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Effectiveness of PBL STEM to Improve Problem Solving Skills

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ABSTRACT

STEM PBL emphasizes integrating several aspects of science, such as technology and design, where in this aspect, there will be an innovative engineering process based on science and mathematics that aims to carry out innovation and problem-solving. The research design is a non-equivalent pre-test and post-test control group design—the tests conducted by pre-test and post-test of the learning process in experiment and control groups. The experiment and the control group were conducted in two classes with different treatments; the experiment class used the PBL STEM model, while the control class was treated using a conventional model. The results present that the average percentage of the student's problem-solving in the experiments class increased after implementing the STEM PBL model. More students were experts in all aspects of problem-solving in the post-test compared with the pre-test.

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1. INTRODUCTION

Currently humans live in a very fast-changing environment. It is hoped that humans can adapt to these changes. For students they must prepare some skills that they can use in the future to promote them to keep up careers in these disciplines. The skill that needs to be improved is the field of science. One of the skills required is problem-solving skills. Problem solving can be described as identifying a problem and solutions choice among many other alternatives (Ferrando et al., 2023). In addition, solutions should be under the guidance of some valid arguments. Problem solving skills have an extensive structure with wide borders. Problem solving skills have been used in many disciplines, such as management, public administration, engineering, and science. The theory explaining problem solving has been the aspect of scientist's process in the different methods to work on different perspectives (Kong & Matore, 2022; Stehle & Peters-Burton, 2019).

In daily life, people have problems that must be solved. When solving the problem, people differentiate the options according to option and process is not simple for some people (Chan & Nagatomo, 2022; Ling et al., 2019). Problem solving is also needed to solve a problem. To support this ability, students must have critical thinking skills. Problem solving is not only the process of students applying concepts, doing experiments but also making a product or work that solves the problem (Park & Choi, 2015; Topsakal et al., 2022). To solve the problems in facing the challenges of teachers can prepare the students to develop the skills using PBL STEM. PBL STEM is a learning model that integrates some scientific disciplines including Science, Technology, Engineering, and Mathematics. STEM education is one of the solutions to solve the problems in a systematic way to help the students from some disciplines of science, technology, engineering, math, and creativity (Stone-Mac Donald et al. 2015) (Amalina & Vidákovich, 2022; English, 2023). One good way of STEM activities is to encourage problem solving skills based on real situations (Mylonas et al., 2021). The other hand, to increase problem solving skills it is mean learning process enforced by students. The ability to solve the real problem that is close to the students requires a skill and ability possessed (Karan & Brown, 2022; Tan et al., 2023).

Based on previous research on STEM provided a lot aspect such as cognitive, procedural, and attitudinal benefits for students (English, 2023; Jamali et al., 2022; Takeuchi et al., 2020). STEM encourages students to develop problem-solving with science, technology, engineering, and math knowledge and skills (Gough, 2021).

STEM education also shows various potentials in developing the literacy needed by students in a 21st-century professional society (Means et al., 2017). STEM education (science, technology, engineering, and mathematics) is important in preparing young people to respond to the challenges they face (Nguyen et al., 2020).

STEM education emphasizes integrating several aspects of science such as technology and design where in this aspect there will be an innovative engineering process based on science and mathematics that aims to carry out innovation and problem-solving (Alkair et al., 2023; Purwaningsih et al., 2020; Topsakal et al., 2022). Thus, STEM education does not only come from knowledge of science and technology but also involves a special approach to aspects of education. The approach to the educational aspect is carried out by applying the knowledge gained in real life (Coufal,2022; Parno et al., 2019). The STEM approach emphasizes not only an integrated approach but also aspects of social problems (Li et al., 2020; McLure et al., 2022). To connect scientific knowledge, problem solving skills, and real problem situations, we must renegotiate the disciplinary boundaries and make a relation with the other aspect. In higher education, especially in the context of learning, developing the problem-solving learning skills must make a variety of teaching strategies for preparing the students to solve all kinds of problems and provide opportunities in theoretical concepts (Alsmadi, 2020; Belbase et al., 2021).

The purpose of this study is analyzing the effect of STEM activities on the creativity of junior school students. This study was carried out on students who attend a state-owned school institution in Indonesia. With this purpose, we seek to find answers to these questions: How does a STEM PBL education model affect junior problem-solving skills?

2. RESEARCH METHOD

The research design is a pre-test and post-test control group design non-equivalent, with tests conducted by pretest and posttest of learning process in control and experimental groups, as shown in Table 1.

Table 1. Pre-Test and Post-Test Control Group Design Non-Equivalent.

	Pre-Test	Treatment	Post-Test
Experiment	O1	X1	O3
Control	O2	X2	O4

Notes:
O1: Pre-test on experiment group
O2: Pre-test on control group
X1: PBL STEM model learning
X2: Conventional model learning
O3: Post-test on experiment group
O4: Post-test on experiment group

This research was conducted at the Universitas Negeri Malang, in Biology Departement. Participants in this research activitiy are students who took the Technobiology course in the five semester Agust to Desember. The students who participated comprised 64 students dicided into two class groups namely exprimental group and the control group. The experiment group consisted of 32 students and the control group consisted of 32 students. This research was conducted in the bioremediation topic course which was carried out for four meetings. This research was conducted with following steps, as shown in Table 2.

Table 2. The steps of learning process

Step	Experiment Group	Control Group
Frist	Identify pollution problems arising from factory waste. In these steps, the students must identify from the videos and articles provided in the learning module.	Reading learning modules related to bioremediation concept material.
Second	Identify multiple solutions. After analyzing the articles and videos, students must locate various solutions that will choose to solve existing problems. In this stage, students must make a solution by considering three stakeholder aspects; government, society, and self	Working on learning modules related to bioremediation, which consists of the topics of bioremediation, biocontrol, biofertilization, and their utilization
Third	Determine the solution. In this stage, students must determine the best solution based on the results of discussions in one group	Discuss in large groups related to the results of the material
Fourth	Design and evaluation. At this stage, students must make a prototype of the product to solve the problems in the first stage; evaluate related to the product being made	Reinforcement by the teacher related to bioremediation material.

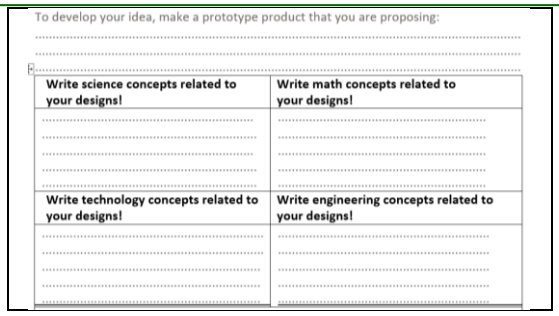

Figure 1. STEM concepts integrated by students

Table 3. The project that made by students

	The Project
Group 1	Nanofilter (Nf) with bacterial biofilm and rice husk biosilica
Group 2	Cow waste biogas
Group 3	Cow's Milk Waste Disposal Site
Group 4	Bioremediation Zone
Group 5	Self-Purification
Group 6	Recirculation by submerged biofilter method
Group 7	Waste treatment with bacterial biofilter
Group 8	Sand filter Biofilter

The problem-solving skills instrument is developed from the formulation by Greenstein (2012) in which the problem-solving skills consist of Identifying the problem, identifying multiple solutions, and solutions, as shown in Table 4. The criteria for scoring problem solving skills are shown in Table 4. Hypothesis testing was conducted on student learning outcomes from test scores on problem solving skills. The hypothesis tested was using ANCOVA with the criteria, if the probability level of significance $\alpha = 5\%$ so H0 is rejected. The data was collected from pre-test and post-tests data. Before collecting the post-test data, in the process of learning we are using the PBL STEM model in the experimental group and conventional model learning in the control group. The data was analyzed using descriptive statistics for determining the validation and implementation of STEM PBL and the effectiveness of the PBL STEM model to improve students' problem-solving skills. Hypothesis test was performed using one-way ANCOVA. After that, the BNT test was carried out to find out the significant differences between the two research classes that were carried out.

Table 4. Problem Solving Skills Rubric

Aspect	**4**	**3**	**2**	**1**
Identification the Problem	Described the problem in relation to the situation an included several supporting details.	Described the basic of the problem with some details and supporting information.	Explained some of the problem but had trouble understanding all the parts of the problem.	Difficulty recognizing and defining the parts of the problem.
Plan	Came up with at least four feasible and clearly described solutions.	Offered two or three plausible solutions.	Describd one or two possible solutions.	One solution, butnot the clear solutions.
Implementation for the plan	Analyzed all the solutions and picked one that shows my understanding of the problem ant that outcomes	Evaluated the solutions and picked one that seems feasible	Give a simple explanation for the one choicce that made sense	Was not able to explain a solution.

Table 4. Problem Solving Skills Rubric

Reflect on the Results	Explain in detail related to the product was made and explain the advantages and	Explain the advantages and disadvantages of the product was made.	Give a simple explanation for the reflection on the results.	Was not able to reflect on the results

	disadvantages for all stakeholders.

Information:
4: Expert
3: Competent
2: Apprentice
1: Novice

3. RESULT AND DISCUSSION

STEM PBL is significant with conventional model because it provides an opportunity for the students to directly orientate the problem based on a real situation to the students through observation, thereby developing their identification of the problem solving. Students' problem solving is powered through observation and analysis of the real problem from the article in the student's worksheet ((Perignat & Katz-Buonincontro, 2019)) like in the Figure 1 students identify problems after that students identify if students become policy makers. Students' problem solving can encourage the students to get in width about the following material. (Rahmawatiningrum et al., 2019; Shu et al., 2020) which reported that students who have a high problem-solving skill were able to provide analysis.

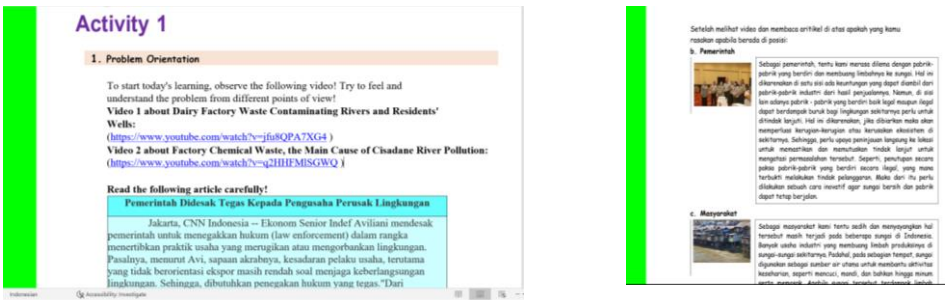

Figure 1. Identification the Problem

For example, for students to analyze and identify the impact of the factory waste that pollutes the environment, they must identify what is the problem that will come for the future if it continues, and make some plan and decision to solve the problem. In this case, students are directed to identify multiple solutions and take action to solve the problems. Through identifying multiple solutions, the students are directed to need more information so they can know about the material in more depth and breadth (Blackburn, 2017; Skowronek et al., 2022).After students identify the Problem students must plan to solve the problem. Plans made by students must consist of four aspects of PBL STEM like in the figure 2.

Likewise, (Park & Choi, 2015; Rahmawatiningrum et al., 2019) explains that problem solving is the originator of critical thinking and creativity. After knowing deeper material and being able to connect with existing problems the student's plan. In this stage that students plan, the student can develop their other skills such as creativity and critical thinking (Huber & Kuncel, 2016). In this aspect students can get anything positive such as a science process skill. STEM activities, students identified a problem, planned, drew a sketch to create a prototype, and made some evaluations. This stage will help them to learn for the content of science successfully (Amalina & Vidákovich, 2022a; English, 2023). STEM activities as a process so the students can using their science process skills (Carlisle & Weaver, 2018; Wongta et al., 2021).

Figure 2. Plan a design

There have similarities with the engineering design process used in PBL STEM activities and science process skills. The engineering design process, in the first step is defined and the determination of the variables that related to the problem is like the science process skills. In the design process, students are searching for solutions and create the prototype of the appropriate solution, they use science process skills such as experiment, using appropriate tools, recording data, modeling, interpreting the data and drawing a conclusion for the final project such as making a prototype and evaluation Figure 3.

Figure 3. Plan and evaluation from the design of bioremidiasi project

The results of the variance of the effectiveness of STEM PBL models on students' problem solving are shown in the Table 5 and Table 6.

Table 5. The average percentage of students' problem-solving pretest

Pre-Test				
Problem Solving Aspect	Level Performance			
	Expert	Competent	Apprentice	Novice
Identification the Problem	12,5	62,5	25	
Plan	12,5	75	12,5	
Implementation for the plan	37,5	37,5	25	
Reflect on the Results	25	75		

Table 6. The average percentage of students' problem-solving post-test

Post-Test				
Problem Solving Aspect	Level Performance			
	Expert	Competent	Apprentice	Novice
Identification the Problem	37,5	62,5		
Plan	50	50		
Implementation for the plan		100		
Evaluations	37,5	62,5		

The results show that the average percentage of the student's problem solving in the experiments class increased after implementating the STEM PBL model. More students were experts in all aspects of problem-solving in the post-test compared with the pre-test. The ANACOVA of problem-solving results is provided in the Table 7 showing that there are differences in learning model variance [Fcount = 9.508 with p-value = 0.00. P-value < ($\alpha = 0.05$)], indicating that the learning model affects students' problem solving.

Table 7. ANCOVA results of Problem Solving.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	319.236[a]	2	159.618	5.726	.005
Intercept	993.987	1	993.987	35.656	.000
PreTest	12.986	1	12.986	.466	.498
Kelas	265.058	1	265.058	9.508	.003
Error	1700.514	61	27.877		
Total	410980.000	64			
Corrected Total	2019.750	63			

a. R Squared = ,158 (Adjusted R Squared = ,130)

The problem solving BNT test results are presented in Table 8 showing that the learning models are significantly different from conventional models.

Table 8. BNT result showing that the learning models

	pretest		postest		Difference	Average	Notation
Class	mean	SD	mean	SD			
Experiment	71	2,8125	82	5,3125	10	82	b
Control	69	3,90625	77	4,1406	8	77	a

In PBL STEM activities, the opportunity to conduct research as a problem solver and to design like an engineer increased their motivation. The STEM activities increased their interest in STEM fields even if they must solve a problem. PBL STEM can improve students' abilities because for the first time it had a positive effect for the students to understand the integration every aspect of STEM field and realize the activities such as the scientist design process(Ferrando et al., 2023; Karahan et al., 2015b). They made their designs, presented the ideas and bring out their motivation to be successful in the application of STEM activities. Similarly, there were many research suggest that STEM learning increased students' problem-solving skills (Karahan et al., 2015a; Roberts et al., 2022). The result of integrating PBL STEM their attitudes, their improved science and design process, motivation, willingness to engage in class discussions and scientific content increased (Amalina & Vidákovich, 2022b; Delahunty et al., 2020; Priemer et al., 2020).The students' engagement in the scientific design process increased their problem-solving skills (Amalina & Vidákovich, 2022a; Contente & Galvão, 2022).

The difference between the experiment group and control group in terms of problem-solving skills are the fact that they structured their knowledge within the filed of PBL STEM process as a result of their research and the chance to transform this knowledge by using technology for design the prototype. Students can use their talents in PBL STEM learning process, material and technological tools during the activities affect their problem-solving skills and their visual literacy. During PBL STEM learning process, students have the chance to use their skills such as doing research, finding the problem, using technology, working in groups for designing and making presentations.

4. CONCLUSION

STEM PBL education model affects junior problem-solving skills. In PBL STEM activities, the chance to research as a scientist and students can make a design like an engineer can increased their interests in earning process. PBL STEM can improve students' abilities because had a positive effect to understand the integration of STEM and to realize the activities such as the engineering design process. They made their own designs, presented their ideas and motivated to be successful in the application of STEM activities. For future research, it is hoped that there will be more research related to STEM at the tertiary level to develop other 21st-century abilities.

5. REFERENCES

Alkair, S., Ali, R., Abouhashem, A., Aledamat, R., Bhadra, J., Ahmad, Z., Sellami, A., & Al-Thani, N. J. (2023). A STEM model for engaging students in environmental sustainability programs through a problem-solving approach. *Applied Environmental Education & Communication*, 1–14. https://doi.org/10.1080/1533015x.2023.2179556

Alsmadi, M. A. (2020). Requirements for application of the STEM approach as perceived by science, math and computer teachers and their attitudes towards it. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(9). https://doi.org/10.29333/EJMSTE/8391

Amalina, I. K., & Vidákovich, T. (2022a). An integrated STEM-based mathematical problem-solving test: Developing and reporting psychometric evidence. *Journal on Mathematics Education*, *13*(4). https://doi.org/10.22342/jme.v13i4.pp587-604

Amalina, I. K., & Vidákovich, T. (2022b). Assessment in STEM Problem-Solving: A Systematic Review. *International Journal of Assessment and Evaluation*, *29*(2). https://doi.org/10.18848/2327-7920/CGP/v29i02/63-80

Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2021). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*. https://doi.org/10.1080/0020739X.2021.1922943

Blackburn, G. (2017). A university's strategic adoption process of an PBL-aligned eLearning environment: an exploratory case study. *Educational Technology Research and Development*, *65*(1). https://doi.org/10.1007/s11423-016-9472-3

Carlisle, D. L., & Weaver, G. C. (2018). STEM education centers: catalyzing the improvement of undergraduate STEM education. *International Journal of STEM Education*, *5*(1). https://doi.org/10.1186/s40594-018-0143-2

Chan, M. N., & Nagatomo, D. (2022). Study of STEM for sustainability in design education: Framework for student learning and outcomes with design for a disaster project. *Sustainability (Switzerland)*, *14*(1). https://doi.org/10.3390/su14010312

Contente, J., & Galvão, C. (2022). STEM Education and Problem-Solving in Space Science: A Case Study with CanSat. *Education Sciences*, *12*(4). https://doi.org/10.3390/educsci12040251

Coufal, P. (2022a). Project-Based STEM Learning Using Educational Robotics as the Development of Student Problem-Solving Competence. *Mathematics*, *10*(23). https://doi.org/10.3390/math10234618

Coufal, P. (2022b). Project-Based STEM Learning Using Educational Robotics as the Development of Student Problem-Solving Competence. *Mathematics*, *10*(23). https://doi.org/10.3390/math10234618

Delahunty, T., Seery, N., & Lynch, R. (2020). Exploring problem conceptualization and performance in STEM problem solving contexts. *Instructional Science*, *48*(4). https://doi.org/10.1007/s11251-020-09515-4

English, L. D. (2023). Ways of thinking in STEM-based problem solving. *ZDM - Mathematics Education*. https://doi.org/10.1007/s11858-023-01474-7

Ferrando, I., Albarracín, L., & Diago, P. D. (2023). Where Is It Best to Sit in Class? Description of an Experience Based on STEM Problem Solving in a School Context. *Education Sciences*, *13*(4). https://doi.org/10.3390/educsci13040417

Gough, A. (2021). All STEM-ed up: Gaps and silences around ecological education in Australia. *Sustainability (Switzerland)*, *13*(7). https://doi.org/10.3390/su13073801

Huber, C. R., & Kuncel, N. R. (2016). Does College Teach Critical Thinking? A Meta-Analysis. *Review of Educational Research*, *86*(2), 431–468. https://doi.org/10.3102/0034654315605917

Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2022). The role of STEM Education in improving the quality of education: a bibliometric study. *International Journal of Technology and Design Education*. https://doi.org/10.1007/s10798-022-09762-1

Karahan, E., Canbazoglu Bilici, S., & Unal, A. (2015a). Fen, teknoloji, mühendislik ve matematik (FeTeMM) eğitimine medya tasarım süreçlerinin entegrasyonu [Integration of media design processes into science, technology, engineering and mathematics (STEM) education]. *Eurasian Journal of Educational Research*, *60*.

Karahan, E., Canbazoglu Bilici, S., & Unal, A. (2015b). Integration of media design processes in science, technology, engineering, and mathematics (Stem) education. *Eurasian Journal of Educational Research*, *60*. https://doi.org/10.14689/ejer.2015.60.15

Karan, E., & Brown, L. (2022). Enhancing Student's Problem-solving Skills through Project-based Learning. *Journal of Problem Based Learning in Higher Education*, *10*(1), 74–87. https://doi.org/10.54337/ojs.jpblhe.v10i1.6887

Kong, S. F., & Matore, M. E. E. M. (2022). Can a science, technology, engineering, and mathematics (Stem) approach enhance students' mathematics performance? *Sustainability (Switzerland)*, *14*(1). https://doi.org/10.3390/su14010379

Li, Y., Wang, K., Xiao, Y., Froyd, J. E., & Nite, S. B. (2020). Research and trends in STEM education: a systematic analysis of publicly funded projects. In *International Journal of STEM Education* (Vol. 7, Issue 1). https://doi.org/10.1186/s40594-020-00213-8

Ling, L. S., Pang, V., & Lajium, D. (2019). THE PLANNING OF INTEGRATED STEM EDUCATION BASED ON STANDARDS AND CONTEXTUAL ISSUES OF SUSTAINABLE DEVELOPMENT GOALS (SDG). *Journal of Nusantara Studies (JONUS)*, *4*(1). https://doi.org/10.24200/jonus.vol4iss1pp300-315

McLure, F. I., Tang, K. S., & Williams, P. J. (2022). What do integrated STEM projects look like in middle school and high school classrooms? A systematic literature review of empirical studies of iSTEM projects. In *International Journal of STEM Education* (Vol. 9, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s40594-022-00390-8

Means, B., Peters, V., Wang, H., Young, V., Wei, X., Lynch, S., & Allen, C. (2017). *Expanding STEM opportunities through inclusive STEM-focused high schools*. *March 2016*, 1–35. https://doi.org/10.1002/sce.21281

Mylonas, G., Paganelli, F., Cuffaro, G., Nesi, I., & Karantzis, D. (2021). Using gamification and IoT-based educational tools towards energy savings - some experiences from two schools in Italy and Greece. *Journal of Ambient Intelligence and Humanized Computing*. https://doi.org/10.1007/s12652-020-02838-7

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM education in secondary schools: Teachers' perspective towards sustainable development. *Sustainability (Switzerland)*, *12*(21), 1–16. https://doi.org/10.3390/su12218865

Park, S., & Choi, S. (2015). *Effects of Problem-based Learning on the Learning Atti-tudes, Critical Thinking Disposition and Problem-Solving Skills of Nursing Students: Infant Care*. https://doi.org/10.14257/astl.2015.103.41

Parno, Yuliati, L., & Ni'Mah, B. Q. A. (2019). The influence of PBL-STEM on students' problem-solving skills in the topic of optical instruments. *Journal of Physics: Conference Series*, *1171*(1). https://doi.org/10.1088/1742-6596/1171/1/012013

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*. https://doi.org/10.1016/j.tsc.2018.10.002

Priemer, B., Eilerts, K., Filler, A., Pinkwart, N., Rösken-Winter, B., Tiemann, R., & Zu Belzen, A. U. (2020). A framework to foster problem-solving in STEM and computing education. *Research in Science and Technological Education*, *38*(1). https://doi.org/10.1080/02635143.2019.1600490

Purwaningsih, E., Sari, S. P., Sari, A. M., & Suryadi, A. (2020). The effect of stem-pjbl and discovery learning on improving students' problem-solving skills of the impulse and momentum topic. *Jurnal Pendidikan IPA Indonesia*, *9*(4), 465–476. https://doi.org/10.15294/jpii.v9i4.26432

Rahmawatiningrum, A., Kusmayadi, T. A., & Fitriana, L. (2019). Student's ability in solving higher order thinking skills (HOTS) mathematics problem based on learning achievement. *Journal of Physics: Conference Series*, *1318*(1). https://doi.org/10.1088/1742-6596/1318/1/012090

Roberts, T., Maiorca, C., Jackson, C., & Mohr-Schroeder, M. (2022). Integrated STEM as Problem-Solving Practices. *Investigations in Mathematics Learning*, *14*(1). https://doi.org/10.1080/19477503.2021.2024721

Shu, Y., Ho, S. J., & Huang, T. C. (2020). The Development of a Sustainability-Oriented Creativity, Innovation, and Entrepreneurship Education Framework: A Perspective Study. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.01878

Skowronek, M., Gilberti, R. M., Petro, M., Sancomb, C., Maddern, S., & Jankovic, J. (2022). Inclusive STEAM education in diverse disciplines of sustainable energy and AI. *Energy and AI*, *7*. https://doi.org/10.1016/j.egyai.2021.100124

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, *6*(1). https://doi.org/10.1186/s40594-019-0192-1

Takeuchi, M. A., Sengupta, P., Shanahan, M. C., Adams, J. D., & Hachem, M. (2020). Transdisciplinarity in STEM education: a critical review. In *Studies in Science Education* (Vol. 56, Issue 2). https://doi.org/10.1080/03057267.2020.1755802

Tan, A. L., Ong, Y. S., Ng, Y. S., & Tan, J. H. J. (2023). STEM Problem Solving: Inquiry, Concepts, and Reasoning. *Science and Education*, *32*(2), 381–397. https://doi.org/10.1007/s11191-021-00310-2

Topsakal, I., Yalçin, S. A., & Çakir, Z. (2022). The Effect of Problem-based STEM Education on the Students' Critical Thinking Tendencies and Their Perceptions for Problem Solving Skills. *Science Education International*, *33*(2), 136–145. https://doi.org/10.33828/sei.v33.i2.1

Wongta, J., Grosseau, C., Yachulawetkunakorn, C., Watthana, C., & Wongwatkit, C. (2021). Effects of a collaborative STEM-based orientation approach on senior high-school students' creativity and operacy. *International Journal of Mobile Learning and Organisation*, *15*(1). https://doi.org/10.1504/IJMLO.2021.111599