. Prabaningrum & Waluya (2020) also reported in their study that students' communication skills improved through the project-based learning (PjBL) model with the STEM approach strategy. This is further supported by Diana & Sukma (2021) who stated that PjBL and STEM education can improve students' communication skills.

Table 8. Results of the Wilcoxon Signed Rank Tests for Students' Communication Skills Gain

Rank	N	Sum of Ranks	Mean Ranks	Z	p	Cohen's d
Negative Rank	6	4.600	0.760		0.673	
Positive Rank	8	5,900	0.380	-0.422	(no sig diff)	
Ties	43					

p < .05 = significant difference

Table 9. Results of the Wilcoxon Signed Rank Tests for Students' Collaboration Skills Gain

Rank	N	Sum of Ranks	Mean Ranks	Z	p	Cohen's d
Negative Rank	6	4.150	0.692		0.030	
Positive Rank	13	14.850	2.900	-2.172		0.255 (Medium)
Ties	38				(sig. diff)	

p < .05 = significant difference

CONCLUSION

All stages in STEM learning used in this study are considered successfully carried out. The results of the statistical analysis of students' pretest and posttest results as well as the Wilcoxon Signed-Rank Tests on students' communication skills indicate no significant difference between the scores of students' communication skills before and after the implementation of STEM learning.

Conversely, based on the results of the statistical analysis of students' pretest and posttest results as well as the Wilcoxon Signed-Rank Tests on students' collaboration skills, there is a significant difference between the scores of students' collaboration skills before and after the implementation of STEM learning. Furthermore, Cohen's d effect size on students' collaboration skills shows that it can be considered to have experienced moderate improvement.

The findings of this study imply that, compared to conventional learning, the implementation of STEM learning successfully improved students' ability to collaborate, but not their ability to communicate. This may be due to students' different understanding of the concepts of effective communication and the lack of activities that encourage students to exercise their communication skills. In conclusion, while STEM learning can be used to increase students' collaboration skills, other methods may need to be employed to improve students' communication skills. The findings of this study can help researchers and educators determine how effective the implementation of STEM learning is in improving students' collaboration and communication skills, which are parts of the 4Cs needed in the 21st century.

REFERENCES

Accreditation Board for Engineering and Technology (ABET). (2005). *ABET accreditation yearbook*.

Akgündüz, D., Aydeniz, M., Çakmakçı, G., Çavas, B., Çorlu, M. S., Öner, T., & Özdemir, S. (2015). *STEM egitimi Türkiye raporu*. Scala Basım.

Allen, T. (2002). Charting a communication pathway: Using assessment to guide curriculum development in a re-vitalized general education plan. *Communication education, 51*(1), 26-39.

Andersen, H. (2002). Experiences from a pedagogical shift in engineering education. *Global J. of Engng. Educ, 6*(2), 139-144.

Baydere, F. K., & Bodur, A. M. (2022). 9th Grade Students' Learning of Designing an Incubator through Instruction Based on Engineering Design Tasks. *Journal of Science Learning, 5*(3), 500-508.

Bilen, M. (2009). *Saglıklı insan iliskileri*. Anı Yayıncılık.

Brownell, M. T., & Walther-Thomas, C. (2002). Dr. Marilyn Friend. *Intervention in School and Clinic, 37*(4), 223-228.

Buyai, J., & Srisawasdi, N. (2014). An evaluation of macro-micro representation-based computer simulation for physics learning in liquid pressure: Results on students' perceptions and attitude. In *Proceedings of the 22nd International Conference on Computers in Education* (pp. 330-339).

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. National Science Teachers Association.

Corlu, M. S., Capraro, R. M., & Capraro, M. M. (2014). Introducing STEM education: Implications for educating our teachers for the age of innovation. *Education & Science/Egitim ve Bilim, 39*(171).

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications.

Crippen, K. J., & Antonenko, P. D. (2018). Designing for collaborative problem solving in STEM cyberlearning. *Cognition, metacognition, and culture in STEM education: Learning, teaching and assessment*, 89-116.

Dannels, D. P. (2001). Time to speak up: A theoretical framework of situated pedagogy and practice for communication across the curriculum. *Communication Education, 50*, 144–158.

Dannels, D. P. (2002). Communication across the curriculum and in the disciplines: Speaking in engineering. *Communication Education, 51,* 254–268.

Denise, L. (1999). Collaboration vs. C-Three (cooperation, coordination and communication). Innovating, 7, 1–6.

Diana, N., & Sukma, Y. (2021, May). The effectiveness of implementing project-based learning (PjBL) model in STEM education: A literature review. *Journal of Physics: Conference Series , 1882*(1).

Dougan, A. M. (1996). Student assessment by portfolio: One institution's journey. *The History Teacher, 29*, 171–178.

Dunbar, N. E., Brooks, C. F., & Kubicka-Miller, T. (2006). Oral communication skills in higher education: Using a performance-based evaluation rubric to assess communication skills. *Innovative Higher Education, 31*, 115-128.

Erözkan, A. (2009). Lise ögrencilerinde kisilerarası iliski tarzlarının yordayıcıları. *Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 21*, 543-551.

Erozkan, A. (2013). The effect of communication skills and interpersonal problem solving skills on social self-efficacy. *Educational Sciences: Theory and Practice, 13*(2), 739-745.

Erwin, T. D. (1991). *Assessing student learning and development.*

Erwin, T. D., & Sebrell, K. W. (2003). Assessment of critical thinking: ETS's tasks in critical thinking. *The Journal of General Education, 52*, 50–70.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2011). *How to Design and Evaluate Research in Education (Eigth Edit).*

Gencer, A. S., Dogan, H., Bilen, K., & Can, B. (2019). *Integrated STEM education models.*

Griffin, P., & Care, E. (2014). *Assessment and teaching of 21st century skills: Methods and approach*.

Hamdu, G., Muiz, D. A., & Silma, G. (2020). 4c's skills performance assessment in stem learning in elementary school. *Universal Journal of Educational Research, 8*(12), 7668-7675.

Han, H. J., & Shim, K. C. (2019). Development of an engineering design process-based teaching and learning model for scientifically gifted students at the Science Education Institute for the Gifted in South Korea. *Asia-Pacific Science Education, 5*(1), 1-18.

Idin, S. (2018). An overview of STEM education and industry 4.0. *Research highlights in STEM Education,* 194.

Jackson, S. (2004). *Leading the modern college or university: Engaging higher education in social change.* Women of Color Administrators and Faculty

American Council on Education, Brown University

Johnson, D. W., & Johnson, R. T. (1975). *Learning together and alone: Cooperative, competitive and individualistic learning*. Englewood Cliffs, NJ: Prentice Hall.

Karakostas, A., & Demetriadis, S. (2011). Enhancing collaborative learning through dynamic forms of support: The impact of an adaptive domain-specifc support strategy. *Journal of Computer Assisted learning, 27*, 243–258.

Kariotoglou, P. V., & Psillos, D. (1993). Pupils' pressure models and their implications for instruction. *Research in Science & Technological Education, 11*(1), 95-108.

Kopp, B., Hasenbein, M., & Mandl, H. (2014). Case-based learning in virtual groups—collaborative problem solving activities and learning outcomes in a virtual professional training course. *Interactive Learning Environments, 22*(3), 351–372.

Latip, A., Andriani, Y., Purnamasari, S., & Abdurrahman, D. (2020, October). Integration of educational robotic in STEM learning to promote students' collaborative skill. In *Journal of Physics: Conference Series* (Vol. 1663, No. 1, p. 012052). IOP Publishing.

Lin, K. Y., Hsiao, H. S., Williams, P. J., & Chen, Y. H. (2020). Effects of 6E-oriented STEM practical activities in cultivating middle school students' attitudes toward technology and technological inquiry ability. *Research in Science & Technological Education, 38*(1), 1-18.

Loewen, S., & Plonsky, L. (2017). *An A–Z of applied linguistics research methods*. Bloomsbury Publishing.

Mitnik, R., Recabarren, M., Nussbaum, M., & Soto, A. (2009). Collaborative robotic instruction: A graph teaching experience. *Computers & Education, 53*(2), 330-342.

Morreale, S. P., Moore, M. R., Taylor, K. P., Surges-Tatum, D., & Hulbert-Johnson, R. (1993). *The competent speaker speech evaluation form*. Annandale, VA: Speech Communication Association.

Morreale, S. P., Rubin, R. B., & Jones, E. A. (1998). *Competencies for college students: Basic skills for persuading, informing, and relating*

Mukaromah, S. H., & Wusqo, I. U. (2020, March). The influence of PjBL model with stem approach on global warming topic to students' creative thinking and communication skills. In *Journal of Physics: Conference Series* (Vol. 1521, No. 4, p. 042052). IOP Publishing.

Musa, F., Mufti, N., Latiff, R. A., & Amin, M. M. (2012). Project-based learning (PjBL): Inculcating soft skills in 21st century workplace. *Procedia-Social and Behavioral Sciences, 59*, 565-573.

National Science Board (2010) *Preparing the next generation of STEM innovators: identifying and developing our nation's human capital*.

Nugent, G., Barker, B., Grandgenett, N., & Adamchuk, V. I. (2010). Impact of robotics and geospatial technology interventions on youth STEM learning and attitudes. *Journal of Research on Technology in Education, 42*(4), 391-408.

Ofstedal, K., & Dahlberg, K. (2009). Collaboration in student teaching: Introducing the collaboration self-assessment tool. *Journal of Early Childhood Teacher Education, 30*(1), 37-48.

Ridlo, S. (2020). Critical thinking skills reviewed from communication skills of the primary school students in STEM-based project-based learning model. *Journal of Primary Education, 9*(3), 311-320.

Prabaningrum, D., & Waluya, S. B. (2020, June). The Improvement of mathematical communication skill through project based learning with STEM strategy. In *International Conference on Science and Education and Technology (ISET 2019)* (pp. 646-651). Atlantis Press.

Putri, I. Y., Desnita, D., Putra, A., & Murtiani, M. (2022). Meta analysis of the effect of student worksheet use on student learning outcomes. *Pillar of physics education, 14*(4), 251-258.

Rogers, J., & Revesz, A. (2019). Experimental and quasi-experimental designs. In *The Routledge handbook of research methods in applied linguistics* (pp. 133-143). Routledge.

Roschelle, J. (1995). *The construction of shared knowledge in collaborative problem solving*. Computer Supported Collaborative Learning/Springer-Verlag.

Schleicher, A. (2018). Insights and interpretations. *Pisa 2018*, 10.

Socratous, C., & Ioannou, A. (2018). *A study of collaborative knowledge construction in STEM via educational robotics*. International Society of the Learning Sciences, Inc.[ISLS].

Soh, T. M. T., Arsad, N. M., & Osman, K. (2010). The relationship of 21st century skills on students' attitude and perception towards physics. *Procedia-Social and Behavioral Sciences, 7*, 546-554.

Suwarma, I. R., & Kumano, Y. (2019, November). Implementation of STEM education in Indonesia: Teachers' perception of STEM integration into curriculum. In *Journal of Physics: Conference Series* (Vol. 1280, No. 5, p. 052052). IOP Publishing.

Trianto. (2012). *Model Pembelajaran Terpadu*.

Ziaeefard, S., Miller, M. H., Rastgaar, M., & Mahmoudian, N. (2017). Co-robotics hands-on activities: A gateway to engineering design and STEM learning. *Robotics and Autonomous Systems, 97*, 40-50.