15 (2) (2026) 235-246

Unnes Science Education Journal

Accredited Sinta 2

https://journal.unnes.ac.id/journals/usej

Developing Scientific Communication through Sustainability-Oriented STEM Project-Based Learning: Evidence from an Edible Film Project

Ova Dhea Ariesta✉, Dadan Rosana

DOI: http://dx.doi.org/10.15294/usej.v15i2. 54258

Universitas Negeri Yogyakarta, Indonesia

Article Info

Submitted 2026-06-12
Revised 2026-07-21
Accepted 2026-08-29

Keywords

Junior high school; Scientific communication; Socioscientific issues; STEM Project-Based Learning; Sustainability-oriented learning

Abstract

Developing scientific communication requires more than students' ability to convey information; it requires sustained opportunities to interpret evidence, communicate scientific ideas, and construct evidence-based conclusions through meaningful scientific practices. This study investigates the development of students' scientific communication skills within Sustainability-Oriented STEM Project-Based Learning through an edible film project. Scientific communication was conceptualized as a multidimensional competency involving identifying information, communicating scientific ideas, and constructing evidence-based conclusions. The study employed a quantitative repeated-measures classroom intervention design involving 22 seventh-grade students. Data were collected using an observation instrument and analyzed using descriptive statistics, the Friedman test, and Spearman rank correlation analysis. The results showed significant improvement across all dimensions of scientific communication throughout the three learning sessions ($p < 0.001$), with the greatest improvement observed in students' ability to construct evidence-based conclusions. Correlation analysis revealed significant relationships among all dimensions. These findings suggest that Sustainability-Oriented STEM Project-Based Learning provides opportunities for students to engage in collaborative inquiry, scientific reasoning, and communication through contextual sustainability issues. The findings indicate that scientific communication develops as an interconnected multidimensional competency in collaborative STEM learning experiences.

How to Cite

Ariesta, O. D., & Rosana, D. (2026). Developing Scientific Communication through Sustainability-Oriented STEM Project-Based Learning: Evidence from an Edible Film Project. *Unnes Science Education Journal*, 15(2), 235-246.

✉ Correspondence Author:
E-mail: ovadhea.2023@student.uny.ac.id

p-ISSN 2252-6617

INTRODUCTION

Scientific communication has increasingly been recognized as a fundamental competency in science education, particularly in preparing students to participate meaningfully in scientific practices and inquiry processes (National Research Council, 2012). Recent bibliometric studies further demonstrate growing international attention toward scientific communication research in STEM education, particularly in relation to collaborative inquiry, problem-solving, and scientific literacy development (Ishmuradova et al., 2023). This trend reflects the recognition that communication is not merely a supporting skill but an essential component of students' participation in science learning. Burns et al., (2003) define scientific communication as the use of communication processes that promote understanding, engagement, and personal responses to science. Scientific communication involves not only sharing information but also interpreting evidence, negotiating meaning, and constructing understanding through interaction. In classroom inquiry contexts, students are expected to articulate scientific reasoning, interpret evidence, and communicate explanations, making scientific communication particularly important in school science learning.

In the context of twenty-first century education, scientific communication is increasingly aligned with the competencies required for deep learning and lifelong learning. Darling-Hammond et al. (2020) emphasize that effective learning environments support students' abilities to process information, articulate ideas, and construct understanding through social interaction. Scientific communication functions as a bridge between cognitive processes and social learning, enabling students to externalize their reasoning, negotiate meaning, and refine their understanding through dialogue. Consequently, strengthening students' scientific communication skills has become an important goal of science education, particularly at the secondary school level, where students begin engaging with more abstract scientific ideas through classroom interaction. In science classrooms, communication is not only a learning outcome but also a core mechanism through which students construct scientific understanding (Jay, 1991; Scott & Mortimer, 2005). Therefore, promoting scientific communication is essential to support students' scientific literacy development and active participation in inquiry-based learning.

Importantly, scientific communication should not be conceptualized as a single, isolated skill. Prior studies highlight that scientific communication encompasses multiple interrelated dimensions, including processing scientific information, engaging in scientific discourse, and constructing evidence-based conclusions or arguments (Höttecke & Allchin, 2020; Jiménez-Aleixandre & Erduran, 2007; Mercer et al., 2009; Osborne, 2010). The abilities to identify relevant information, communicate scientific ideas, and participate in scientific conclusion-making are interconnected rather than independent processes. In this study, scientific communication is operationalized through three key dimensions: identifying scientific information, communicating ideas and evidence, and participating in collaborative scientific conclusion-making. These dimensions provide a framework for examining students' scientific communication development during collaborative inquiry activities (Galimova et al., 2025; Ruiz-Primo & Shavelson, 1996). Despite this theoretical recognition, empirical research has rarely examined how these dimensions develop simultaneously and interact during learning processes. As a result, scientific communication is frequently reported as a single outcome variable, providing limited understanding of its multidimensional nature in classroom learning environments.

These challenges become particularly evident at the secondary school level, especially in junior high school, where the development of scientific communication skills is both crucial and demanding. Students at this stage are transitioning from concrete to more abstract forms of scientific reasoning, yet classroom practices often remain focused on content acquisition rather than communicative engagement. This developmental stage is particularly important because early adolescents are transitioning from concrete operational thinking toward more abstract and formal reasoning processes. During this period, students begin to develop greater capacity for evidence evaluation, argument construction, and scientific explanation, yet often still require structured learning experiences to support these emerging competencies. Therefore, inquiry- and project-based STEM learning environments may provide valuable opportunities for fostering scientific communication during this critical developmental phase (Hilton, 2010; Maspul, 2024; Sani et al., 2026)

Previous studies indicate that junior high school students often experience difficulties in explaining scientific ideas coherently, interpreting data meaningfully, and constructing evidence-based conclusions (Berland & Reiser, 2009; Driver et al., 2000; Muspiroh et al., 2024; Pambayun et al., 2025; Putra et al., 2025). These challenges highlight the need for instructional approaches that intentionally support students' scientific communication development.

Project-Based Learning (PjBL), particularly when integrated with a STEM approach, has been widely recognized as a promising pedagogical model for fostering higher-order skills, including communication and collaboration. STEM Project-Based Learning emphasizes authentic problems, interdisciplinary integration, and student-centered inquiry, creating learning environments in which communication becomes an integral component of inquiry processes (Bybee, 2013; Capraro et al., 2013; English, 2016; Kelley & Knowles, 2016). Contemporary studies indicate that STEM project-based learning environments provide opportunities for students to collaboratively construct understanding through inquiry and problem-solving activities (Owens & Hite, 2022; Teo & Mabulo, 2024; Van Haaske & Samelik, 2025).

Within this framework, the use of edible film projects offers a contextualized and environmentally relevant learning experience. Edible films, often discussed in relation to sustainable packaging and environmental issues, provide a real-world context that connects scientific concepts with students' everyday experiences and environmental concerns (Sothornvit & Krochta, 2005; Souza et al., 2025). Such contextual learning environments support scientific communication by engaging students in authentic problem-solving situations rather than decontextualized classroom exercises (Faber et al., 2024).

Previous studies have widely reported the potential of STEM Project-Based Learning in improving students' communication and collaboration skills. However, scientific communication is often examined as a general learning outcome, providing limited insight into the developmental patterns of its individual dimensions and the relationships among these dimensions during learning processes. Consequently, further investigation is needed to understand whether identifying information, communicating scientific ideas, and constructing conclusions develop independently or as interconnected components of scientific communication within STEM learning experiences.

Furthermore, empirical studies examining these developmental relationships remain limited, particularly at the junior high school level and within sustainability-oriented socioscientific learning contexts. Therefore, this study investigates the multidimensional development of students' scientific communication skills and explores the relationships among its dimensions within a Sustainability-Oriented STEM Project-Based Learning environment through an edible film project context. Understanding these relationships is important because scientific communication in classroom inquiry does not occur through isolated actions; rather, students continuously move between identifying information, communicating ideas, and constructing conclusions as part of a single meaning-making process.

This study aims to (1) examine the development of students' scientific communication skills across repeated learning sessions within a Sustainability-Oriented STEM Project-Based Learning environment, and (2) analyze the relationships among the dimensions of scientific communication skills during an edible film project.

METHOD

This study employed a quantitative repeated-measures classroom intervention design to examine the development of students' scientific communication skills across three consecutive learning sessions. Repeated observations of the same participants enabled the identification of patterns of change following the instructional intervention without involving control or comparison groups.

The participants consisted of 22 seventh-grade students from a private junior high school in Sleman, Yogyakarta, Indonesia. The study was conducted during the second semester of the 2024/2025 academic year within the ecology and environmental pollution topic. Each learning session lasted approximately 80–120 minutes and was implemented across three consecutive meetings.

A convenience sampling technique was employed because the selected class was accessible to the researchers and aligned with the instructional context of the study. The school had initiated efforts to integrate STEM learning into its curriculum; however, science practical activities had previously been conducted primarily through virtual simulations due to limitations in laboratory facilities and equipment. Therefore, the class was selected to implement a hands-on STEM Project-Based Learning experience through an edible film project.

Considering the classroom-based nature of this study, the findings should be interpreted within the scope of this specific learning context. The limited sample size and single-school setting may restrict statistical power and the generalizability of the findings to broader student populations.

The learning intervention integrated contextual environmental issues related to plastic pollution through project-based activities involving the design and testing of edible film as an alternative packaging material. In the first meeting, students were introduced to ecological concepts and environmental pollution problems, during which observations were conducted to capture students' initial scientific communication skills. In the second meeting, students explored the impacts of plastic waste and designed edible film prototypes using different material compositions through group experimentation. In the third meeting, students tested and evaluated the produced edible films based on physical characteristics such as elasticity, thickness, and tear resistance, followed by group discussions and the formulation of conclusions regarding environmentally friendly solutions.

Data were collected using an observation instrument developed by the researchers to assess students' scientific communication skills. The instrument was constructed through a synthesis of multiple theoretical frameworks to ensure conceptual validity, including the Toulmin Argument Pattern (Erduran et al., 2004), science communication competencies (Aurbach et al., 2019), and the EEES framework (Wack et al., 2021). These frameworks informed the development of indicators related to evidence-based reasoning, scientific communication, and collaborative conclusion-making. Based on this synthesis, three aspects of scientific communication skills were identified: (1) identifying and evaluating information, (2) communicating scientific information, and (3) constructing and presenting evidence-based conclusions. Each aspect was operationalized into observable student behaviors as presented in Table 1.

Each aspect consisted of three observable indicators assessed using a four-point Likert-type scale ranging from 1 (very low) to 4 (very high) (Ferrando et al., 2025; Koo & Yang, 2025). The instrument underwent content validation through expert judgment involving two university lecturers in science education. Validation focused on indicator relevance, conceptual accuracy, language clarity, presentation quality, and usability. The content validity was quantified using Aiken's V coefficient based on expert judgments. The average Aiken's V value across the assessed aspects was 0.976, indicating a very high level of content validity for the instrument. Minor revisions were incorporated based on expert feedback prior to implementation.

Table 1. Indicators of Students' Scientific Communication Skills

Aspect	Observable Indicators
Identifying and Evaluating Information	1. Uses appropriate information sources (e.g., eBook, infographic, video) during discussion
	2. Selects relevant information to answer questions
	3. Applies appropriate scientific concepts when expressing ideas
Communicating Scientific Information	1. Presents information clearly and in a logical sequence
	2. Uses visual aids (e.g., slides, posters, infographics) to support explanations
	3. Responds to questions with clear and logical reasoning
Constructing and Presenting Evidence-Based Conclusions	1. Contributes arguments to support group conclusions
	2. Connects conclusions with analyzed data or information
	3. Presents conclusions clearly to peers

To ensure consistency in data collection, three observers participated in a calibration session conducted by the researchers to develop a shared understanding of scoring criteria and rubric interpretation. Inter-rater reliability was assessed using the Intraclass Correlation Coefficient (ICC). The analysis showed excellent agreement among observers, with an ICC value of 0.948 for single measures and 0.982 for average measures, indicating strong consistency among observer ratings. Scores for each aspect were obtained by averaging the ratings across the corresponding indicators for all participants.

Descriptive statistics were used to describe the progression of students' scientific communication skills across the three measurement points, supported by graphical representations. Prior to inferential analysis, the normality assumption was examined using the Shapiro-Wilk test.

Table 2. Results of Shapiro-Wilk Normality Test

Aspect	Sig. (p-value) meeting		
	1	2	3
Identifying	0.005	0.034	0.015
Communicating	0.001	0.006	0.027
Conclusion Making	0.006	0.003	0.011

The results indicated that all dimensions of scientific communication across the three measurement sessions showed significant deviations from normality ($p < 0.05$). Therefore, non-parametric statistical procedures were applied.

Inferential statistical analysis was conducted using the Friedman test to determine whether significant differences existed across repeated observations. The Friedman test is appropriate for non-parametric repeated measures data (Field, 2013). When significant differences were identified, mean rank values were examined to interpret the direction of change across meetings. Additionally, Spearman rank correlation analysis was conducted to examine relationships among the three aspects of scientific communication skills. Spearman correlation is suitable for ordinal data and non-normal distributions (Field, 2013). Correlation strength was interpreted based on Cohen (2013) criteria, where coefficients of 0.10–0.29 indicate weak, 0.30-0.49 moderate, and ≥0.50 strong correlations. All analyses were performed using SPSS software.

RESULT AND DISCUSSION

The results indicate a consistent improvement in students' scientific communication skills across the three learning meetings. As presented in Figure 1, all observed aspects, namely identifying information, communicating information, and participating in scientific conclusion-making, showed a consistent upward trend across the three meetings. This pattern suggests that students' scientific communication skills developed gradually through repeated engagement in collaborative learning activities rather than through a single instructional exposure. This developmental trajectory aligns with recent evidence demonstrating that critical competencies in science education cannot be mastered instantaneously; instead, they require sustained, cyclical engagement in collaborative problem-solving tasks to allow skills to mature over time (Angeloska-Galevska, 2023; Torrijos-Martí, 2026).

The visual trend shown in Figure 1 suggests that STEM Project-Based Learning supports scientific communication through repeated engagement in collaborative inquiry and problem-solving activities. Throughout the learning cycles, students engaged in explaining ideas, interpreting evidence, negotiating meaning, and reflecting on group findings. Such processes suggest that communication functions as an integral component of constructing and sharing scientific understanding rather than merely as an additional learning outcome within STEM learning environments (Firetto et al., 2023; Ishmuradova et al., 2023; Owens & Hite, 2022).

To examine whether the observed improvements across the three learning meetings were statistically significant, a Friedman test was conducted for each dimension of scientific communication. The results indicated significant differences across the three measurement points, as presented in Table 2. These findings demonstrate that students' scientific communication skills developed progressively throughout the Sustainability-Oriented STEM Project-Based Learning implementation.

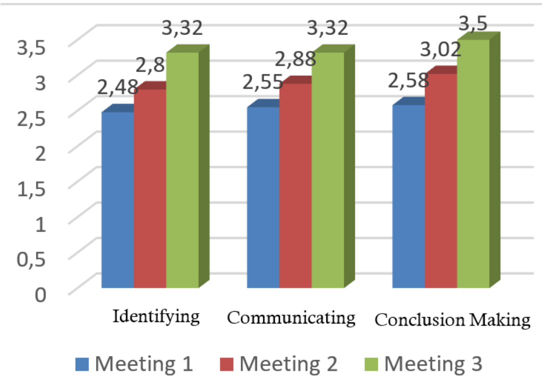

Figure 1. Mean scores of students' scientific communication dimensions across three learning meetings

Table 3. Results of Friedman Test for Each Aspect of Scientific Communication

Aspect	Meeting			x^2 (df=2)	p-value
	1	2	3		
Identifying	1.20	1.89	2.91	37.013	*< 0.001*
Communi-cating	1.23	1.93	2.84	33.787	*< 0.001*
Conclusion Making	1.05	1.98	2.98	42.518	*< 0.001*

Although all dimensions demonstrated significant improvement across learning sessions, the magnitude of development differed among aspects of scientific communication. The identifying information dimension showed progressive improvement throughout the STEM project implementation. This pattern suggests that students gradually became more capable of recognizing relevant scientific concepts, selecting appropriate information, and connecting scientific knowledge with the problems investigated during the edible film project. Such improvement is consistent with previous studies indicating that inquiry-oriented STEM environments support students in identifying, evaluating, and interpreting scientific information through authentic investigation processes (Arifin et al., 2025; Faber et al., 2024; Vo & Simmie, 2025)

A similar improvement pattern was observed in students' ability to communicate scientific information. The development of this dimension indicates that collaborative STEM activities provided opportunities for students to articulate ideas, negotiate meanings, and justify explanations during group discussions. These interaction processes represent important characteristics of project-based STEM learning, where communication and collaborative reasoning are developed through problem-solving activities (Faif Pasani & Amelia, 2024; Teo & Mabulo, 2024).

The greatest improvement occurred in students' participation in scientific conclusion-making. This finding suggests that the edible film project supported students in integrating information, evaluating evidence, and constructing explanations related to environmental problems. The socioscientific context embedded within the project may have encouraged students to move beyond describing information toward making evidence-based decisions. Previous studies have highlighted that socioscientific STEM contexts facilitate the coordination of evidence, reasoning, and decision-making in scientific communication activities (Bozkurt Altan et al., 2018; Dauer et al., 2025; Lesnefsky et al., 2025; Macalalag et al., 2020). This pattern may indicate that repeated collaborative inquiry activities gradually supported students in integrating evidence, discussion outcomes, and contextual reasoning into more comprehensive scientific conclusions.

Collectively, these findings demonstrate that all aspects of scientific communication improved significantly over time, with the strongest development observed in students' ability to formulate scientific conclusions. This pattern suggests that while foundational skills such as identifying and communicating information may develop earlier, more complex skills such as conclusion-making may require more sustained engagement in inquiry-based learning activities

To further substantiate this developmental pattern, a Spearman rank correlation analysis was conducted to examine the relationships among the aspects of scientific communication. The results revealed significant positive correlations among all observed aspects, suggesting that these skills are interconnected and tend to develop in a coordinated manner. More importantly, these findings suggest that scientific communication may be better understood as an integrated system of competencies rather than as separate communication skills. The observed correlations indicate that these dimensions were closely related throughout the learning process. This perspective extends beyond viewing scientific communication solely as an outcome and instead highlights its multidimensional nature within collaborative STEM learning environments.

Table 4. Spearman Rank Correlation Among Aspects of Scientific Communication

Variables	Identifying	Communicating	Conclusion Making
Identifying	1.000	0.648**	0.765**
Communicating	0.648**	1.000	0.534*
Conclusion Making	0.765**	0.534*	1.000

The correlation analysis revealed meaningful relationships among dimensions of scientific communication. The strongest relationship was found between identifying scientific information and participating in conclusion-making, suggesting that students' ability to recognize and process relevant information was closely associated with their ability to construct evidence-based conclusions. Within the STEM project context, students were required to identify scientific information related to environmental issues and use this information to develop solutions, which may explain the connection between these two dimensions (Arifin et al., 2025; Vo & Simmie, 2025).

A positive relationship was also observed between identifying information and communicating information. This finding indicates that students who were better able to organize scientific information tended to demonstrate stronger abilities in expressing scientific ideas clearly. Such a relationship aligns with sociocultural perspectives that emphasize the role of interaction and knowledge construction in the development of scientific communication (Kreijns et al., 2022; Lehtinen et al., 2023).

Meanwhile, the relationship between communicating information and conclusion-making was comparatively weaker. This pattern suggests that communicating ideas and constructing scientific conclusions represent related but distinct cognitive processes. Although students may actively exchange ideas during discussions, developing evidence-based conclusions requires additional processes, including evaluating evidence, integrating information sources, and justifying claims. This finding is consistent with previous research indicating that early adolescent learners may experience challenges in transforming collaborative discussions into coherent scientific arguments (Murty et al., 2016; Wen et al., 2023).

Based on (Cohen, 2013) interpretation guidelines, the observed coefficients indicate moderate to strong relationships among the dimensions of scientific communication. These findings suggest that scientific communication skills develop as interconnected competencies that mutually reinforce one another during collaborative STEM learning activities. Similar patterns have been reported in STEM education studies showing that communication, reasoning, and collaborative inquiry tend to develop simultaneously when students engage in authentic project-based tasks (Le et al., 2025; Liu et al., 2026; Wahono et al., 2025).

The strong correlations among the dimensions may reflect the collaborative nature of STEM Project-Based Learning, in which students continuously exchange information and construct shared explanations during project activities. This finding supports previous STEM education studies emphasizing the role of collaborative inquiry and peer interaction in the development of scientific communication competencies (Baze et al., 2023; Firetto et al., 2023; Fitria et al., 2025).

Rather than functioning as separate communication skills, the observed dimensions appeared to develop as a coordinated system throughout the learning process. Students who became more capable of identifying relevant scientific information also tended to communicate ideas more effectively and construct stronger evidence-based conclusions. This pattern suggests that scientific communication development may be better understood as a multidimensional process in which cognitive, communicative, and reasoning practices interact continuously during inquiry activities. Within the sustainability-oriented STEM Project-Based Learning environment, students were not merely asked to communicate scientific ideas; they were simultaneously required to interpret information, negotiate meaning, evaluate evidence, and formulate conclusions. Consequently, the development of one dimension may have supported the development of others, reinforcing scientific communication as an integrated competency rather than a collection of isolated skills.

This finding aligns with sociocultural perspectives of learning, which view communication, reasoning, and knowledge construction as mutually constitutive processes that develop through participation in collaborative activities. From this perspective, scientific communication is not merely a means of expressing understanding but also a mechanism through which understanding itself is constructed and refined.

The observed improvement across all aspects of scientific communication may be associated with the characteristics of STEM Project-Based Learning, which emphasizes active engagement, collaboration, and authentic problem-solving. Within such learning environments, communication becomes a functional component of inquiry, as students are required to articulate ideas, negotiate meaning, and justify reasoning throughout project activities (Sivaraj et al., 2021; Vincent-Lancrin et al., 2019; Wiggins et al., 2021).

The iterative nature of project-based learning also plays a significant role in supporting this development. Across the three measurement points, students were continuously engaged in cycles of planning, experimenting, discussing, and reflecting. These repeated opportunities allowed students to gradually refine both conceptual understanding and scientific communication skills. This finding supports the perspective that communication skills develop progressively through sustained practice and social interaction rather than through isolated instructional activities (Darling-Hammond et al., 2020; Reith-Hall & Montgomery, 2023; Wayal, 2025).

The observed improvement in identifying information and constructing conclusions reflects the development of evidence-based reasoning practices. The ability to identify relevant information serves as the foundation for building scientific arguments, while the ability to construct conclusions represents a higher-order integration of evidence and reasoning. This progression is consistent with the framework of scientific argumentation, where data and evidence function as the basis for constructing claims (Osborne, 2010; Toulmin, 2003).

The use of the edible film project as a contextual learning medium further strengthened this process. Unlike abstract or decontextualized classroom tasks, the edible film project provided a tangible and meaningful problem related to environmental issues, particularly plastic pollution and sustainable alternatives. This context required students not only to understand scientific concepts but also to apply them in decision-making situations, such as comparing material properties and evaluating experimental results. Contextual and socioscientific learning environments have been shown to enhance students' engagement and communication by connecting scientific concepts with real-world issues (Kumar et al., 2024; Nuangchalerm, 2010; Viehmann et al., 2024).

Such a context creates authentic communicative demands. Rather than merely completing classroom tasks, students were engaged in explaining, arguing, and justifying ideas within meaningful real-world contexts. This supports the view of scientific communication as a situated practice in which knowledge is constructed and expressed within meaningful contexts (Burns et al., 2003; Fischer et al., 2024; Fuentes-Cancell et al., 2026; Santhiago, 2025).

Unlike many previous studies that treat scientific communication as a generalized learning outcome, this study examined its multidimensional development through repeated classroom observation within a sustainability-oriented STEM Project-Based Learning context. The edible film project connected ecological concepts with real-world environmental issues, allowing students to engage in scientific communication through meaningful problem-solving activities. These findings suggest that sustainability-oriented STEM learning has strong potential to support the development of scientific communication in junior high school science education.

The overall pattern indicates that scientific communication develops as an integrated process involving reasoning, collaboration, and contextual problem-solving within STEM Project-Based Learning environments. These findings have several implications for science education practice. First, scientific communication appears to develop more effectively when integrated throughout the learning process rather than treated solely as a final assessment outcome. Learning activities that continuously engage students in expressing, discussing, and refining ideas may better support scientific communication development. This aligns with sociocultural perspectives emphasizing that communication develops through interaction and collaborative meaning-making processes (Firetto et al., 2023; Owens & Hite, 2022).

Second, instructional strategies should emphasize the integration of cognitive and communicative processes. The development of scientific communication is closely linked to students' ability to process information, reason with evidence, and articulate ideas. Therefore, learning environments should be designed to support these processes simultaneously.

Finally, the use of contextual and project-based learning approaches, particularly those connected to real-world and sustainability issues, can provide meaningful opportunities for students to develop scientific communication skills. Such approaches not only enhance student engagement but also prepare learners to participate more effectively in scientific discourse beyond classroom contexts.

Despite these findings, this study has several limitations. The study involved a relatively small number of participants from a single classroom context, which may limit the generalizability of the findings. In addition, the intervention was conducted over a relatively short period and may not fully capture the long-term development of students' scientific communication skills. Although observer calibration was conducted prior to data collection, observational assessment inherently involves the possibility of subjective interpretation during classroom interactions.

Furthermore, this study relied primarily on observational measures and did not examine students' perceptions or long-term communication development beyond the intervention period. Future studies may involve larger participant groups, multiple school contexts, and mixed-method approaches. In particular, qualitative analyses of students' discussion transcripts, argumentation patterns, and collaborative interactions may provide deeper insight into how the dimensions of scientific communication develop and interact throughout STEM learning processes.

CONCLUSION

This study demonstrates that the implementation of Sustainability-Oriented STEM Project-Based Learning was associated with the progressive development of students' scientific communication skills across repeated learning sessions. All dimensions, including identifying information, communicating ideas, and constructing conclusions, showed progressive development, with the greatest improvement observed in students' ability to formulate evidence-based conclusions. These findings indicate that scientific communication is a multidimensional and interconnected competency, in which the development of different dimensions occurs in relation to one another. The edible film project provided a meaningful sustainability-oriented context that encouraged students to engage in scientific reasoning, communication, and collaborative problem-solving, supporting the development of scientific communication as an integrated set of competencies rather than isolated skills. These findings highlight the importance of embedding communication throughout learning activities rather than treating it solely as a final learning outcome. Overall, Sustainability-Oriented STEM Project-Based Learning demonstrates potential for fostering interconnected scientific communication practices among junior high school students.

REFERENCES

Angeloska-Galevska, N. (2023). Developing Research and Academic Competencies of Students through Three Cycles of Studies. *Education & Social Sciences (EPESS),* 33, 63–69. www.isres.org

Arifin, Z., Sukarmin, S., Saputro, S., & Kamari, A. (2025). The effect of inquiry-based learning on students' critical thinking skills in science education: A systematic review and meta-analysis. *Eurasia Journal of Mathematics, Science and Technology Education,* 21(3), em2592. https://doi.org/10.29333/ejmste/15988

Aurbach, E. L., Prater, K. E., Fellow, R., Cloyd, E. T., & Lindenfeld, L. (2019). *Foundational Skills for Science Communication: A Preliminary Framework [White Paper]*. https://doi.org/10.3998/2027.42/150489

Baze, C., González, Howard, M., Sampson, V., Fenech, M., Crawford, R., Hutner, T., Chu, L., & Hamilton, X. (2023). Understanding student use of epistemic criteria in engineering design contexts. *Science Education*, 107(4), 1033–1067. https://doi.org/10.1002/sce.21795

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education,* 93(1), 26–55. https://doi.org/10.1002/sce.20286

Bozkurt Altan, E., Ozturk, N., & Yenilmez Turkoglu, A. (2018). Socio-Scientific Issues as a Context for STEM Education: A Case Study Research with Pre-Service Science Teachers. *European Journal of Educational Research,* 7(4), 805–812. https://doi.org/10.12973/eu-jer.7.4.805

Burns, T. W., O'Connor, D. J., & Stocklmayer, S. M. (2003). Science Communication: A Contemporary Definition. *Public Understanding of Science,* 12(2), 183–202. https://doi.org/10.1177/09636625030122004

Bybee, R. W. (2013). *The Case for Education: STEM Challenges and Opportunities.* NSTA (National Science Teachers Assocation).

Capraro, R. M., Capraro, M. M., & Morgan, J. R. (2013). *STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach, Second Edition.* In STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach, Second Edition. https://doi.org/10.1007/978-94-6209-143-6

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences.* In Statistical Power Analysis for the Behavioral Sciences (Second Edi). Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203771587

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science,* 24(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791

Dauer, J. M., Kirby, C. K., & Sorensen, A. E. (2025). Defining students' socioscientific issues classroom decision-making components and practice proficiencies. *Disciplinary and Interdisciplinary Science Education Research,* 7(1), 12. https://doi.org/10.1186/s43031-025-00132-0

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education,* 84(3). https://doi.org/10.1002/(sici)1098-237x(200005)84:3<287::aid-sce1>3.0.co;2-a

English, L. D. (2016). STEM education K-12: perspectives on integration. *International Journal of STEM Education*, 3(1), 3. https://doi.org/10.1186/s40594-016-0036-1

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education,* 88(6). https://doi.org/10.1002/sce.20012

Faber, E. S. L., Colthorpe, K., Ainscough, L., & Kibedi, J. (2024). Students' approaches to developing scientific communication skills. *Advances in Physiology Education,* 48(3), 639–647. https://doi.org/10.1152/advan.00009.2024

Faif Pasani, C., & Amelia, R. (2024). *Developing Collaborative Skills through STEM Approach*. https://doi.org/10.5772/intechopen.113880

Ferrando, P. J., Morales-Vives, F., Casas, J. M., & Muñiz, J. (2025). Likert Scales: A Practical Guide to Design, Construction and Use. *Psicothema,* 37(4), 1–15. https://doi.org/10.70478/psicothema.2025.37.24

Field, A. (2013). *Discovering statistics using IBM SPSS statistics.* In Statistics (4th Editio, Vol. 58). SAGE Publications. https://books.google.co.id/books?id=c0Wk9IuBmAoC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Firetto, C. M., Starrett, E., & Jordan, M. E. (2023). Embracing a culture of talk: STEM teachers' engagement in small-group discussions about photovoltaics. *International Journal of STEM Education,* 10(1), 50. https://doi.org/10.1186/s40594-023-00442-7

Fischer, L., Barata, G., Scheu, A. M., & Ziegler, R. (2024). Connecting science communication research and practice: challenges and ways forward. *Journal of Science Communication*, 23(02). https://doi.org/10.22323/2.23020501

Fitria, A. R., Hasnunidah, N., Fadiawati, N., & Suyatna, A. (2025). Enhancing Scientific Argumentation through the Integration of Argument-Driven Inquiry and STEM in E-Worksheets for Secondary Science Education. *Jurnal Penelitian Pendidikan IPA,* 11(7), 263–272. https://doi.org/10.29303/jppipa.v11i7.11603

Fuentes-Cancell, D. R., Estrada-Molina, O., & Gutiérrez-Ortega, M. (2026). Developing Science Communication Competence in Initial Teacher Training. *Education Sciences,* 16(1), 86. https://doi.org/10.3390/educsci16010086

Galimova, E. G., Sergeeva, O. V., Zheltukhina, M. R., Sokolova, N. L., Zakharova, V. L., & Drobysheva, N. N. (2025). Mobile learning in science education to improve higher-order thinking skills and communication skills: scoping review. *Frontiers in Communication,* 10. https://doi.org/10.3389/fcomm.2025.1624012

Hilton, M. (2010). *Adolescents' developing capacity for 21st century skills.* In Exploring the intersection of Science education and 21st Century skills: A workshop summary (pp. 30–39). National Academies Press. https://www.ncbi.nlm.nih.gov/books/NBK32685/

Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature of science education in the age of social media. *Science Education,* 104(4), 641–666. https://doi.org/10.1002/sce.21575

Ishmuradova, A. M., Svintsova, M. N., Kondakchian, N. A., Zaitseva, N. A., Sokolova, N. L., & Khairullina, E. R. (2023). A bibliometric overview of science communication research in STEM education. *Online Journal of Communication and Media Technologies,* 13(4), e202341. https://doi.org/10.30935/ojcmt/13415

Jay, L. (1991). *Talking science: language, learning, and values.* In Choice Reviews Online (Vol. 28, Issue 09). https://doi.org/10.5860/choice.28-5211

Jiménez-Aleixandre, M. P., & Erduran, S. (2007). Argumentation in Science Education: An Overview. *In Revista Brasileira de Linguística Aplicada* (Vol. 5, Issue 1, pp. 3–27). https://doi.org/10.1007/978-1-4020-6670-2_1

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Koo, M., & Yang, S.-W. (2025). Likert-Type Scale. *Encyclopedia*, 5(1), 18. https://doi.org/10.3390/encyclopedia5010018

Kreijns, K., Xu, K., & Weidlich, J. (2022). Social Presence: Conceptualization and Measurement. *Educational Psychology Review,* 34(1), 139–170. https://doi.org/10.1007/s10648-021-09623-8

Kumar, V., Choudhary, S. K., & Singh, R. (2024). Environmental socio-scientific issues as contexts in developing scientific literacy in science education: A systematic literature review. *Social Sciences & Humanities Open,* 9, 100765. https://doi.org/10.1016/j.ssaho.2023.100765

Le, N. H. M., Mai, U. H. P., & Nguyen, A. T. K. (2025). Students' Collaborative Performance Through Stem Topic "Led Card – Light It Up" for 8Th Grade. *Jurnal Pendidikan IPA Indonesia*, 14(1), 83–92. https://doi.org/10.15294/jpii.v14i1.15761

Lehtinen, A., Kostiainen, E., & Näykki, P. (2023). Co-construction of knowledge and socioemotional interaction in pre-service teachers' video-based online collaborative learning. *Teaching and Teacher Education,* 133, 104299. https://doi.org/10.1016/j.tate.2023.104299

Lesnefsky, R. R., Elsner, J., Kirk, E. A., Yeldell, J., Ke, L., & Sadler, T. D. (2025). Exploring Resources and Reasoning Practices in Socioscientific System Modeling for Justice-Centered Science Education. *CBE—Life Sciences Education*, 24(1). https://doi.org/10.1187/cbe.24-01-0017

Liu, S., Xu, M., & Chen, Y.-C. (2026). Navigating Scientific Uncertainty Through Scripted Collaborative Argumentation: Effects on Conceptual Understanding, Critical Thinking, and Learning Engagement. *Science & Education*. https://doi.org/10.1007/s11191-026-00740-w

Macalalag, A. Z., Johnson, J., & Lai, M. (2020). How do we do this: learning how to teach socioscientific issues. *Cultural Studies of Science Education,* 15(2), 389–413. https://doi.org/10.1007/s11422-019-09944-9

Maspul, K. A. (2024). Enhancing Project-Based Learning in STEM Education with Integrated Technology and Coding. *Journal of Intelligent Systems and Information Technology,* 1(1), 16–24. https://doi.org/10.61971/jisit.v1i1.20

Mercer, N., Dawes, L., & Staarman, J. K. (2009). Dialogic teaching in the primary science classroom. *Language and Education,* 23(4), 353–369. https://doi.org/10.1080/09500780902954273

Murty, V. P., Calabro, F., & Luna, B. (2016). The role of experience in adolescent cognitive development: Integration of executive, memory, and mesolimbic systems. *Neuroscience and Biobehavioral Reviews*, 70, 46–58. https://doi.org/10.1016/j.neubiorev.2016.07.034

Muspiroh, N., Shofiyah, S., Nada, S., & Kusmawan, U. (2024). Enhancing Students' Scientific Argumentation Skills through STEM-Based Problem Based Learning. *International Journal of Research in STEM Education*, 6(1), 85–96. https://doi.org/10.33830/ijrse.v6i1.1691

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* In A Framework for K-12 Science Education: Practices, Crosscutting

Concepts, and Core Ideas. National Academies Press. https://doi.org/10.17226/13165

Nuangchalerm, P. (2010). Engaging students to perceive nature of science through socioscientific issues-based instruction. *European Journal of Social Sciences*, 13(1), 34–37.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, 328(5977), 463–466. https://doi.org/10.1126/science.1183944

Owens, A. D., & Hite, R. L. (2022). Enhancing student communication competencies in STEM using virtual global collaboration project based learning. *Research in Science & Technological Education,* 40(1), 76–102. https://doi.org/10.1080/02635143.2020.1778663

Pambayun, P. P., Ernawati, T., & Astuti, S. (2025). Enhancing Scientific Argumentation Skills through Problem- Based Learning in Science Education at SMP Negeri 8 Yogyakarta. *Proceedings of International Conference on Teacher Profession Education*, 3(1), 768–794. https://seminar.ustjogja.ac.id/index.php/ICoTPE/article/view/3461

Putra, P. D. A., Wahyuni, S., Sulaeman, N. F., Handayani, R. D., & Yustika, D. (2025). Enhancing scientific communication skills in junior high school pupils: A mixed methods investigation of engineering design process tools. *Journal of Turkish Science Education,* 22(3), 436–450. https://doi.org/10.36681/tused.2025.022

Reith-Hall, E., & Montgomery, P. (2023). Communication skills training for improving the communicative abilities of student social workers: A systematic review. *Campbell Systematic Reviews,* 19(1). https://doi.org/10.1002/cl2.1309

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching,* 33(6), 569–600. https://doi.org/10.1002/(SICI)1098-2736(199608)33:6<569::AID-TEA1>3.0.CO;2-M

Sani, D. M., Saputro, S., Sukarmin, S., & Sugiharto, B. (2026). Synthesizing Inquiry and STEM for Junior High School: Content Validity and Theoretical Framework of a New Instructional Learning Model. *International Journal of Learning, Teaching and Educational Research,* 25(4), 104–119. https://doi.org/10.26803/ijlter.25.4.5

Santhiago, M. R. (2025). Communicating science: a responsibility on par with scientific practice. *Arquivos Brasileiros de Oftalmologia*, 88(5), 1–3. https://doi.org/10.5935/0004-2749.2024-1017

Scott, P., & Mortimer, E. (2005). Meaning Making in High School Science Classrooms: A Framework for Analysing Meaning Making Interactions. In Research and the Quality of Science Education (pp. 395–406). *Springer Netherlands.* https://doi.org/10.1007/1-4020-3673-6_31

Sivaraj, R., Wieselmann, J. R., & Roehrig, G. (2021). Designing Solutions in Middle School Engineering: An Exploration of Epistemic Practices of Engineering in Small Group Contexts (Work in Progress). *ASEE Annual Conference and Exposition, Conference Proceedings*. https://doi.org/10.18260/1-2--36930

Sothornvit, R., & Krochta, J. M. (2005). Plasticizers in edible films and coatings. *In Innovations in Food Packaging (pp. 403–433).* https://doi.org/10.1016/B978-012311632-1/50055-3

Souza, P. S., Grisi, C. V. B., Silva, R. de C. A., Silva, E. M. da, Silva, F. A. P. da, & Souza, A. L. de. (2025). From Food Waste to Edible Packaging: Development and Characterization of Biodegradable Gelatin Films with Microfibrillated Cellulose from Cowpea Pod Skin (Vigna unguiculata) and Corn Straw (Zea mays). *Foods*, 14(17), 3033. https://doi.org/10.3390/foods14173033

Teo, T. W., & Mabulo, S. J. S. B. (2024). Examining 'STEM Education as Culture' through an Analysis of Lesson Plans as Cultural Apparatus. *Research in Integrated STEM Education,* 2(2), 147–181. https://doi.org/10.1163/27726673-bja00022

Torrijos-Martí, I. (2026). Beyond fluency: perceived professional growth across repeated simulation cycles in scientific english for psychology. *Frontiers in Education,* 11. https://doi.org/10.3389/feduc.2026.1855680

Toulmin, S. E. (2003). *The uses of argument: Updated edition.* In The Uses of Argument: Updated Edition. https://doi.org/10.1017/CBO9780511840005

Van Haaske, L., & Samelik, Y. (2025). Interdisciplinary project-based learning in STEM education: Advantages and specifics of organization. *AIP Conference Proceedings,* 3268(1), 060008. https://doi.org/10.1063/5.0257332

Viehmann, C., Fernández Cárdenas, J. M., & Reynaga Peña, C. G. (2024). The Use of Socioscientific Issues in Science Lessons: A Scoping Review. *Sustainability*, 16(14), 5827. https://doi.org/10.3390/su16145827

Vincent-Lancrin, S., González-Sancho, C., Bouckaert, M., de Luca, F., Fernández-Barrerra, M., Jacotin, G., Urgel, J., & Vidal, Q. (2019). Fostering students' creativity and critical thinking. *In Educational Research and Innovation.*

Vo, D. Van, & Simmie, G. M. (2025). Assessing Scientific Inquiry: A Systematic Literature Review of Tasks, Tools and Techniques. *International Journal of Science and Mathematics Education,* 23(4), 871–906. https://doi.org/10.1007/s10763-024-10498-8

Wack, J., Jaeger, C., Yuan, S., & Bergan-Roller, H. E. (2021). A Framework & Lesson to Engage Biology Students in Communicating Science with Nonexperts. *The American Biology Teacher*, 83(1), 17–25. https://doi.org/10.1525/abt.2021.83.1.17

Wahono, B., Purmanna, A., Ramadhani, R., & Manalu, M. S. (2025). Strengthens the Student Collaboration and Decision-making Skills through Integrated STEM Education: A Research and Development Study. *Science Education International,* 36(1), 86–93. https://doi.org/10.33828/sei.v36.i1.9

Wayal, L. S. (2025). A Framework for Developing Communication Skills Through Structured School-Based Learning Activities. *International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)*, 2(2), 1279–1290. https://doi.org/10.65578/ijarmt.v2.i2.676

Wen, Z., Lin, T. J., Glassman, M., Kim, S., Tilak, S., Nagpal, M., & Ha, S. Y. (2023). The Development of Early Adolescents' Social Perspective Taking Through Small-Group Discussion. *Journal of Early Adolescence,* 43(9), 1129–1163. https://doi.org/10.1177/02724316221149630

Wiggins, B. L., Sefi-Cyr, H., Lily, L. S., & Dahlberg, C. L. (2021). Repetition Is Important to Students and Their Understanding during Laboratory Courses That Include Research. *Journal of Microbiology & Biology Education,* 22(2). https://doi.org/10.1128/jmbe.00158-21

.