Students' Perceptions of STEM Careers, Systems Thinking, Communication, and Teamwork in Chemistry Learning: A Gender-Based Survey

Shaffira Noor Fatima, Ari Syahidul Shidiq*, Sri Yamtinah, Agung Nugroho Catur Saputro

Universitas Sebelas Maret, Ir. Sutami St. No. 36A, Surakarta, Central Java, 57126, Indonesia
*Corresponding author, email: arishidiq@staff.uns.ac.id

https://doi.org/10.17977/um065.v6.i9.2026.1

Article history
Submitted: 7 May 2026
Revised: 2 June 2026
Accepted: 6 June 2026
Published: 8 June 2026

Keywords
Chemistry learning
Communication and teamwork
Gender
STEM career
System thinking skills

Abstract
This study aims to analyze students' perceptions of STEM careers, systems thinking, communication, and teamwork within the context of chemistry learning, as well as to explore potential gender based differences in these perceptions. This study used a survey design method involving 46 grade XI Mathematics and Natural Sciences students, consisting of 14 male students and 32 female students. Data were collected using a structured online questionnaire adapted from a previously validated instrument, which covered STEM career orientation, systems thinking skills, and communication and teamwork competencies. Data analysis was conducted using descriptive statistics in the form of frequencies and percentages. The questionnaire consisted of 11 STEM career questions and 10 systems thinking skills questions, 11 communication and teamwork skills question. The results indicate that students' perceptions of STEM careers are positive in three aspects: self-efficacy in STEM abilities, environmental support, and interest and orientation towards STEM careers. Students reported positive perceptions of their systems thinking skills at the core and advanced levels, demonstrating students' ability to understand systems of relationships, analyze dynamic interactions, and consider long-term impacts. Communication and teamwork skills also performed well, particularly in collaboration, emotional regulation, and inclusive decision-making, although scientific communication skills require further improvement. These findings suggest that STEM-based chemistry learning supports the development of essential 21st century skills and contributes to students' readiness for STEM-related careers.

1. Introduction

The rapid development of technology in the era of the Industrial Revolution 4.0 has had a very significant impact on various aspects of life, including the world of education. Digital transformation and information technology advances require the education system to adapt to evolving global social and economic changes (Hamidah et al., 2025) In line with this, education in Indonesia is currently undergoing reforms to meet the demands of the 21st century, where critical thinking skills, creativity, and the ability to collaborate are increasingly important elements in education (Fitriani & Santiani, 2025) Therefore, a learning approach is needed that is able to integrate these various skills holistically, one of which is through the STEM approach. The STEM approach is an approach that refers to the four components of science, namely science, technology, engineering, and mathematics (Davidi et al., 2021). Through this approach, students not only understand the theory, but are also able to apply it in daily life through exploration, design, and problem-solving activities (Muttaqiin, 2023) The characteristics of STEM learning are not only integrated between science, technology, engineering and mathematics, STEM is project-based learning, and develops students' skills and creativity, developing a collaborative attitude among fellow students (Supriyatun, 2019).

In addition, the STEM educational approach emphasizes new ways of teaching and learning that focus on direct inquiry and open exploration (Katehi et al.,2009). Furthermore, the application of STEM approaches in learning is closely related to the development of student orientation and career readiness in the STEM field. Students' career interests and future career activities will influence their intention to pursue a career in STEM (Blotnicky et al., 2018). The development of one's career interests is described in Social Cognitive Career Theory (SCCT) where career development is a lifelong process that focuses on an individual's internal environmental and socio-cultural factors, as well as cognitive-social dynamics (Bagaskara et al., 2023) STEM careers offer many advantages, including competitive salaries, job security, and extensive career development opportunities. To prepare students for these career demands, STEM learning needs to equip students with high-level thinking skills, one of which is systems thinking skills.

ISSN: 2797-3174

In STEM learning, systems thinking skills are the ability or approach to see organizational systems interact and influence each other as a whole (Saputra et al.,2022). Systems thinking is necessary to understand the relationships between components in a complex system (Shidiq et al., 2020; 2022). Research (Mahaffy, Matlin, Whalen, & Holme, 2019) states that the systems thinking approach emphasizes the interdependence between components in a dynamic system. In line with that, another study conducted by Talanquer et al., (2024) states that systems thinking skills in chemistry learning are essential for building a holistic and integrated understanding of key concepts of chemistry. Research Shidiq et al., (2022) also states that systems thinking skills are able to support the achievement of goals in the learning process. Thus, systems thinking is an important foundation in building a deep and actionable conceptual understanding.

In addition to systems thinking skills, STEM learning also demands effective communication and teamwork skills. Communication skills are one of the four essentials 21st century abilities that every student must possess (Mawaddah et al., 2021). On the other hand, cooperation skills play an important role in increasing individual confidence and the effectiveness of group performance (Umar, 2019). Through communication and teamwork, students learn to work independently and take responsibility for their contributions in the group. In addition, students learn to manage time, organize tasks, and work together to achieve common goals (Mulyani et al., 2021) STEM learning not only develops cognitive skills, but also collaborative skills needed in the world of work Alam et al., (2025) STEM learning not only focuses on mastering concepts, but also encourages students to integrate knowledge, technology, engineering, and mathematics in real-world contexts through exploratory activities, project-based, and problem-solving. Positive perceptions will foster student enthusiasm and motivation in learning activities. Students will find learning more engaging and easier to understand, thereby improving their learning outcomes (Nurmeina et al., 2020). Through contextual and meaningful learning experiences, students can build a cognitive understanding of STEM career opportunities and demands, which further influences their interest and readiness in planning for future careers. Previous research, consistently, has highlighted persistent gender gaps in perception, interest, and participation in STEM careers, which are often influenced by socio-cultural stereotypes and differences in self-efficacy (Shidiq et al., 2021). This gap ultimately has the potential to have an impact on the inhibition of the development of competencies needed to face and solve problems.

Furthermore, systems thinking, communication, and teamwork skills are essential components in STEM learning, particularly in the context of chemistry. Systems thinking skills enable students to understand the interrelationships and dynamics between components in complex systems, while communication and teamwork skills support the effectiveness of collaborative learning and the development of responsibility and leadership. Several studies have shown that STEM-based learning contributes to the development of systems thinking, communication, and teamwork skills in chemistry at the high school level. However, descriptive studies specifically describing these three skills in an integrated manner and based on a conceptual framework are still limited. Therefore, integrating these three aspects into STEM learning is an important foundation for building a deep conceptual understanding and student readiness to face the challenges of the world of work. Thus, this study confirms that STEM-based chemistry learning has great potential in developing students' STEM career perceptions, systems thinking skills, and communication and teamwork skills holistically. These findings are expected to form the basis for the development of STEM studies in the future and serve as a practical reference for educators and educational institutions in designing learning that is adaptive, contextual, and oriented to future needs.

2. Method

This study uses a survey design method aimed at analyzing gender differences in students' perceptions of STEM careers, as well as examining systems thinking skills and communication and teamwork skills. This approach was chosen because it aims to collect data from defined populations to describe existing conditions without manipulating the research variables (Yamtinah et al., 2017) . The research instrument was developed based on the Engineering for One Planet (EOP) framework and underwent content validity testing through expert judgment to ensure clarity and relevance. Furthermore, the reliability of the instrument was evaluated using internal consistency analysis, indicating that the questionnaire was reliable for measuring students' perceptions of systems thinking, communication, and teamwork skills.

The study population included all grade XI Mathematics and Science students at a school in Surakarta City participating in STEM-based learning. Respondents were selected using random sampling, taking into account student availability and active participation in completing the research instrument. Data collection was conducted using a structured online questionnaire developed by the researchers.

The research instrument included three main variables, namely STEM career orientation, systems thinking skills, and communication and teamwork skills. The number of respondents who participated was 46 students, consisting of 14 male students and 32 female students. Each statement is assessed using a four-level Likert scale, namely 1 (strongly agree), 2 (agree), 3 (disagree), and 4 (strongly disagree). This reverse Likert scale is deliberately applied because a lower score indicates stronger approval of the statement. Each questionnaire item was adapted from previous research and adjusted to align with the goals of this study (Anderson & Cooper, 2022; Kier et al., 2014). The validated indicators for each variable are presented in Table 1.

ISSN: 2797-3174

Table 1. Research Indicators

Display	Indicator	Number of Questions
STEM Careers	Self-Efficacy in STEM Abilities	1, 2, 11
	Environmental Support for STEM Careers	4, 5, 6, 7
	Interest and Orientation to STEM Careers	3, 8, 9, 10
Systems Thinking	Core	1, 2, 3, 4, 5
	Advanced	6, 7, 8, 9, 10
Communication and Teamwork	Core	1, 2, 3, 4, 6, 7
	Advanced	5, 8, 9, 10, 11

The data obtained is exported and then analyzed using descriptive statistics, including frequency and percentage calculations. This analysis was conducted to describe the patterns and tendencies of students' responses related to perceptions of STEM careers, systems thinking skills, communication and teamwork. This study is not intended to test the cause effect relationship, but rather to present a comprehensive picture of student characteristics related to these variables.

3. Results and Discussion

The data analysis aims to describe students' perceptions of careers in STEM fields as well as systems thinking, communication, and cooperation skills. Data were collected using a questionnaire instrument with a Likert scale of four categories, namely strongly agree (1), agree (2), disagree (3), and strongly disagree (4). The analysis process is carried out by referring to the indicators that have been set for each research variable.

3.1. Results

3.1.1. STEM Career

This STEM career research variable is based on (Kier et al., 2014) which focuses on the development and validation of instruments used to measure students' interest and awareness of learning and careers in STEM fields at various levels of education. The instruments used were adapted as many as 11 statements that were grouped into three aspects of STEM career perception, namely self-efficacy of STEM skills, environmental support for STEM careers, and students' interest and orientation towards STEM careers. The research subjects amounted to 46 students consisting of 14 males and 32 females. The results of students' perceptions of STEM careers are presented in the following graphs. Self-efficacy in STEM abilities is presented in Figure 1. Meanwhile, environmental support for STEM careers is presented in Figure 2. Furthermore, interest and orientation to STEM careers are presented in Figure 3.

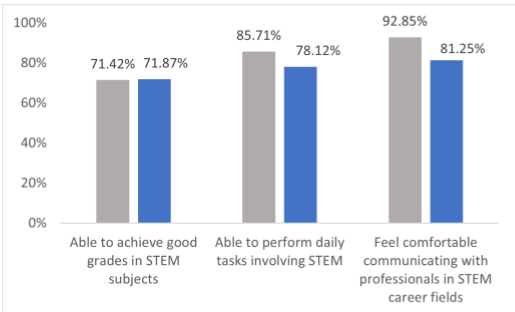

Figure 1. Self-Efficacy in STEM Abilities

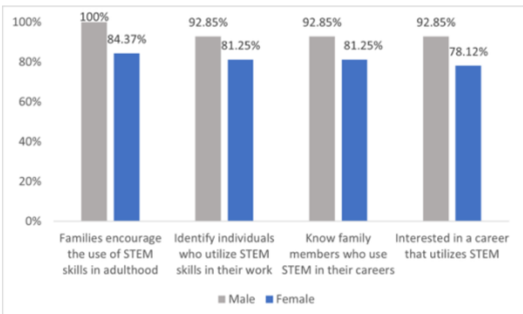

Figure 2. Environmental Support for STEM Careers

ISSN: 2797-3174

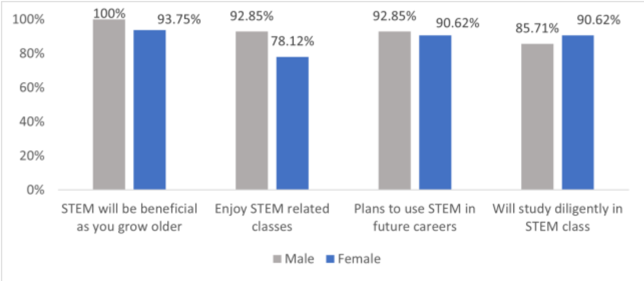

Figure 3. Interest and Orientation to STEM Careers

3.1.2. Systems Thinking

The systems thinking Indicators also refer to the EOP (Engineering for One Planet) framework (Anderson & Cooper, 2022) Student perceptions of systems thinking skills at the core level were examined using several indicators, as shown in Table 2. Meanwhile, student perceptions of systems thinking skills at the advanced level were evaluated based on the indicators presented in Table 3.

Table 2. Students' Perceptions of Core Level Systems Thinking Skills

Number	Statement	Strongly Agree & Agree	Percentage
1.	Being able to see the relationships between parts of a chemical system.	35	76.08%
2.	Recognize that chemicals, such as reactions made up of various dynamically interacting substances, can affect entire systems.	40	86.95%
3.	Consider how changes in the chemical system may affect other components and the system as a whole.	39	84.78%
4.	Know that the use of chemicals should take into account the situation.	45	97.82%
5.	Feeling able to find solutions to complex chemical problems.	35	76.08%

Table 3. Students' Perceptions of Advanced Systems Thinking Skills

6.	Understanding that small changes can have an impact on the chemical system.	44	95.65%
7.	Recognize the importance of identifying and mapping data patterns from chemical experiments before drawing accurate conclusions.	41	89.13%
8.	Consider the long-term effects of a choice.	43	93.47%
9.	Think about chemical solutions from a variety of perspectives.	40	86.95%
10.	Track down the root cause of problems in chemical experiments before determining solution steps.	43	93.47%

3.1.3. Communication and Teamwork

The communication and teamwork Indicators also refer to the EOP (Engineering for One Planet) framework by (Anderson & Cooper, 2022) Student perceptions of communication and teamwork skills at the core level were analyzed based on several indicators, as presented in Table 4. Meanwhile, student perceptions of communication and teamwork skills at the advanced level were analyzed based on several indicators presented in Table 5.

Table 4. Students' Perceptions of Core Level Communication and Teamwork Skills

Number	Statement	Strongly Agree & Agree	Percentage
1.	Discuss chemistry often with friends from different organizations to deepen the material.	42	91.30%
2.	Actively contribute to problem-solving and support the effectiveness of group work.	44	95.65%
3.	Actively engage in every discussion and activity while working in a group.	44	95.65%
4.	Learn to know yourself and be open to building good communication and teamwork.	45	97.82%
6.	Cooperate and support sustainable ideas in protecting the environment and human needs.	44	95.65%
7.	Explain my ideas, concepts and concepts in the field of science during learning activities.	36	78.26%

ISSN: 2797-3174

Table 5. Students' Perceptions of Advanced Communication and Teamwork Skills

5.	Prioritize projects, schedules, and time effectively and manage team members fairly and inclusively.	43	93.47%
8.	Managing emotions while working in a group.	43	93.47%
9.	Prioritize projects, schedules, and time effectively and manage team members fairly and inclusively.	44	95.65%
10.	Be used to working in a structured and disciplined way in groups and open to input from peers to reach group agreements.	43	93.47%
11.	Collaborate, communicate, and take an active role in a group with friends from different backgrounds and communicate ideas clearly while working in a group.	45	97.82%

3.2. Discussion

Based on Figure 1, it can be seen that students' confidence in STEM abilities is relatively high, as evidenced by positive responses to all three indicators. This aligns with research Mansurah et al., (2023) that states positive perceptions of STEM learning have numerous benefits, such as increasing knowledge, sharpening critical thinking skills, sharpening creativity, and fostering students' sensitivity to their surroundings, which can be felt by students and is in line with 21st century developments. Furthermore, according to Ridwan et al. (2024), integrating STEM into the educational curriculum to prepare future generations demonstrates the importance of an interdisciplinary approach that encompasses not only academic aspects but also practical skills relevant to the needs of an increasingly technology-based workforce. This is consistent with the high percentage of indicators for the ability to achieve grades and perform daily activities related to STEM, indicating that students not only feel capable of understanding the concepts but also confident in applying them in everyday life contexts. Furthermore, students' high level of comfort in interacting and communicating with STEM professionals indicates initial readiness for entering future career environments. Education plays a crucial role in shaping students' character, enabling them to develop their qualities into confident individuals. With self-confidence, students will more easily interact in their learning environment (Novita, 2021). However, these findings require further research, given that high self-confidence does not necessarily fully reflect a student's true abilities. Therefore, it is necessary to strengthen learning that not only builds self-confidence but also ensures mastery of relevant skills so that students' readiness in STEM fields can develop optimally.

Based on Figure 2, it shows that family and environmental support for students' interest and readiness in STEM careers is relatively high in all indicators, both male and female students. This is in line with research (Aulia et al., 2025) which states that families who support and provide a good education are able to increase motivation and confidence in students, so that students are better prepared to overcome challenges in the world of work. In the indicator of family encouraging the use of STEM skills in adulthood, male students showed the highest percentage 100% , while female students were also in the high category 84.37%. This shows the very strong role of families in fostering STEM career orientation, especially in male students. Meanwhile, in the indicator of knowing individuals who utilize STEM skills in work and knowing family members who use STEM in their careers, the percentages of male and female students were at 92.85% and 81.25%. Furthermore, in the indicator of interest in careers that utilize STEM, male students again showed a high percentage 92.85%, while female students reached 78.12%. Overall, this graph shows that environmental support and exposure to STEM careers are relatively strong for students, with a tendency for male students to be higher than female students.

Figure 3 shows that student interest in STEM fields is high across all indicators, for both male and female students. This indicates that the majority of students believe in the relevance and long-term benefits of STEM in their lives. Furthermore, students expressed interest in STEM learning, with a higher percentage of male students. Students' tendency to plan to use STEM in their future careers indicates that their learning is beginning to be linked to long-term career aspirations. This is in line with research Lokollo et al., (2024), which states that STEM education also has a positive impact on students' career readiness. In the era of globalization, many jobs require STEM skills, and the demand for professionals in these fields continues to increase. In terms of learning commitment, female students demonstrated a strong motivation to seriously engage in STEM learning, although male students tended to outperform them in several other indicators. This finding aligns with Apriliana et al., (2025) that there are variations in learning outcomes between male and female students in STEM learning. Overall, these findings indicate that students not only have an interest in STEM but are also beginning to develop a long-term career orientation in these fields.

All three aspects of STEM career perception are in the high category, with gender differences showing complementary characteristics. Male students have a slightly higher percentage tendency on some indicators. Good self-efficacy, relatively strong environmental support, and positive interest and career orientation indicate that students already have an early readiness to develop a career in STEM. These findings are in line with the international framework developed by the Organization for Economic Cooperation and Development (OECD) through the Program for International Student Assessment (PISA), which emphasizes the importance of mastering basic literacy, namely reading, mathematics, and science as the foundation of students' reasoning skills. These three literacies are considered to represent essential competencies needed to meet the demands of

ISSN: 2797-3174

the global labor market (Hisanah et al., 2025; Pratiwi, 2019). Thus, the combination of good self-efficacy, relatively strong environmental support, and positive interest and career orientation indicates that students already have an early readiness to develop a career in STEM fields. These findings reinforce empirical evidence that STEM based learning has great potential in building inclusive, adaptive, and sustainable STEM career perceptions for high school students.

Systems thinking skills are the ability to understand the relationships between components in a system as a whole, which is essential for building a deep conceptual understanding (Mahaffy et al., 2019; Muhammad Chaidir et al., 2024). Systems thinking skills refer to indicators (Anderson & Cooper, 2022) within the framework of EOP (Engineering for One Planet) (Assaraf & Orion, 2005). The researcher used 10 statements grouped into two levels of competence, namely the core level (basic systems thinking skills) and the advanced level (advanced systems thinking skills), which were used to measure students' system thinking abilities in one of the STEM-based subjects, namely chemistry. Based on the data in table 2, the core level system thinking skills of students show quite good categories. This is reflected in the high percentage of positive responses in almost all indicators, especially in students' understanding that chemical systems are dynamic, interacting, and the need to consider the use of chemicals according to certain situations and conditions. These findings indicate that students already have an adequate basic understanding of the relationships between components in a chemical system. However, indicators one and five show a low percentage compared to other indicators. However, the achievements on each indicator are not completely evenly distributed. The ability of students to formulate solutions to complex chemical problems still shows relatively lower results compared to other indicators. This condition indicates that students are better able to recognize interconnectedness and changes in the system, but are not fully skilled in applying that understanding to conduct in-depth analysis and challenging problem-solving. Thus, students' systems thinking skills are still in the early stages of development, which places more emphasis on conceptual understanding than advanced analytical abilities.

Based on the data in Table 3, advanced students' systems thinking skills demonstrated high achievement. This was reflected in positive responses to all indicators, indicating that most students were able to understand the characteristics of chemical systems in greater depth and comprehensively. Students demonstrated an awareness that small changes in a system can impact the entire system and were able to consider the long-term effects of a decision or treatment in a chemical context. These findings align with Julia et al., (2025) research, which states that systems thinking is used not only to analyze problems but also to design sustainable and effective solutions in the long term. Furthermore, students also demonstrated improved analytical thinking skills, such as the importance of identifying and mapping patterns in experimental data before drawing accurate conclusions and tracing the root causes of a problem before determining steps to resolve it. The ability to view chemical solutions from multiple perspectives also indicates that students are beginning to develop flexible and reflective thinking in understanding chemical phenomena. Overall, these findings indicate that students' systems thinking skills have progressed beyond basic understanding and are beginning to lead to more mature analytical, evaluation, and decision-making skills. Research confirms Nuraeni et al., (2020) that systems thinking is a type of complex thinking. Therefore, students' basic understanding is stronger, so these results indicate that applied learning has made a positive contribution in encouraging students to develop advanced systems thinking skills, although continued reinforcement is still needed to optimize these skills and be consistent across various problem contexts.

Based on communication and teamwork skills in Table 4, strengthening communication and teamwork skills in schools not only meets academic demands, but is also an investment in character development and preparing students to face real-world challenges Nugraha et al., (2024). Data analysis shows that core-level communication and teamwork skills fall into the excellent category. The percentage of student approval on this indicator ranges from 78.26% to 97.82%. The highest percentage was found in the ability to learn to know oneself and be open to building good communication 97.82%, which indicates that most students already have a strong interpersonal awareness. However, the indicator in statement number seven related to the ability to explain and discuss science concepts in learning activities shows the lowest percentage (78.26%). This indicates that although students possess good social communication skills, there are still challenges in communicating science concepts clearly and systematically. This is because teacher-centered learning often leads to a lack of communication skills, resulting in students lacking conceptual understanding and unable to solve problems presented by the teacher (Pramesti et al.,2020). These findings indicate the need to strengthen learning strategies that encourage students to more actively practice academic and scientific communication. Therefore, the learning process must be organized and planned in such a way as to easily achieve learning objectives (Sanjani, 2021).

The results of the analysis in Table 5 show that students' advanced skills are in the very good category, with an approval rate that ranges from 93.47% to 97.82%. Indicators of collaboration and effective communication in groups with diverse backgrounds showed the highest achievements, indicating that students have been able to adapt to individual differences and build harmonious cooperation. These findings are in line with the research of Ningtyas (2025) which states that collaborative learning is an effective approach in simultaneously improving students' social and academic skills. In addition, high achievement in the ability to

ISSN: 2797-3174

manage emotions, think objectively, and provide feedback shows that students not only have good interpersonal communication skills, but have also developed social-emotional and leadership skills that are key characteristics of 21st-century skills as well as indicators of job readiness.

Based on the analysis of communication and teamwork skills at the core and advanced levels, it can be concluded that students have demonstrated excellent mastery of 21st century skills. At the core level, students generally possess strong interpersonal awareness and social interaction skills, although they still need strengthening in academic communication, particularly in explaining and discussing science concepts systematically and structured. Meanwhile, at the advanced level, students demonstrated excellent abilities in collaborating and communicating effectively in diverse groups, as well as in managing emotions, thinking objectively, and providing constructive feedback. These findings are supported by research Suleman (2024) which states that good communication skills enable one to convey ideas clearly, interact effectively with others, and build strong relationships. Thus, it can be concluded that the implementation of learning strategies that emphasize communication and teamwork not only improves the quality of student learning interactions but also provides an important foundation in preparing human resources who are adaptive, competitive, and ready to face the demands of the future workforce.

3.3. Implications

The findings of this study have theoretical and practical implications. Theoretically, the results of this study strengthen the STEM learning framework as an approach that is able to integrate the development of students' career perceptions in the cognitive domain, systems thinking skills, and simultaneous communication and teamwork skills. Career perception in this context is understood as the result of students' cognitive processes in assessing, understanding, and interpreting career opportunities and demands in the STEM field. Practically, the findings of this study provide implications for chemistry teachers to apply project-based STEM learning and contextual problems to strengthen students' scientific communication, reasoning, and problem-solving skills. In addition, schools can use the results of this research as a basis for designing and developing STEM career guidance programs that are oriented towards strengthening students' cognitive understanding of the world of work, as well as being inclusive and sustainable.

3.4. Limitations

This research has several limitations. First, the relatively limited number of samples from one school can affect the generalization of the research results. Second, data is obtained through self-report questionnaires so that it is highly dependent on students' subjective perceptions. Further research is recommended to involve a wider sample, use mixed-methods designs, and combine questionnaire instruments with observations or interviews to gain a deeper understanding.

4. Conclusion

STEM-based chemistry learning has proven to have strong potential in building students' STEM career perceptions while developing systems thinking skills as well as communication and teamwork skills. The results showed that students had self-efficacy, environmental support, and interest in STEM careers in the high category, with insignificant gender differences. In addition, students' systems thinking skills develop at both core and advanced levels, accompanied by excellent communication and teamwork skills as part of 21st century skills. These findings confirm that the integration of STEM in chemistry learning not only strengthens conceptual understanding but also prepares students holistically to face the demands of further education and the world of work in the future.

Author Contributions

All authors contributed equally to this paper. All authors have read and approved the final manuscript.

Funding

The authors gratefully acknowledge the financial support provided by the Institute for Research and Community Service (*Lembaga Penelitian dan Pengabdian kepada Masyarakat*/LPPM) of Universitas Sebelas Maret (UNS) through the Fundamental Research Scheme A (PFA-UNS), under contract number 460/UN27.22/PT.01.03/2026. This support has been essential in facilitating the implementation and completion of this research.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

ISSN: 2797-3174

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

Acknowledgement

The authors gratefully acknowledge the financial support provided by the Institute for Research and Community Service (*Lembaga Penelitian dan Pengabdian kepada Masyarakat*/LPPM) of Universitas Sebelas Maret (UNS) through the Fundamental Research Scheme A (PFA-UNS), under contract number 460/UN27.22/PT.01.03/2026. This support has been essential in facilitating the implementation and completion of this research.

References

Alam, S. R., Siswanto, D. H., & Aprilia, D. (2025). Implementasi pembelajaran STEM terintegrasi *computational thinking* untuk meningkatkan kemampuan. *PJMSR, 4*(1), 38–48. https://doi.org/10.56916/pjmsr.v4i1.1130

Anderson, C., & Cooper, C. (2022). *Essential sustainability-focused learning outcomes for engineering education: The Engineering for One Planet framework: Foundational learning outcomes to prepare engineers to protect and improve Earth and the life it sustains*. The Lemelson Foundation. https://engineeringforoneplanet.org/

Apriliana, E., Suhartini, E., Hearani, R. P. R., & Septika, H. D. (2025). Efektivitas LKPD pemanasan global berbasis STEM dalam pembangunan berkelanjutan terhadap sikap sains ditinjau dari perbedaan gender. *Jurnal Pendidikan Matematika dan Sains, 13*(Special issue), 154–165. https://doi.org/10.21831/jpms.v13iSpecial_issue.89002

Assaraf, O. B. Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching, 42*(5), 518–560. https://doi.org/10.1002/tea.20061

Aulia, F. P., Aulia, N., & Miftahunnajah, P. (2025). Kesiapan kerja siswa dengan variabel moderasi *self-efficacy*. *Jurnal Pendidikan Ekonomi, 13*(3), 335–345. https://doi.org/10.26740/jupe.v13n3.p335-345

Bagaskara, B., & Sulistiobudi, R. A. (2023). Keselarasan karir siswa dengan harapan orang tua: *Adolescent-parent career congruences* dan STEM *career interest*. *Jurnal Paedagogy, 10*(4), 964. https://doi.org/10.33394/jp.v10i4.8995

Blotnicky, K. A., Franz-Odendaal, T., French, F., & Joy, P. (2018). A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students. *International Journal of STEM Education, 5*(1). https://doi.org/10.1186/s40594-018-0118-3

Davidi, E. I. N., Sennen, E., & Supardi, K. (2021). Integrasi pendekatan STEM untuk meningkatkan berpikir kritis siswa sekolah dasar. *Scholaria: Jurnal Pendidikan dan Kebudayaan, 11*(1), 11–22. https://doi.org/10.24246/j.js.2021.v11.i1.p11-22

Fitriani, A., & Santiani, S. (2025). Analisis literatur: Pendekatan pembelajaran *deep learning* dalam pendidikan. *JINU, 2*(3), 50–57. https://doi.org/10.61722/jinu.v2i3.4357

Hamidah, D., Andini, D., Sukma, L., & Triandini, L. (2025). Peran inovasi pendidikan pada pembelajaran berbasis digital. *Mimbar Kampus: Jurnal Pendidikan dan Agama Islam, 24*(2), 173–184. https://doi.org/10.47467/mk.v24i2.7370

Hisanah, N., Koeshandayanto, S., & Sulur, S. (2025). Eksplorasi literasi sains berdasarkan perbedaan gender pada materi besaran dan pengukuran kelas X SMA. *JIIP, 8*, 760–770. https://doi.org/10.54371/jiip.v8i1.6572

Julia, A. N., Salsabila, J. F., Niediawan, K., Trianung, T., & Susanto, D. (2025). Analisis dampak kebijakan *full day school* terhadap kesejahteraan guru: Pendekatan berpikir sistem dengan *causal loop diagrams*. *Jurnal Manajemen Pendidikan, 10*(2), 759–771. https://doi.org/10.34125/jmp.v10i2.652

Feder, M., Pearson, G., & Katehi, L. (Eds.). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. National Academies Press. https://doi.org/10.17226/12635

Kier, M. W., Blanchard, M. R., Osborne, J. W., & Albert, J. L. (2014). The development of the STEM Career Interest Survey (STEM-CIS). *Research in Science Education, 44*(3), 461–481. https://doi.org/10.1007/s11165-013-9389-3

Lokollo, L. J., Lasaiba, M. A., Arfa, A. M., & Lasaiba, D. (2024). Mengembangkan kemampuan berpikir spasial melalui pendidikan STEM di sekolah dasar: *Developing spatial thinking abilities through STEM education in elementary schools*. *Scholaria: Jurnal Pendidikan dan Kebudayaan, 14*(3), 293–308. https://doi.org/10.24246/j.js.2024.v14.i3.p293-308

Mahaffy, P. G., Matlin, S. A., Whalen, J. M., & Holme, T. A. (2019). Integrating the molecular basis of sustainability into general chemistry through systems thinking. *Journal of Chemical Education, 96*(12), 2730–2741. https://doi.org/10.1021/acs.jchemed.9b00390

Mansurah, R., Andriani, P., Kurniawati, K. R. A., & Negara, H. R. (2023). Analisis persepsi calon guru matematika terhadap pembelajaran berorientasi STEM: Studi pada Prodi Tadris Matematika UIN Mataram. *JSN: Jurnal Sains Natural, 1*(3), 81–86. https://doi.org/10.35746/jsn.v1i3.390

ISSN: 2797-3174

Mawaddah, S., & Mahmudi, A. (2021). Analisis kemampuan komunikasi matematika siswa melalui penggunaan *project-based learning* terintegrasi STEM. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika, 10*(1), 167. https://doi.org/10.24127/ajpm.v10i1.3179

Chaidir, M., Andini, S., Harahap, U. H. S., & Nasution, A. F. (2024). Peran dan proses berpikir sistem dalam konteks pendidikan. *Student Research Journal, 2*(6), 84–92. https://doi.org/10.55606/srj-yappi.v2i6.1629

Mulyani, A. S., Nurishlah, L., & Tarigan, L. F. B. (2021). Implementasi pembelajaran Bahasa Indonesia berbasis karakter kerja sama. *Jurnal Ilmiah Wahana Pendidikan, 7*(2), 561–568. https://doi.org/10.5281/zenodo.10802602

Muttaqiin, A. (2023). Pendekatan STEM (*science, technology, engineering, mathematics*) pada pembelajaran IPA untuk melatih keterampilan abad 21. *Jurnal Pendidikan MIPA, 13*(1), 34–45. https://doi.org/10.37630/jpm.v13i1.819

Ningtyas, R., Muhlisin, M., & Khobir, A. (2025). Optimalisasi pembelajaran kolaboratif dalam meningkatkan keterampilan sosial dan prestasi akademik siswa. *JIEPP, 5*, 204–210. https://doi.org/10.54371/jiepp.v5i2.915

Nugraha, R. A., & Faridatussalam, S. R. (2024). Penguatan keterampilan komunikasi dan kerjasama siswa melalui program *outbound* pada Yayasan Nur Hidayah Surakarta Jawa Tengah. *JPMII, 2*(1), 101–108. https://doi.org/10.54082/jpmii.331

Nuraeni, R., Setiono, & Himatul, A. (2020). Profil kemampuan berpikir sistem siswa kelas XI SMA pada materi sistem pernapasan. *Pedagogi Hayati, 4*(1), 1–9. https://doi.org/10.31629/ph.v4i1.2123

Nurmeina, H. F., Yamtinah, S., & Agustina, W. (2020). Hasil belajar pada materi asam basa siswa kelas XI MIPA SMA Negeri 3 Surakarta tahun pelajaran 2018/2019. *Jurnal Pendidikan Kimia, 9*(1), 33–39. https://doi.org/10.20961/jpkim.v9i1.32684

Pramesti, O. B., Supeno, S., & Astutik, S. (2020). Pengaruh model pembelajaran inkuiri terbimbing terhadap kemampuan komunikasi ilmiah dan hasil belajar fisika siswa SMA. *Jurnal Ilmu Fisika dan Pembelajarannya (JIFP), 4*(1), 21–30. https://doi.org/10.19109/jifp.v4i1.5612

Pratiwi, I. (2019). Efek program PISA terhadap kurikulum di Indonesia. *Jurnal Pendidikan dan Kebudayaan, 4*(1), 51–71. https://doi.org/10.24832/jpnk.v4i1.1157

Sanjani, M. A. (2021). Pentingnya strategi pembelajaran yang tepat bagi siswa. *Jurnal Serunai Administrasi Pendidikan, 10*(2), 32–37. https://doi.org/10.37755/jsap.v10i2.517

Saputra, A., Gunawan, A., & Fauzi, M. (2022). Model kepemimpinan berpikir sistem prasekolah Islam swasta. *JIEBAR: Journal of Islamic Education: Basic and Applied Research, 3*(1), 44–63. https://doi.org/10.33853/jiebar.v3i1.251

Shidiq, A. S., & Nasrudin, D. (2021). The elementary teacher readiness toward STEM-based contextual learning in 21st century era. *Elementary Education Online, 20*(1), 145–156. https://doi.org/10.17051/ilkonline.2021.01.019

Shidiq, A. S., Permanasari, A., & Hernani, H. (2020). Simple, portable, and inexpensive spectrophotometers for high schools lab activity. *Advances in Social Science, Education and Humanities Research, 438*, 150–154. https://doi.org/10.2991/assehr.k.200513.034

Shidiq, A. S., Permanasari, A., Hernani, & Hendayana, S. (2022). Contemporary hybrid laboratory pedagogy: Construction of a simple spectrophotometer with STEM project-based learning to introduce systems thinking skills. *Asia Pacific Journal of Educators and Education, 37*(2), 107–146. https://doi.org/10.21315/apjee2022.37.2.6

Suleman, M. A. (2024). Meningkatkan keterampilan komunikasi siswa melalui penerapan *experiential learning*. *Ideguru: Jurnal Karya Ilmiah Guru, 9*(3), 1530–1538. https://doi.org/10.51169/ideguru.v9i3.1101

Supriyatun, S. E. (2019). Implementasi pembelajaran sains, teknologi, engineering, dan matematika STEM pada materi fungsi kuadrat. *JUMLAHKU, 5*(1), 80–87. https://doi.org/10.33222/jumlahku.v5i1.567

Talanquer, V., & Szozda, A. R. (2024). An educational framework for teaching chemistry using a systems thinking approach. *Journal of Chemical Education, 101*(5), 1785–1792. https://doi.org/10.1021/acs.jchemed.4c00216

Umar, A. (2019). Analisis kendala kerja sama siswa dalam model pembelajaran Jucama (pengajuan dan pemecahan masalah). *As-Salam, 3*(3), 67–75. https://doi.org/10.37249/as-salam.v3i3.138

Yamtinah, S., Masykuri, M., & Shidiq, A. S. (2017). Gender differences in students' attitudes toward science. *AIP Conference Proceedings*. https://doi.org/10.1063/1.4995102

ISSN: 2797-3174