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Transdisciplinary STEM education based on Among's philosophy implementation against engineering problem-solving and motivation: The case monochromatic light, simple laser project

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Abstract

This study applied transdisciplinary STEM based on Among's philosophy. This innovative program provides experiences using project-based learning (PBL) with limited laboratory facilities for technology learning. Involved 53 pre-service physics teachers in a physics laboratory course with the affordable cost laser creation project. STEM program using correlation study with a pre-experiment one-group pre-/post-test design approach. The instruments used include an engineering problem-solving cognition test and a motivational questionnaire regarding attitude, interest, and learning response, as well as reinforced by project report documentation. The results showed a significant improvement in engineering problem-solving cognition and motivation in STEM, with a moderately strong correlation between them. Among's method and lab hands-on engagement contribute to a better engineering understanding and positively impact motivation. Utilizing equipment and materials at affordable costs can effectively integrate technology and engineering into practices.

Keywords: pre-service teachers, STEM, among, PBL, laser, engineering

INTRODUCTION

STEM, physics, and technology education studies have been a significant focus in Indonesia. Strong interest in the application and development of STEM subjects has been seen in previous studies (Ha et al., 2020). Referring to the studies of Farwati et al. (2021) and Nugraha et al. (2023), most of these studies have been focused on populated islands such as Java and Sumatra. Remote regions such as Irian, Kalimantan, and Sulawesi have yet to be explored in integrating interdisciplinary STEM education as the distribution of STEM research is less than 1% (Farwati et al., 2021). This shows the challenge and potential of developing skills and motivation to learn STEM for teachers in the region.

Although most teachers in Indonesia have the same understanding of STEM education, the application of the STEM approach in science learning is still limited. This causes students' understanding of STEM learning to be weak (Permanasari et al., 2021). STEM integration is generally more focused on one discipline, especially science, which is taught separately and not in an integrated manner with other disciplines, such as Technology and Engineering (Nugraha et al., 2023).

STEM teachers face the obstacle of limited knowledge and understanding, which results in ineffective learning (Bell et al., 2018). Many teachers have limited experience teaching STEM, although they are familiar with the concepts (Sulaeman et al., 2022). Research shows that engagement in technology and engineering learning experiences can enhance students' creativity, higher-order thinking skills, and motivation (Cunningham & Lachapelle, 2012; Moundridou & Kalinoglou, 2008). Therefore, engineering design-based STEM education is important to improve teachers' perception of STEM (Ayaz & Sarikaya, 2019).

Teachers' lack of knowledge about STEM content and integration is also a barrier to future STEM learning (Kim et al., 2019; Radloff & Guzey, 2016). In the opinion of Vasquez et al. (2013) proposed four levels of STEM

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Contribution to the literature

- This study describes implementing and evaluating a transdisciplinary STEM program based on Among's philosophy approach, which originates from local cultural wisdom.
- The study used mixed methods to examine pre-service teachers' achievement in engineering problem-solving and motivation in transdisciplinary STEM courses.
- This study aims to enrich the learning experience by integrating science and technology in education areas with limited facilities.

integration, one of them is transdisciplinary learning. Transdisciplinary learning is the highest level of STEM integration as it applies knowledge and skills from different fields to solve real-world problems (English, 2016; Mayes & Rittschof, 2021). Transdisciplinary STEM education seeks to prepare learners for the challenges of the 21st century by equipping them with various skills and knowledge that can be applied in different fields (Barclay & Bentley, 2021). Transdisciplinary STEM integrates elements from different disciplines to create innovative solutions by combining knowledge and skills from different fields (MacLeod & Nersessian, 2018; Rostoka & Cherevychnyi, 2018). As is the case with teaching about technology by incorporating the social field, namely the collaborative culture of local wisdom applied in transdisciplinary STEM learning.

Technology in this study challenges pre-service teachers to solve problems related to engineering and physics concepts and the availability of easily available materials and equipment, such as laser technology, that has been recognized and used in real life. Lasers are important tools for research and industry and play an important role in education and understanding science (Doss et al., 2010).

Through creating simple lasers, pre-service teachers will understand the physics principles that underlie this technology and connect it to physics, math, and engineering concepts in STEM sciences. This exciting challenge, especially in areas with limited laboratory facilities like Kalimantan Island, is expected to equip prospective teachers with practical engineering problem-solving skills, motivating them to study transdisciplinary STEM.

This study developed a STEM transdisciplinary learning model that promotes student collaboration, solution planning, and engineering problem-solving in simple laser creation by pre-service teachers. The model encourages discussion, practical skills, and appreciation of collaboration through authentic practice (Dotson et al., 2020; English & King, 2015; Glancy & Moore, 2013; Hallström & Schönborn, 2019).

Using transdisciplinary STEM learning, the ability to solve engineering problems collaboratively is expected to be improved. In addition, pre-service teachers are also invited to understand and apply Indonesian cultural wisdom through Among's method, which creates an atmosphere of kinship, fairness, and responsibility in understanding physics concepts about lasers, planning solutions, and solving engineering problems. Among's method supports student learning by focusing on active engagement and integrating local cultural values. It motivates students and incorporates social, moral, and ethical aspects in learning, providing a holistic view of science and technology in everyday life. A transdisciplinary approach is also applied, integrating knowledge from various disciplines. One of the main objectives of this model is to motivate pre-service teachers to learn to practice laser-related technologies.

This study is expected to understand better transdisciplinary STEM programs based on Among's philosophy learning approach to improving engineering problem-solving skills and motivation as seen from pre-service teachers' attitudes, interests, and responses to their learning. This study is a solution to provide teachers with intensive training in interdisciplinary STEM approaches and transdisciplinary learning (Mayes & Rittschof, 2021). This training helps pre-service teachers overcome limitations in teaching STEM and promotes deeper understanding (Colakoglu, 2018; Firat, 2020).

In addition, by integrating culture and local wisdom in transdisciplinary STEM learning, this cultural approach will be more meaningful and relevant for pre-service teachers, provide richer and more contextualized learning experiences, help improve STEM education in these areas, and make a positive contribution to the overall development of STEM education in Indonesia (Nugraha et al., 2023). Based on this, the research questions in this study can be formulated:

1. How do the application of a transdisciplinary STEM program based on Among's philosophy to pre-service teachers through technology courses by creating simple lasers? What factors support or hinder the course?
2. Does applying a transdisciplinary STEM program based on Among's philosophy through technology courses by creating simple lasers improve engineering problem-solving and motivation?
3. What is the correlation between understanding engineering problem-solving skills and motivation as seen from pre-service teachers' attitudes, interests, and responses?

LITERATURE REVIEW

STEM: Definition and Goals

STEM curriculum and pedagogy focus on developing knowledge through an interdisciplinary approach with one or two disciplines by incorporating problems or projects as the basis for learning (Falloon et al., 2020). Enhancing student learning requires a curriculum that connects STEM fields with other academic areas (Faulconer et al., 2020). Moreover, it also benefits the student's individual and social development and teaching (Cinar et al., 2016). Integrating PBL and STEM can improve the efficiency of science and engineering courses and impact students' attitudes toward pursuing future careers (Cinar et al., 2016; Tseng et al., 2013). Integrated STEM programs could provide opportunities for students to gain significant experience and use it in various fields to address real-world problems (Atkinson & Mayo, 2010; Bush & Cook, 2019; Sari et al., 2017). Additionally, STEM education integrates instruction to foster students' knowledge and skills for real-life applications (Chen & Chen, 2021). Collaborative project-based learning (PBL), which is interdisciplinary, effectively enhances students' technological and collaborative skills (Baser et al., 2017). PBL emphasizes the learning process and requires students to work on a project for several weeks or months (Jones, 2019).

PBL integrates knowledge from various disciplines. It connects theory and practice, while STEM learning emphasizes problem-solving from different interdisciplinary perspectives (Martín-Páez et al., 2019). Vasquez et al. (2013) proposed four levels of integration: disciplinary, where STEM subjects are studied individually; multidisciplinary, where the principles and skills of each subject are learned individually by students while being related to the same topic; interdisciplinary learning combines learning from two or more concepts and abilities from a closely related discipline to deepen knowledge and skills. Transdisciplinary learning involves applying knowledge and skills from two or more fields to a real-world problem or project to shape a student's learning experience.

Transdisciplinary STEM

The STEM approach takes integration a step further, going "beyond the discipline" to utilize prior knowledge or acquire new knowledge from multiple disciplines to create new solutions to authentic problems (Lesseig et al., 2023). To prepare students for their future careers by practicing interdisciplinary problem-solving skills in the complex real world, the approach involves integration, collaboration, and communication across multiple disciplines, such as science, technology, engineering, and mathematics (Liao, 2016; MacLeod & Nersessian, 2018; Takeuchi et al., 2020). There are several reasons for the lack of multidisciplinary and transdisciplinary subjects in STEM education. One of them is a lack of knowledge and comprehension of the significance of such techniques in tackling the complexity of the actual world. Research on STEM education continues to be specialized and does not include ideas and methods from other fields (Slavinec et al., 2019).

Technology and cultural philosophy can be connected via transdisciplinary STEM. To tackle difficulties in the actual world, this method pushes students to combine their knowledge and abilities from various fields, as well as their local cultural understanding. This enables students to build technical abilities pertinent to contemporary demands and recognize and use local cultural expertise in a STEM setting (Slavinec et al., 2019). A STEM learning theme, such as creating a simple laser, might be learning that emphasizes engineering practice as the foundation for a transdisciplinary learning context (Lesseig et al., 2023). In this activity, Students will gain knowledge of the physics of light and optics, the technology used in the design and manufacture of lasers, the engineering used in the assembly of laser components, and the math used in calculating laser properties and characteristics via this project. According to Rostoka and Cherevychnyi (2018), incorporating local wisdom culture into the transdisciplinary STEM approach can improve students' learning opportunities, promote cultural appreciation, and strengthen their identity and ownership in STEM education.

Ki Hajar Dewantara Among's Method

Ki Hajar Dewantara is an academic, politician, writer, and journalist actively involved in the Indonesian War of Independence. His contribution to the promotion of national independence and nationalism is highly regarded. Ki Hajar Deontara had a profound impact on education in Indonesia. He is considered a national hero for his commitment and contribution to the foundation of the country's educational system (Wiryopranoto et al., 2017).

The Indonesian educational system now incorporates the ideas of Ki Hajar Dewantara, which was influenced by national ideology (Darmawan & Sujoko, 2019; Wiryopranoto et al., 2017). that in the ki Hajar Dewantara philosophy, "among" means "together" or "togetherness," borrowed from Javanese. Among's philosophy in education teaches the importance of role modeling, supporting each other, sharing knowledge and experience, and encouraging teachers and students. It fostered a spirit of anti-colonialism and striving for an independent and self-reliant society. Among's approach applies to all aspects of teaching, including instructional strategies and collaborative learning environments involving teachers and students (Riyanti et al., 2021; Sugiarta et al., 2019). This approach encourages character learning by providing positive role models. It helps students develop independence by encouraging and supporting their goals. Using Among's approach creates a collaborative environment within the school, where values such as discipline, practice, compassion, sacrifice, and responsibility are valued and encouraged.

Laser Technology

Laser teaching is essential because it is technology-linked, authentic and relevant to the real world, and related to interdisciplinary science (Clark et al., 2019; Jaime et al., 2016; Li et al., 2017; Prinsloo & Deventer, 2017; Wengrowicz et al., 2017). Several universities in China, Taiwan, and the United States have used PBL to teach laser and optics materials to improve students' design skills, knowledge management skills, confidence, and professionalism for the future (Bilgin et al., 2015; Clark et al., 2020; Tsybulsky & Muchnik-Rozanov, 2019). Learning about laser technology also involves interdisciplinary integration that includes science (physics), technology (electronics, electrical, mechanical), and mathematics (STEM) (Spencer et al., 2014). By understanding laser technology through PBL, students can improve their problem-solving and team communication skills and prepare themselves to tackle global issues in the future (Euefueno, 2019). Therefore, PBL in science and STEM fields is essential and emerging to advance STEM education. Likewise, a technology-integrated STEM curriculum will increase students' perceptions and interest in STEM, which is critical to engaging students in STEM fields (Chen & Chang, 2018). To introduce students to modern technology, the application and development of technology in higher education must incorporate many ideas and concepts that support modern technology (Jones, 1991).

Engineering Interdisciplinary STEM

Through engineering design, students can appreciate various ideas and approaches to solving complex problems and the type of tools and representations to achieve the desired end product. They also understand that failures in early design are part of the learning process. According to National Research Council (2012), through a scientific approach to engineering design, there are three core components:

(1) clearly defining the engineering problem,
(2) designing solutions with initial variations and evaluations, and
(3) optimizing solutions through trial and error and systematic improvement, considering the exchange of less essential features with more important features in the final design.

Transdisciplinary STEM model based on Among's philosophy using a combination of designs developed by English and King (2015) and Glancy and Moore (2013).

As shown in **Figure 1**, researchers consider idea generation to include brainstorming and planning,

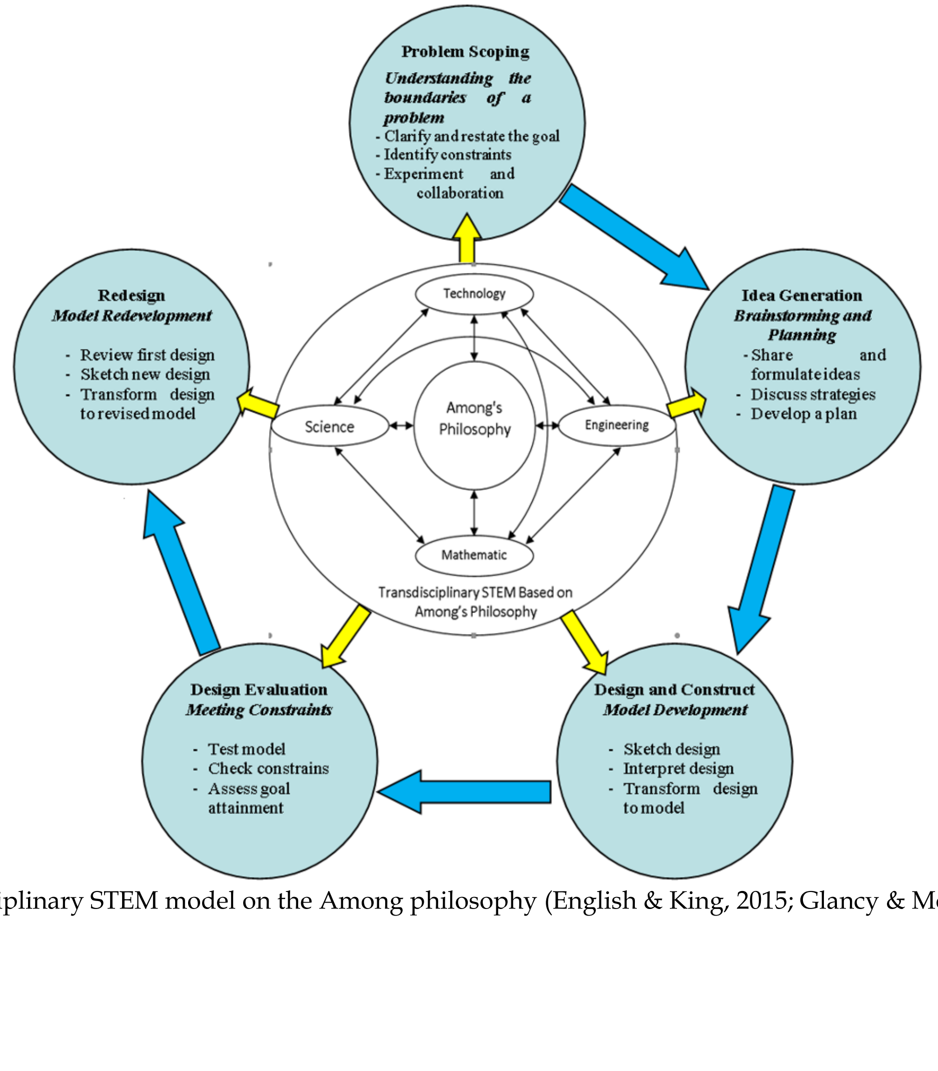

Figure 1. Transdisciplinary STEM model on the Among philosophy (English & King, 2015; Glancy & Moore, 2013)

where students share and formulate ideas, discuss strategies, and develop collaborative plans. Applying STEM content knowledge during the design process becomes a key component of student learning in engineering problem-solving.

Direct interaction with the material and the process of making lasers is an important part of learning the theory of laser technology. Instructor guide and provide feedback to help students understand the theory and process of creating simple lasers in learning the Physics Laboratory course in the form of laser technology theory, which includes the interaction of substances with light, laser properties, application of theory and practice of making lasers, spontaneous and stimulated emission processes, pumping processes, and Bohr atomic theory to understand laser emissions.

METHODS

The method of this study is a correlation that aims to identify and analyze the relationship between students' motivation and engineering problem-solving cognition and evaluate the ability-enhancing impact of learning on both variables. Correlational studies aim to identify and measure the statistical relationship between two or more variables. The extent to which two or more variables covary, that is, changes that occur in one of the variables, are reflected in changes in the other variable (Creswell, 2011).

This study uses a correlation with a pre-experiment one-group pre-/post-test design approach. With this method, the study can provide a deeper understanding of the correlation between motivation and engineering problem-solving cognition.

In this study, the type of sampling used was a purposive sampling of the entire population of pre-service physics teachers in Palangkaraya Central Kalimantan Province into the study sample, without selecting a random or proportional sample. All 6th-semester 3rd-year students taking physics laboratory courses from Palangkaraya University and the Palangkaraya State Islamic Institute who met the research criteria for training became part of the sample because the population was relatively moderate.

Measurement before the course began, an initial measurement was conducted using a 100-minute essay test to measure engineering problem-solving cognition. After completing the course, a re-measurement was conducted using an essay test and a questionnaire to measure 100-minute engineering problem-solving cognition and student motivation regarding attitude, interest, and responses after the course.

Participants

The course is a 12-week face-to-face program, where 53 teacher candidates (11 male and 42 female) participate. They are divided into three classes and enrolled in the physics laboratory course. Participants are grouped in three-four member teams based on ability and gender, aged 17-19 from diverse ethnicities (Banjar, Dayak, Javanese, and Malay). Before this course, the participants completed basic physics, mathematics, chemistry, electronics, and modern physics prerequisite lessons.

Instrument

The data collection of this study is obtained from the results of essay tests, questionnaires, and documentation reports spread over each indicator testing. Before use, the test instrument has been tested to obtain data on difficulty, validity, and reliability tests.

Engineering Problem-Solving Cognition Tests in Simple Laser-Creating Projects

Test of nine essay questions. To ensure the validity of the test, a team of experts categorized each question into the appropriate knowledge type. The team consisted of three physics PhD. with extensive backgrounds and 20 years of experience teaching physics at universities. After an in-depth discussion, the questions were categorized based on the majority opinion. Then the test results were analyzed to evaluate the answers of pre-service teachers. Compared the average scores between the pre-test and post-test using paired t-tests and assessed the effect size and N-gain values.

Attitude, Interest, & Response to STEM Learning Questionnaire

Attitude, interest, and response questionnaires to measure student motivation in transdisciplinary STEM learning after the course. The questionnaires were designed and validated specifically for transdisciplinary STEM learning programs on simple laser creation. Then they analyzed the questionnaire results to evaluate the answers of pre-service teachers. Retrieved conducted one-sample t-tests to assess the scores of attitude, interest, and response questionnaires after learning and assessing the effect size value.

The test and questionnaire instruments were strengthened by the documentation of the project reports. Data was collected from project reports for text analysis, documenting systematic events and activities related to the project. Project reports were written based on their reflections on learning activities and problems encountered. The report recorded objectives, discussion results, scientific concepts, data from project activities, and technical constraints. Qualitative data collection complemented quantitative data by analyzing connotative sentences in the project reports that reflected students' understanding during the simple laser-creating project.

Table 1. Among's learning steps

Project activities	Among's activities
Stage 1. Collecting information	Understanding philosophy of Among's: -In early stages of project, instructors & pre-service teachers understood principles of Among's philosophy. -Collecting information on making a simple laser, & discussing importance of modeling, collaboration, & mutual support in this project.
Stage 2. Group discussion for solutions on how to create a simple laser	Collaboration in learning: Instructor divides pre-service teachers into small groups to work together on project. Each group is responsible for designing, building, & testing a laser component. They collaborate in sharing ideas, solving problems, & supporting each other.
Stage 3. Creating a simple laser	Character learning independence & togetherness: -During project, instructor models good character by emphasizing importance of discipline (following safety rules), compassion (helping a group mate who is struggling), sacrifice (taking on additional responsibilities to ensure project is successful), & responsibility (taking good care of tools). -Instructor gave pre-service teachers freedom to set their goals in laser project. Each group plans steps that need to be taken, resources needed, & time required. Instructor supports them in formulating plan & organizing necessary actions.
Stage 4. Making corrections & improvements to product	Evaluation & continuous learning: During project, instructors & pre-service teachers regularly evaluate progress of project & analyze any problems that arise. They make continuous improvements in laser creation process.

RESULTS

Data was collected from the engineering problem-solving cognition test, motivation questionnaire (attitude, interest, and response), and project report documentation.

Answer to Research Question One

Forming Among's collaborative groups

The learning system promotes a family spirit based on togetherness, supporting each other, sharing knowledge and experiences, and motivating. Group divisions are made through deliberation, considering an equal distribution of men and women in each group. Students are encouraged to divide members based on their abilities, ensuring a balanced distribution of knowledge and fostering a collaborative learning environment, where experienced students can teach and guide their peers. There is no competition; togetherness is emphasized based on the spirit of family in learning.

Each group establishes rules regarding the rights and responsibilities of its members through agreement and deliberation. These rules are documented, signed, and upheld through mutual understanding. Within each group, a leader is chosen based on the collective awareness of the group members. The group leader is selected for their wisdom and serves as a guide and guardian for each member. All group members are committed to following and obeying the leader in right and beneficial matters. The group leader assumes the role of a teacher or instructor when the group gathers and collaborates.

Learning Among's creates an environment that supports the development of character, independence, and collaboration in education. applying these steps, it is expected to build an educational culture that is based on the values valued and encouraged by Among's philosophy. Application of Among's learning steps on a simple laser-creating project in **Table 1**.

Following steps of Among's learning, simple laser-creating project becomes a learning experience that not only develops technical skills but also builds positive character.

Stages of project implementation

Project stages are based on a target completion time to develop STEM in simple laser creating for 12 weeks. The process carried out consists of four stages:

1. **Stage 1.** Collecting information (one week)
2. **Stage 2.** Group discussion for solutions on how to create a simple laser (two weeks)
3. **Stage 3.** Creating a simple laser (six weeks)
4. **Stage 4.** Making corrections & improvements to product (four weeks)

Project preparation and initial design solutions are critical to ensuring project success. Each team member can provide suggestions and discuss them during project implementation.

Stage 1. Collecting information: Students took an initial engineering problem-solving cognition test at the first meeting. Next, during the first week, students begin the group project by using questions from the project assignment to identify and understand the problem by gathering information from websites, YouTube, and social media about the simple laser to create. They perform information searches for simple laser project tasks designed independently and together at an affordable cost. The groups presented their information search results in the second meeting and participated in the discussion. After two hours of presentations, the

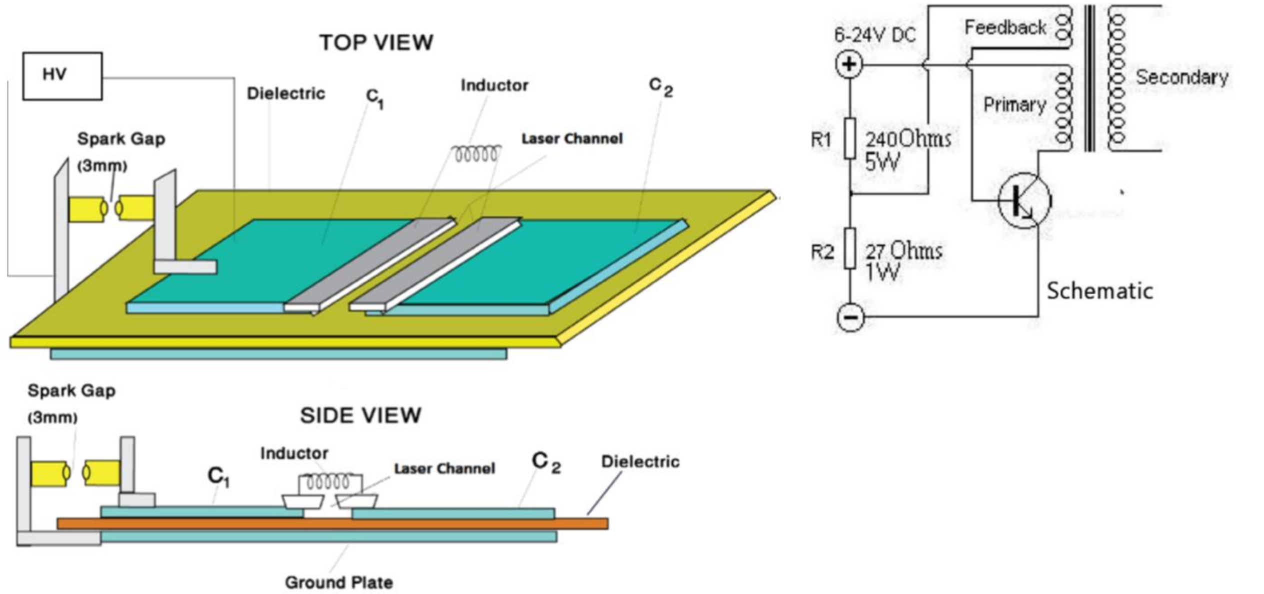

Figure 2. Schematic construction of a simple laser (TEA laser) with a high-voltage discharge circuit (Hussain & Imran, 2015)

students completed a second project report the following week.

The main obstacle is finding a suitable reference to explain the concept and how the laser works. Difficulties still arise in finding relevant references because there needs to be a clear picture of the laser to be made and in determining the appropriate components and materials for the project. At first, references found from websites, YouTube, and social media were only related to the manufacture of diode lasers. Furthermore, references were found that discussed the creation of TEA (transversely excited atmospheric) lasers using simple materials such as helium gas, nitrogen, and carbon dioxide, as well as vibronic lasers with a wavelength of 337.1 nm made using materials such as board, aluminum foil, and plastic sheets.

Stage 2. Group discussion for solutions on how to create a simple laser: Pre-service teachers analyzed data from the first project report, engaging in brainstorming sessions to enhance communication and comprehension of spontaneous and stimulated emission, radiation-matter interactions, pumping processes, and Bohr's atomic theory. PHET simulation software was utilized by instructors to aid in concept understanding. The pre-service teachers then prepared for group experiments, acquiring reusable electronic components and assembling laser media using easily accessible materials. In the laboratory, they met with instructors twice a week for 6 hours, presenting their second project report twice and engaging in inter-group discussions to deepen their understanding, totaling four hours of presentation time.

To address challenges in obtaining coherent and monochromatic laser light for TEA laser project, the pre-service teachers conducted reference searches and collaborated to generate innovative solutions. However, the lack of clear references and limited conceptual understanding hindered progress. Websites, YouTube, and social media platforms provided valuable information on circuits, tools, and required materials for TEA laser. The pre-service teachers also experimented with various laser shapes and evaluated their ideas with guidance from the obtained references.

Based on the references from websites, YouTube, and social media, creating TEA lasers involves utilizing various components such as resistors, capacitors, diodes, inductors, transistors, and flybacks to construct a high-voltage power supply. The device design incorporates a flat board, mica plastic, elbow aluminum, aluminum foil, cables, cap screws, and bolts. Attention is given to factors like electrode shape, plate size, appropriate aluminum foil selection, precise electrode cuts, dielectric material type, voltage magnitude, and applied polarity to ensure the success and optimal performance of TEA laser (Hussain & Imran, 2015), as shown in **Figure 2**. The critical step lies in constructing capacitors with low inductance using an aluminum foil of suitable thickness. This enables TEA laser to generate coherent and monochromatic light by utilizing a gas or air mixture as its media.

Stage 3. Creating a simple laser: Pre-service teachers dedicated a total to the lab, holding two-hour meetings twice a week from the fourth to the ninth to develop ideas and formulate project completion plans. They presented project results every two weeks, with a total presentation time of four hours. Throughout the process, team members searched for information to enhance their understanding and integration of data into project reports. The instructor guided applying the concepts of monochromatic wavelength and light intensity measurement, which were crucial for generating laser light.

The pre-service teachers encountered challenges in various aspects of TEA laser project, including ideation, time management, communication, and technical issues. Despite the difficulty in obtaining coherent and monochromatic laser light, they successfully created a TEA laser for measuring and collecting data on emitted laser light from the plate gap. Precision in laser creation, particularly in determining the plate gap size, was critical for optimal results. Wavelength measurement involved the laser beam passing through the plate gap, dispersing, and being captured by a colored paper screen.

During data capture using TEA laser light, the pre-service teachers faced challenges such as obtaining a single coherent monochromatic light, working with limited light intensity measuring equipment, and conducting measurements in a darkened room to minimize the influence of external light. The collected observations required further calculations to derive the expected results while considering the impact of external light and collecting data in a dark environment. Discussions with other groups and applying mathematical formulas enabled the determination of light intensity, wavelength, and frequency values. Group members managed project financing, taking turns purchasing materials with a minimum expenditure of approximately 50,000 to 200,000 rupiahs per group. The project's success depended on utilizing well-functioning materials and components and fostering effective collaboration and communication within the group.

Stage 4. Making corrections & improvements to product: Pre-service teachers focused on refining their projects. They conducted improvement experiments in the lab for 12 hours, meeting twice weekly for two hours each. Each group member prepared a project report and presentation for the final product, dedicating two hours to these tasks. Towards the end of the project, an engineering problem-solving final test was administered, and the participants filled out a questionnaire regarding their attitudes, interests, and responses.

The pre-service teachers encountered challenges in effectively integrating the laser media with the high-voltage power supply. The first challenge involved securely mounting the aluminum plate onto the laser media board, ensuring that the monochromatic laser beam would not be lost due to plate displacement. Additionally, the students discovered that the plastic cover sheet and aluminum foil were prone to leakage, even when the plate was locked. The student group developed a locking mechanism for the laser media to address this issue.

STEM problem-solving engineering connotations on project report documentation

Understanding the pre-service teacher engineering process, researchers look at reports containing each activity related to project tasks that must be completed. The project report reveals that students can integrate the connotations of STEM in engineering aspects into their work according to the activity planning of making simple laser products. The connotations of the engineering aspect are described at the stages of project implementation:

The ability to design and create the laser based on their knowledge was essential in engineering problem-solving, as example evidenced in the report code R2-S2-G4-(ELY) stated:

> "We will create a TEA laser, which is a gas laser that uses a capacitor made of aluminum foil with a sheet of polyethylene as the dielectric and sometimes equipped with a ceramic cover. Two closely spaced aluminum plates form the laser channel in this method, which uses a spark gap as a quick switch to release high voltage. We will fill the spark gap and laser channel with low-pressure nitrogen to produce an ultraviolet beam in very short pulses."

The pre-service teacher practiced the engineering of optimizing TEA laser, which involves several steps and requires precision in laser slit production to produce monochromatic light. The report code R3-S3-G4-(ELY) is an example:

> "We have successfully created a simple laser that produces monochromatic light and measures the light intensity and wavelength. This requires great precision, as the shape and spacing of the aluminum plates that make up the laser channel can interfere with the laser beam produced if they are not precise."

The pre-service teacher improved TEA laser system and created permanent laser media. They improved TEA laser equipment to enhance the quality of the monochromatic beam. as example evidenced in the report code R4-S4-G2-(NCD) report:

> "We encountered several obstacles in our project, one of which was when we wanted to strengthen the aluminum rod with wood to the laser media in the form of a board. The monochromatic laser beam was lost, and we had to carefully Slide the wooden and aluminum plates. Another obstacle was when the plastic and aluminum foil leaked even though the rod had strengthened."

The project report notes that constructing TEA lasers requires the precise assembly of a high-voltage power

Table 2. Paired t-test of cognition engineering problem-solving

Engineering problem-solving cognition	Pre/ post	M (n=53)	SD	t-test		Effect size category		N-gain category	
				t	Sig.				
Explaining lasers with physics concepts	Pre	20.943	8.324	10.350	.000***	1.422	Very large	0.381	Medium
	Post	51.321	20.851						
Engineering design for designing a simple laser	Pre	8.066	9.401	18.163	.000***	2.495	Very large	0.505	Medium
	Post	55.236	15.018						
Engineering understanding of measurement with instruments	Pre	2.358	7.378	10.126	.000***	1.391	Very large	0.388	Medium
	Post	40.094	27.882						
Engineering understanding to correct errors & provide solutions	Pre	13.941	11.290	11.960	.000***	1.643	Very large	0.579	Medium
	Post	65.042	26.983						
Engineering knowledge to interpretation	Pre	2.358	7.378	11.032	.000***	1.515	Very large	0.434	Medium
	Post	45.283	26.880						
Overall mean	Pre	9.534	5.374	17.044	.000***	2.341	Very large	0.460	Medium
	Post	51.395	16.855						

Note. M: Mean; SD: Standard deviation; *p<0.05; **p<0.01; & ***p<0.001

supply and laser gaps within the laser media to produce monochromatic light. Pre-service teachers gain valuable problem-solving experience through laser-creating activities and develop essential engineering competence for completing the project. The supportive and caring environment among pre-service teachers further enhances their motivation and active participation in the project. For those needing more practical engineering knowledge in science, math, and technology, additional support may be necessary to achieve success. Consequently, they dedicate extra time and effort to engage in discussions and practical exercises, ensuring the success of their final product.

Answer to Research Question Two

Paired t-test analysis in **Table 2** shows significant impact of improving engineering problem-solving skills. This is evident from substantial overall mean difference between pre-test (mean [M]=9.534, standard deviation [SD]=5.374) and post-test (M=51.395, SD=16.855) scores, as well as the statistical significance (t=17.044, p<0.001, d=2.341, N-gain=0.460) has an effect size in very large category and N-gain in medium category. Notably, knowledge areas experiencing the most significant improvement are engineering design for creating simple lasers, understanding error correction techniques, and providing solutions. Hands-on involvement in laser-making activities gives authentic experiences in tackling engineering challenges.

The evaluation of motivation in laser technology learning among pre-service teachers in technology courses through the creation of simple lasers was assessed using questionnaires on attitudes, interests, and responses. The results of the one-sample t-test in **Table 3** revealed that the difference in scores from the overall mean of the attitude questionnaire (M=3.8308, SD=.545) significantly exceeded the intermediate scale value of three, representing the neutral position on the defined scale. The significance of the results (t=11.099, p<.000, d=1.523) indicated a positive acceptance and trust in the transdisciplinary STEM program within technology courses through the creation of simple lasers has an

Table 3. One-sample t-test for attitudes

Attitude items	Test value=3					
	Mean (n=53)	SD	t-test		Effect size category	
			t	Sig.		
With PBL, I feel more capable of understanding feelings & appreciating teamwork of colleagues when working collaboratively on a project.	3.793	.906	6.365	.000***	0.874	L
I believe practical knowledge can complement technical expertise in science, mathematics, & engineering when working on project tasks.	3.943	.718	9.561	.000***	1.313	VL
In my opinion, it is essential to integrate science, technology, engineering, & mathematics in collaborative PBL.	3.943	.864	7.948	.000***	1.092	VL
Through PBL, I have come to understand challenges engineers face.	3.868	.941	6.713	.000***	0.922	L
I have become adept at finding solutions to every problem by communicating with other team members while working on a project.	3.830	.753	8.028	.000***	1.103	VL
Collaborating with & trusting peers can improve my learning outcomes in PBL.	3.925	.675	9.970	.000***	1.370	VL
I believe that ability to integrate ideas from various disciplines, such as science, technology, engineering, & mathematics, as well as practical experience, is interconnected.	3.981	.693	10.305	.000***	1.416	VL
I am eager to collaborate by sharing interdisciplinary info that I have acquired.	3.491	.669	5.342	.000***	0.734	L
I attempt to integrate knowledge of science, technology, engineering, & maths into my learning to solve problems that I encounter in daily life.	3.6981	.890	5.712	.000***	0.785	L
Overall mean	3.8308	.545	11.099	.000***	1.523	VL

Note. M: Mean; SD: Standard deviation; L: Large; VL: Very large; *p<0.05; **p<0.01; & ***p<0.001

Table 4. One-sample t-test for interests

Interest items	Test value=3					
	Mean (n=53)	SD	t-test		Effect size category	
			t	Sig.		
I enjoy learning about various aspects of technology	3.396	.863	3.345	.002**	0.459	S
The application of project-based learning fuels my imagination as an engineer.	3.472	.992	3.460	.001**	0.475	S
I enjoy studying electronics, engineering, and design.	3.321	.872	2.678	.010*	0.368	S
I am fond of integrating scientific concepts into other subjects.	3.208	.988	1.530	.132	0.210	S
I like applying science, technology, engineering, and mathematics to solve problems in other areas of study.	3.566	.910	4.531	.000***	0.622	M
In future, I aspire to pursue a degree in science, technology, engineering, or mathematics.	3.491	.891	4.010	.000***	0.551	M
In future, I aspire to work in science, technology, engineering, or mathematics.	3.547	.952	4.184	.000***	0.575	M
Overall mean	3.428	.711	4.386	.000***	0.603	M

Note. M: Mean; SD: Standard deviation; S: Small; M: Medium; *p<0.05; **p<0.01; & ***p<0.001

Table 5. One-sample t-test for responses

Response items	Test value=3					
	Mean (n=53)	SD	t-test		Effect size category	
			t	Sig.		
In my opinion, a self-designed and self-made laser is better than a factory-made laser in terms of the process of understanding technology.	3.245	1.054	1.694	.096***	0.233	S
Through project-based learning, I found it easier to comprehend the concept of lasers by creating a simple laser.	3.755	.939	5.854	.000***	0.804	L
Through collaborative project-based learning, I gained hands-on experience making a simple laser.	4.038	.733	10.309	.000***	1.416	VL
I became more familiar with every detail of the simple laser task that must be done collaboratively.	3.755	.875	6.279	.000***	0.863	L
Learning through experiment of making a simple laser can facilitate my ability to actively participate & establish trust & cooperation with colleagues in learning.	3.774	.800	7.039	.000***	0.967	L
I think project-based learning is suitable for learning the concept of laser technology and working collaboratively on making a simple laser.	3.717	.948	5.505	.000***	0.756	M
Learning about the physics topic, such as experimenting with creating a simple laser, helped me develop observational skills during the experiment.	3.717	.818	6.385	.000***	0.877	L
Overall mean	3.715	.652	7.977	.000***	1.095	VL

Note. M: Mean; SD: Standard deviation; S: Small; M: Medium; L: Large; VL: Very large; *p<0.05; **p<0.01; & ***p<0.001

Effect Size with a very large category. The significance and effect size demonstrated increased confidence among pre-service teachers in integrating ideas from various disciplines, such as STEM, with practical experience. Furthermore, the findings highlighted that practical knowledge complements technical expertise in STEM when working on project tasks, and STEM in PBL facilitates problem-solving in everyday life.

The one-sample t-test analysis in **Table 4** revealed that the difference in scores from the overall mean of the interest questionnaire (M=3.428, SD=.711) significantly exceeded the intermediate scale value of three. The significance of the results (t=4.386, p<.000, d=0.603) indicates a positive interest in the transdisciplinary STEM program within technology courses through the creation of simple lasers has an effect size with medium category. These findings suggest that pre-service teachers develop a heightened self-interest in integrating ideas from STEM disciplines and applying STEM knowledge to solve problems in various fields of study. Moreover, it reflects their aspirations to pursue further education and work in STEM-related fields.

The one-sample t-test analysis in **Table 5** demonstrated that the score difference from the overall mean of the response questionnaire (M=3.715, SD=.652) significantly exceeded the intermediate scale value of three.

The significance of the results (t=7.977, p<.000, d=1.095) indicated positive responses towards the transdisciplinary STEM within technology learning through the creation of simple lasers has an effect size with a very large category. The significant effect and size of the result suggested that pre-service teachers perceived a valuable gain in practical experience from making simple lasers. Through this experiment, pre-service teachers actively participated, built trust, and enhanced peer cooperation. Learning physics through simple laser-creating experiments also helped them develop essential observation skills.

Answer to Research Question Three

Correlation test analysis in **Table 6** shows motivation to engineering problem-solving cognition in STEM transdisciplinary learning on Among's philosophy for

Table 6. Correlation test of motivation with engineering problem-solving

Motivation		Engineering problem-solving cognition	
		Value	Correlation category
Attitude	Correlation coefficient (Spearman's rho)	-0.410**	Moderate
	Sig. (2-tailed)	0.002	
	n	53	
Interest	Correlation coefficient (Spearman's rho)	-0.370**	Moderate
	Sig. (2-tailed)	0.006	
	n	53	
Response	Correlation coefficient (Spearman's rho)	-.541**	Strong
	Sig. (2-tailed)	0.000	
	n	53	

Note. **Correlation is significant at 0.01 level (2-tailed)

attitude to engineering problem-solving has a correlation coefficient of -0.410; Sig. (2-tailed)=0.002 with a moderate category. Interest in engineering problem-solving has a correlation coefficient of -0.370; Sig. (2-tailed)=0.006 with a moderate category. Response to engineering problem-solving has a correlation coefficient of -0.541; Sig. (2-tailed)=0.000, with a strong category**.** The results show that motivation in terms of attitude, interest, and response to engineering problem-solving ability has a significant relationship. Strong results in response case suggest that this factor may have the strongest influence on engineering problem-solving ability in this learning. But it is important to remember that these are correlation findings and cannot determine causation, as there is a negative correlation coefficient number indicating that as attitude, interest, and response increase, engineering problem-solving ability tends to decrease, and vice versa.

DISCUSSION

These results underline how crucial it is to overcome these challenges. The need for assistance in locating relevant references to comprehend concepts and choose suitable components is one of the issues that has been identified. Other issues include mastering engineering skills in creating TEA lasers, effectively managing time and communication, and producing coherent and monochromatic laser light. The last stage also faces a considerable hurdle in permanently integrating the laser medium with the high-voltage power supply. For pre-service teachers to complete their projects successfully, these challenges must be resolved. This emphasizes the importance of professional development and training for pre-service teachers to effectively incorporate knowledge and skills of STEM concepts into their teaching practices (Colakoglu, 2018).

Several support factors played a significant role in overcoming the obstacles faced by pre-service teachers. These factors include active participation in discussion sessions to understand physics concepts, using references, experimentation with simple laser forms, and evaluating ideas with guidance from references. The accurate selection and arrangement of components affected the successful performance of TEA lasers. The technical aspects of constructing a high-voltage power supply and designing a laser cavity were vital elements in producing monochromatic light. Collaboration and effective communication among group members was essential to achieving project success. Thus pre-service teachers demonstrated commitment by investing additional time and effort in discussing and practicing the engineering aspects of the project to ensure end product success. The practice of this technique encourages interdisciplinary collaboration in a transdisciplinary approach, resulting in innovative solutions to complex problems and stimulating creativity (Mokiy, 2020).

The study showed that using transdisciplinary STEM to create simple lasers significantly improved cognitive capacities for engineering problem-solving. This finding supports earlier studies by Baser et al. (2017), Jalinus et al. (2019), and Lou et al. (2013) that place a strong emphasis on the application of science and technology to deliver workable solutions. The direct participation in practice activities, which encouraged engineering problem-solving experience, was cited by Chiang and Lee (2016) as the reason for this improvement. Due to their active participation in technical activities, students developed a greater interest in engineering (Changtong et al., 2020; Chen & Chang, 2018). Providing hands-on experience in real-world engineering activities, such as designing prototypes and solving open-ended problems, helps pre-service teachers better understand engineering and scientific and mathematical concepts. Collaboration in groups encourages teamwork, communication, and engineering problem-solving skills, enabling knowledge pre-service teachers for a more comprehensive understanding of engineering concepts (Irmak & Ozturk, 2022).

STEM is the process of creating products through engineering skills, knowledge, and strategies to create added value by combining science, math, technology, and engineering, which brings learners to the level of invention and innovation (Firat, 2020). During the creation phase, pre-service teachers required additional time to familiarize themselves with interdisciplinary challenges, such as tool assembly and electronic and mechanical equipment development. This adjustment time was extremely important for operations requiring highly technical abilities, like creating high-voltage electric arcs or producing coherent light through a metal plate's slit. The training positively influenced students' attitudes toward STEM (Martynenko et al., 2023). Employing instructional techniques that integrate theoretical training, hands-on laboratory experiences, and references is advantageous because it helps students overcome challenges and thoroughly comprehend scientific knowledge (Awad & Barak, 2018). The study results showed that the transdisciplinary STEM program based on Among's philosophy resulted in increased motivation, as seen from pre-service teachers' attitudes, interests, and responses. These findings are in line with Awad and Barak (2018), Karakas and Hidiroglu (2022), and Mayes and Rittschof (2021) research that the transdisciplinary STEM approach can increase learner motivation due to the connection between various disciplines and the relevance of learning in a real context of technology usage.

According to pre-service teachers' attitudes, interests, and responses, the study's findings demonstrated that the transdisciplinary STEM curriculum, based on Among's philosophy, increased motivation. These results are consistent with studies by Awad and Barak (2018) and Karakas and Hidiroglu (2022), which found that the transdisciplinary STEM method can boost learner motivation due to the connections between different disciplines and the applicability of what is being learned in a real-world setting of technology use. The pre-service teachers complete projects that require creative problem-solving and teamwork to increase their intrinsic motivation (Rostoka & Cherevychnyi, 2018; Vicentini & Nasta, 2017), and this approach is also taken in transdisciplinary STEM based on Among's philosophy method. Implementing transdisciplinary STEM strategies that actively engage learners in learning can increase motivation. However, some weaknesses need to be addressed in the effectiveness of its implementation, as explained by the research of Slavinec et al. (2019), the occurrence of shallow understanding and conceptual changes in science concepts. Therefore, teachers' knowledge and perceptions of STEM will impact their ability to implement integrated STEM education (Firat, 2020).

The data showed a negative correlation between Interest, attitude, and response to technical problem-solving ability after learning, meaning that as Interest, attitude, and response increased, engineering problem-solving ability decreased, and vice versa. When the research subjects have low engineering problem-solving ability but high motivation, this can be explained by various factors and learning processes, according to Among's philosophy in education.

1. During transdisciplinary STEM learning based on Among's philosophy, the instructors and pre-service teachers engage in intensive interactions that encourage collaboration. This results in a supportive environment, where pre-service teachers feel comfortable asking questions, experimenting, and trying new things without fear of negative judgment. In this environment, motivation to learn and try new things can grow, even if initial engineering problem-solving cognition are low.
2. Pre-service teachers are encouraged to design and build projects, conduct experiments, and solve engineering problems. This process may take time, especially if initial engineering problem-solving cognition are low. However, the desire to develop these skills can be a strong motivator.
3. Instructors practice Among's philosophy in STEM learning and thus serve as a source of inspiration for pre-service teachers. They may have better engineering problem-solving cognition and share their experiences with pre-service teachers. This inspiration from experienced faculty can increase students' motivation to follow in their footsteps and try harder.

These factors can create a supportive and motivating learning environment, even if initial engineering problem-solving cognition is low. Transdisciplinary STEM learning based on Among's philosophy encourages students to grow and develop themselves in a positive and collaborative context, which can produce positive outcomes regarding motivation and engineering problem-solving cognition.

Limitations & Future Study

The study limitations were not possible to use a control class with conventional teaching because the learning model requires hands-on lab work to create the laser product, and the lab experience plays an important role in engineering problem-solving. So, it is difficult to limit the practical experience in the control group. Therefore, this study adopted an experimental design without a control group. Experimental designs without control groups include medium sample sizes, short duration, and environmental and contextual elements that may affect the generalizability of findings. The findings may be bolstered by expanding the look to a large population in an environment with various technological subjects. Future research will verify the study's impact on instructor applicants when they become instructors and teach STEM. The aim was to see if knowledge of technology and transdisciplinary STEM evolved and improved after their course.

CONCLUSIONS

The study claims successfully introduced a transdisciplinary STEM program designed to improve learning in technology and engineering in education settings with limited facilities, focusing on technology course experiences. Despite the limited laboratory facilities in the research area, implementing positively impacted the engineering problem-solving cognition and motivation of pre-service teachers in technology and engineering practice. Implementing Among's method in transdisciplinary STEM creates a collaborative atmosphere in the course, where sacrifice, initiative, and responsibility are valued, contributing to improving conceptual understanding, motivation, and inspiration. Pre-service teachers have an important future role in guiding and supporting their students in utilizing technology effectively by integrating technology and engineering in STEM courses.

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