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# Enhancing Science Teachers' Competence in Scientific Research through a STEM-ESD to Achieve Quality of Education

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**Abstract.** Competence in scientific research is essential for science teachers to support quality education and guide student research focused on sustainability issues. However, some teachers still face difficulties in formulating research questions, determining methods, designing instruments, analyzing data, and integrating STEM-ESD into scientific research. This community service activity aims to enhance the scientific research competencies of science teachers in Semarang City through STEM-ESD-based training and mentoring. The activity employs a capacity-building approach based on action learning, implemented through preparation, implementation, and evaluation phases. The participants were 40 junior high school science teachers who are members of the Semarang City MGMP. Data were collected through pre- and post-tests of research competencies and participant response questionnaires, then analyzed descriptively using percentages and N-Gain. The results showed an improvement in research competencies across all indicators, ranging from moderate to high. Participants also gave very positive feedback on the relevance of the training materials and the training delivery. These findings indicate that STEM-ESD training is effective in sustainably strengthening the research capacity of science teachers at partner schools.

**Keywords:** STEM-ESD; research competencies; science teachers; SDG 4: quality education

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## INTRODUCTION

21st-century education requires schools to prepare students who are capable of critical thinking, creativity, collaboration, effective communication, and adaptability to global changes (Nada et al., 2021; Rehman, 2025). This aligns with the Sustainable Development Goals agenda, particularly Goal 4, which emphasizes the importance of inclusive, equitable, high-quality, and relevant education that addresses real-life needs to achieve quality education (Shabalala et al., 2025; Ahmed et al., 2025). In science education, it is not enough for students to understand concepts; they must also be able to conduct scientific investigations, solve problems, and produce innovative and useful work (Nurhayati, 2024; Salsabila et al., 2026). Therefore, science teachers, as educators, need to possess professional competencies that encompass not only mastery of the subject matter but also the ability to design learning experiences and research that optimally foster students' potential.

Competence in scientific research is an essential skill that science teachers must possess to meet the demands of delivering quality education. This competence enables teachers to identify learning problems, design data-driven solutions, develop assessment tools, analyze results, and document their findings scientifically (Wijaya, 2023; Sumarlin & Laniar, 2025). Teachers with research competencies can develop instructional innovations that can be implemented in the classroom as practices that can be continuously refined (Meyvita et al., 2025; Muslimin, 2020). Furthermore, teachers who are proficient in research are better prepared to guide students in preparing scientific papers in accordance with academic norms and competition standards (Robiatul & Hamdi, 2023). Thus, research competencies serve as a bridge between enhancing teacher professionalism, strengthening

the school's scientific culture, and improving the quality of science education.

Strengthening science teachers' research competencies can be achieved through the STEM-ESD approach, as it aligns with the characteristics of problem-based science learning rooted in everyday life (Ratmani et al., 2024; Gunantiani et al., 2026). STEM integrates science, technology, engineering, and mathematics so that students can understand scientific concepts while using them to design solutions (Widiyatmoko et al., 2025; English, 2023). The integration of STEM with Education for Sustainable Development broadens the scope of learning because the problems examined can be linked to issues such as the environment, energy, waste, water, food, health, and quality of life (Kurniawan et al., 2025; Fathurohman et al., 2023; Salama et al., 2025). This helps teachers and students transform contextual problems into research ideas that are systematic, measurable, and relevant to sustainability values. Therefore, STEM-ESD functions not only as a learning approach but also as a framework for fostering scientific research in schools.

Previous research has shown that teachers' research competencies can be enhanced through structured, contextual, and needs-based training. Ariyanti et al. (2025) emphasize that research competencies are linked to critical thinking skills, as teachers need to connect data, theory, and pedagogical decisions in the learning process. Furthermore, studies on STEM-ESD indicate that integrating science, technology, engineering, mathematics, and sustainability can strengthen students' science literacy, problem-solving skills, and understanding of sustainable development issues (Setiawan et al., 2025; Apriliana et al., 2025). These findings indicate an urgent need to implement STEM-ESD-based scientific research training to help teachers design research projects that address learning challenges and sustainability issues.

Preliminary findings from an assessment of science teachers in Semarang City indicate that 68.8% still face limitations in writing scientific papers. This situation has resulted in suboptimal research guidance, as schools do not yet have a structured framework for mentoring the writing of scientific papers. In light of these challenges, this initiative aims to enhance STEM-ESD-based scientific research competencies among science teachers through training and mentoring. The results of this initiative are expected to strengthen science teachers' capacity and contribute to the development of a STEM-ESD-based scientific research training model.

## METHODS

The community service activity employs an action-learning-based capacity-building approach (Rusilowati & Cahyono, 2012) consisting of the Preparation, Implementation, and Evaluation phases. Through this approach, participants not only received instruction in STEM-ESD and scientific research in science education but also gained hands-on experience implementing STEM-ESD projects and drafting research proposals applicable to mentoring students in academic competitions. Therefore, the community service activity was designed to be participatory, collaborative, and product-oriented to enhance STEM-ESD-based science teachers' scientific research competencies in support of quality education.

### Preparation Phase

The preparation phase involved coordination between the community service team and the executive board of the Semarang City Junior High School Science Teachers' Working Group (MGMP IPA) to agree on implementation details, the activity schedule, participant needs, and training materials. During this phase, the team developed training materials covering STEM-ESD concepts, the integration of the SDGs into science education, and standards and techniques for writing scientific research proposals. The team also prepared evaluation instruments, including pre- and post-tests of research competencies, a questionnaire on participant feedback regarding the implementation of activities, worksheets for designing STEM-ESD-based research proposals, and a STEM-ESD project kit to serve as a practical learning tool for participants.

### Implementation Stage

The implementation phase consisted of presentations, discussions, group activities, coaching clinics, and simulations of research idea presentations. Participants were guided to identify sustainability issues relevant to science education, such as renewable energy, water, waste, the school environment, and quality of life. These issues were then developed into project proposals using the STEM-ESD KIT as the basis for drafting scientific research proposals. The proposals include a title, background, problem statement, objectives, benefits, a brief literature review, methods,


(a) (b) (c)

**Figure 1.** Presentations by the community service team: (a) integrating the SDGs and ESD into the classroom; (b) science research competitions; (c) techniques for drafting STEM-ESD-based scientific research proposals

instruments, data analysis, a timeline, and research ethics considerations. Throughout the process, the implementation team provides guidance and feedback to help the resulting research proposals be developed into student research papers.

**Evaluation Stage**

The evaluation phase was conducted to measure improvements in teachers' research competencies and assess the quality of the program's implementation. Research competencies were measured using a 1-4 scale instrument consisting of 20 items and covering eight indicators, adapted from studies by Al Yahmadi et al. (2025), Liwanag et al. (2023), Vu et al. (2024), Insorio (2026), Evardo and Abina (2023), and Murro (2022). Participants' responses to the activities were measured using a 1-5 scale questionnaire covering the aspects of material suitability and training delivery. Data were analyzed quantitatively using descriptive and inferential statistics. Pretest and posttest scores, as well as participant responses, were converted into percentages, while improvements in research competence were analyzed using N-gain, categorized as low, moderate, and high.

## RESULTS AND DISCUSSION

A community service team consisting of faculty members and students conducted a training program to enhance STEM-ESD-based science teachers' research competencies. This activity took place in 2026 at SMP Negeri 41 Semarang. Prior to the event, the community service team coordinated with the executive board of the Semarang City Junior High School Science Teachers' Working Group (MGMP IPA), prepared training materials, developed evaluation instruments, and prepared worksheets and STEM-ESD project kits. The training was attended by 40 junior high school science teachers who are members of the Semarang City MGMP. The program was designed to help teachers understand the concepts of scientific research, relate research to STEM-ESD, and draft proposals for use in science instruction and in guiding students' research for competitions.

The community service activity began with a pretest to assess the teachers' initial competencies in designing STEM-ESD-based scientific research projects. Following the pretest, the session continued with presentations by resource persons from the community service team (see Figure.1). The first session covered integrating the SDGs and ESD into the classroom. The second session explained science research competitions. The third session covered techniques for drafting STEM-ESD-based scientific research proposals.

The material was presented interactively so that participants would not only grasp the concepts but also relate them to their teaching experiences at school. Participants were allowed to share the challenges they commonly face when writing scientific papers, such as difficulty finding research ideas, determining variables, designing methods, and interpreting data. These discussions served as the basis for the community service team's guidance to participants in developing more contextually relevant research ideas. In this session, participants were also introduced to sustainability issues that can be addressed in science research, such as renewable energy, water, waste, the school environment, food, health, and quality of life. Thus, the training material was not merely theoretical but directly linked to teachers'


**Figure 2.** STEM-ESD-based scientific research design practices: (a) group discussions using worksheets and the STEM-ESD Project Kit; (b) drafting research proposals; (c) guidance through coaching clinics for each group; (d) presentations of research ideas by participants

needs in guiding students' scientific research projects.

Following the presentation of the material, the activity continued with group exercises using worksheets for designing STEM-ESD-based scientific research proposals. Participants were divided into several groups to identify real-world problems relevant to science education and sustainability issues. As shown in Figure 2, each group was guided to examine the STEM-ESD project kit, analyze the science phenomena that emerged, map out the elements of science, technology, engineering, and mathematics, and identify sustainability values that could be developed into research ideas. This process helped participants understand that scientific research does not have to start with a broad topic but can begin with simple problems close to students' daily lives. The results of the group analysis were then compiled into a draft proposal containing the title, background, problem statement, objectives, benefits, a brief literature review, methods, instruments, data analysis, timeline, and research ethics considerations.

Group activities demonstrated that participants could connect science concepts to sustainability issues through STEM-ESD projects. In the science component, participants identified science concepts relevant to the issues, such as energy, water, environmental change, waste, or simple technology. In the technology component, participants linked tools, digital media, or information sources that supported the research process. From an engineering perspective, participants design products, models, or problem-solving procedures that can be tested straightforwardly. In the mathematics aspect, participants determine measurable data, such as size, volume, time, quantity, efficiency, or quantitative observation results. ESD integration is evident when participants connect research ideas to environmental, social, or economic benefits for students, schools, and the community.

During the practical activities, the community service team guided coaching clinics for each group. This guidance was designed to improve the

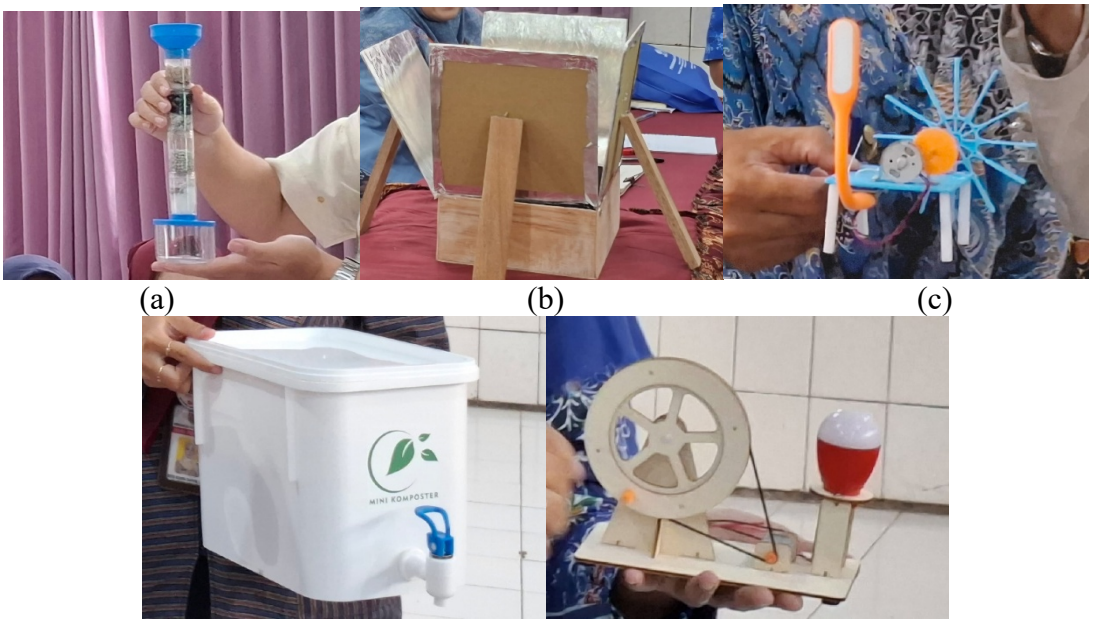


**Figure 3.** STEM-ESD KIT products resulting from group projects, serving as the basis for developing research ideas for scientific papers: (a) Water Purification Filter, (b) Solar Stove, (c) Mini Water Turbine, (d) Easy Composter, and (e) Kinetic Lamp

precision of problem formulations, the appropriateness of research objectives, the suitability of methods, the clarity of research instruments, and the adequacy of data analysis. Initially, some groups still formulated titles that were too general and did not yet indicate clear research variables or a clear research focus. After receiving feedback, participants began refining their titles to include the research subject, variables, context, and benefits. This process demonstrated that hands-on practice and feedback play a crucial role in helping teachers transform their initial ideas into more systematic research designs.

At the end of the activity, each group presented a research idea they had developed based on the worksheet and the STEM-ESD KIT (see Figure 3). These presentations allowed participants to explain the problem, objectives, methods, and potential for implementing the research in science education. Other participants provided feedback on the feasibility of the ideas, the measurability of the data, the safety of the tools and materials, and the alignment with STEM-ESD principles. The presentation activity also trained teachers to critically assess the quality of research designs based on the provided rubric. Thus, this training not only enhanced individual understanding but also fostered a culture of collaboration in the development of scientific work within the MGMP community.

After completing the entire series of activities, participants took a posttest on STEM-ESD-based scientific research competencies. The research competency instrument covered eight indicators: identification of STEM-ESD-based research problems or topics; literature review and gap analysis; research design and methodology planning; academic ethics and integrity; data analysis and interpretation of results; scientific writing; use of technology and research collaboration; and integration of STEM-ESD and dissemination of results. The pretest and posttest results indicate an increase in teachers' research competencies after participating in the training. Data on the increase in science teachers' research competencies are presented in Table 1.

Based on Table 1, science teachers' scientific research competencies improved across all indicators after participating in the training. The average pretest score of 72.3% increased to 93.0% on the posttest. The average N-Gain of 0.74 indicates that the improvement in teachers' research competencies falls into the high category. These results indicate that STEM-ESD-based training and mentoring are effective in helping teachers understand the components of scientific research more systematically. This improvement occurred because participants not only received instructional materials but also practiced

**Table 1.** Results of the Analysis of STEM-ESD-Based Research Competencies in Science Teachers

| Research Competency Indicators | Pretest (%) | Posttest (%) | N-Gain | Criteria |
|---|---|---|---|---|
| Identification of STEM-ESD-based research problems/topics | 74.2 | 91.5 | 0.67 | Moderate |
| Literature review and gap analysis | 70.9 | 93.8 | 0.78 | High |
| Research design and methodology planning | 69.4 | 93.8 | 0.8 | High |
| Academic ethics and integrity | 75.0 | 91.9 | 0.68 | Moderate |
| Data analysis and interpretation of results | 70.6 | 96.7 | 0.89 | High |
| Scientific writing | 73.8 | 92.5 | 0.71 | High |
| Use of technology and research collaboration | 75.9 | 91.9 | 0.66 | Moderate |
| Integration of STEM-ESD and dissemination of results | 69.1 | 90.6 | 0.70 | Moderate |
| **Average** | **72.3** | **93** | **0.74** | **High** |

**Table 2.** Participants' Responses to the Training Program

| Evaluated Aspects | % | Criteria |
|---|---|---|
| **Aspects of Training Material Suitability** | | |
| The training materials are tailored to the needs of teachers in the era of 21st-century learning and the Fourth Industrial Revolution | 97.5 | Very good |
| The training materials are relevant to the need to enhance science teachers' competencies in guiding students' scientific research | 97.0 | Very good |
| The training materials align with the demands of 21st-century education and the advancement of the SDGs, particularly SDG 4 | 97.5 | Very good |
| The training materials clearly and systematically integrate the STEM approach with ESD | 96.5 | Very good |
| The training materials support the enhancement of teachers' capacity to competitively guide students' scientific research | 97.0 | Very good |
| **Average score for material suitability** | **97.1** | **Very good** |
| **Aspects of Training Presentation** | | |
| The objectives of the training were clearly communicated to the participants | 96.0 | Very good |
| The material was presented in a systematic and easy-to-understand manner | 95.0 | Very good |
| The training material was presented in an engaging way by the presenters | 96.0 | Very good |
| The presentation of the material made it easier for teachers to implement STEM-ESD in science education | 95.5 | Very good |
| The training encouraged teachers' active participation in discussions and the implementation of STEM-ESD in science education | 96.5 | Very good |
| **Average score for the training presentation** | **95.8** | **Very good** |
| **Average** | **96.45** | **Very good** |

designing research proposals through worksheets, group discussions, and coaching clinics.

Improvements across all indicators show that the training helped participants develop their research competencies more systematically. Participants began to transform general problems into contextual research topics, conduct literature reviews to identify gaps, determine realistic designs and methods, and understand the importance of research ethics such as permissions, safety, citations, and plagiarism prevention. The greatest improvement in the indicators for data analysis and interpretation of results shows that participants increasingly understand the importance of designing measurable data from the outset such as measurements, time, quantity,

efficiency, observational results, or specific changes related to the STEM-ESD KIT. Additionally, training through worksheets, group exercises, and coaching clinics helped participants draft more coherent proposals, utilize technology for research and data processing, and build collaborations through the MGMP. Participants also gained a deeper understanding that STEM-ESD is not merely a product or teaching aid, but must incorporate problems, scientific concepts, solution designs, measurable data, and sustainable benefits.

In addition to assessing research competencies, this activity also evaluated participants' feedback on the training program. Participant feedback was measured across two aspects: the relevance of the training material and the delivery of the training. Participant feedback indicates that the training received a "very good" rating. The average participant rating for all aspects was 96.45%. The data on participant feedback regarding the activity's implementation are presented in Table 2.

Based on Table 2, the material's relevance averaged 97.1%, placing it in the "very good" category. These results indicate that participants assessed the training material as aligned with the needs of science teachers in developing scientific research competencies. The material was also deemed relevant to 21st-century learning demands and to the advancement of SDG 4, as the activities guided teachers in linking science learning to sustainability issues. The integration of STEM and ESD in the training materials helped participants understand that scientific research can be developed from real-world problems relevant to students. Thus, the training material was considered appropriate because it provided direct benefits to teachers in teaching and guiding students' scientific research.

The training delivery aspect received an average score of 95.8%, placing it in the "very good" category. These results indicate that participants felt the training objectives were clearly communicated, the material was organized systematically, and the presenters delivered the content engagingly. The training delivery was also deemed helpful in enabling teachers to understand how to implement STEM-ESD in science education. In addition, group activities, discussions, and coaching clinics encouraged participants to engage actively during the sessions. This active engagement was a key factor because research competencies cannot be sufficiently developed through lectures alone; rather, they must be built through the hands-on experience of designing and refining research proposals.

Overall, the results of the activity indicate that capacity-building and action-learning-based training can enhance science teachers' research competencies in scientific writing. The training process which combined instruction, hands-on practice using the STEM-ESD kit, worksheet development, mentoring, and research idea presentations provided participants with a comprehensive learning experience. Teachers not only understood STEM-ESD concepts but also learned to transform contextual problems into structured research proposals. These results support the findings of Evardo and Abina (2023) that teacher capacity-building programs need to be designed based on actual research competency needs. These results are also consistent with Murro (2022), who states that research competency is related to teachers' ability to connect data, theory, and instructional decisions.

This training also demonstrates that STEM-ESD can serve as a relevant framework for guiding students' scientific projects in school. Through this approach, teachers can guide students to select real-world problems, design solutions, collect data, and explain the benefits of their research for the environment or society. Fathurohman et al. (2023) state that STEM-ESD can support quality education by connecting scientific concepts to the challenges of sustainable development. Kurniawan et al. (2025) also demonstrate that integrating STEM design thinking with ESD can strengthen scientific modeling skills. Therefore, this community service activity makes a practical contribution to the development of a teacher research training model that is contextual, applied, and sustainability-oriented.

The contribution of this activity lies in the development of a training model for science teachers' research projects that integrates research competencies, STEM-ESD, structured worksheets, and product-based mentoring. This model can be applied in MGMP activities because the process involves collective discussion, group practice, feedback, and follow-up plans. Teachers gain hands-on experience in drafting proposals that can be developed into student research projects for both learning activities and competitions. This activity also strengthens MGMP's role as a collaborative space for teachers to share ideas, evaluate research designs, and build a scientific mentoring ecosystem. Thus, this training not only enhances individual teachers' competencies but also has the potential to

strengthen the culture of research in schools sustainably.

## CONCLUSION

Community service activities in the form of training and research mentoring for STEM-ESD-based scientific papers successfully improved the research competencies of junior high school science teachers in Semarang. This was demonstrated by an increase in N-Gain scores across all research competency indicators ranging from moderate to high and by positive participant feedback on the training program. The presentation of materials, hands-on practice with STEM-ESD worksheets and kits, group discussions, coaching clinics, and research idea presentations helped teachers develop a more systematic understanding of the scientific paper-writing process. Participants rated the program as relevant and beneficial because it provided hands-on experience in identifying contextual problems, designing methods, determining measurable data, and integrating STEM and ESD elements into research designs. The results of this program are expected to strengthen science teachers' capacity to guide students' scientific projects and foster a culture of research in schools. However, the scope of participants remains limited, necessitating expansion to a broader scale and ongoing support.

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