Technological Fluency as a Catalyst for Chemistry Content Mastery in STEM Education

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ABSTRACT

This study examined the relationship between chemistry content proficiency and technological fluency among 50 Senior High School (SHS) STEM learners at Sulangon National High School. Employing a descriptive–correlational research design with purposive sampling, the study assessed learners' mastery of identified least mastered competencies in Gas Laws and their technological proficiency in software applications, web navigation, and online security. Data were analyzed using descriptive statistics and the Pearson product–moment correlation coefficient. Results revealed a mean content knowledge score of 16.95, corresponding to the Novice proficiency level (56.5% mastery), and a mean technological proficiency score of 3.00. Correlation analysis yielded a statistically significant moderate positive relationship between the variables ($r = 0.589$, $p = 0.000006$), leading to the rejection of the null hypothesis. The findings indicate that chemistry content proficiency and technological fluency are mutually reinforcing: a strong conceptual foundation supports effective technology use, while increased technological fluency enhances content mastery. This synergy suggests that technology may function as a cognitive catalyst, facilitating deeper conceptual understanding of abstract STEM concepts. The study recommends the systematic integration of digital tools into chemistry instruction and the prioritization of digital infrastructure to support the reciprocal development of learners' academic and technological competencies.

Keywords: chemistry proficiency, Senior High School STEM learners, technological fluency;

INTRODUCTION

The Fourth Industrial Revolution has intensified the demand for both scientific literacy and digital competence in contemporary education systems. Despite increased global participation in secondary education, achievement in Science, Technology, Engineering, and Mathematics (STEM) remains uneven. Data from the UNESCO Institute for Statistics indicate that in many developing regions, fewer than 25% of secondary learners attain minimum proficiency in science, underscoring persistent gaps in conceptual understanding and problem-solving skills (UNESCO, 2023). These challenges are further compounded by the digital divide, wherein disparities in technological proficiency significantly influence learners' access to, and engagement with, complex scientific content (Livingstone et al., 2021).

Chemistry, often described as the central science, presents unique cognitive demands due to its reliance on multiple representational levels. Meaningful learning in chemistry requires learners to coordinate macroscopic phenomena, submicroscopic particle behavior, and symbolic representations (Johnstone, 1991). This cognitive complexity is particularly evident in topics involving gases, where abstract constructs such as pressure, temperature, and volume must be understood through the lens of the kinetic molecular theory. Previous studies report that a substantial proportion of secondary learners exhibit persistent misconceptions in this domain, resulting in consistently low mastery levels for gas-related competencies (Talanquer, 2018).

To mitigate these learning difficulties, the integration of information and communication technology (ICT), including simulations, animations, and virtual laboratories, has been widely promoted as an instructional

strategy for visualizing abstract chemical processes (Chang et al., 2022). However, emerging evidence suggests that access to digital tools alone does not guarantee improved learning outcomes. Rather, students' technological proficiency—defined as their ability to effectively use digital tools for learning—plays a critical mediating role. International assessments indicate that learners with higher levels of digital literacy outperform their peers on conceptual science tasks, even when both groups are exposed to similar technological resources (OECD, 2021).

In the Philippine context, the Department of Education has emphasized the integration of 21st-century skills within the K–12 curriculum. Nevertheless, national and international assessments continue to reveal low levels of science literacy among Filipino learners. Results from the 2018 Programme for International Student Assessment (PISA) placed the Philippines among the lowest-performing countries in science, with a large proportion of students failing to reach baseline proficiency (DepEd, 2019). As schools increasingly adopt hybrid and technology-mediated learning modalities in the post-pandemic period, understanding the interplay between chemistry content mastery and technological proficiency has become increasingly critical.

Against this backdrop, the present study examines the least mastered chemistry competencies related to gases among Senior High School STEM learners and investigates the relationship between learners' conceptual understanding and their level of technological proficiency. By generating localized empirical evidence, this study seeks to inform instructional planning and support the design of pedagogical interventions that effectively integrate digital tools to enhance chemistry learning outcomes.

METHODOLOGY

Research Design. This study employed a descriptive–correlational research design to examine Senior High School STEM learners' mastery of selected chemistry competencies and its relationship with technological proficiency. The descriptive component was used to determine learners' levels of content mastery and technological fluency, while the correlational component examined the strength and direction of the association between these variables.

Participants and Research Setting. The study was conducted at Sulangon National High School, located in Barangay Sulangon, Dapitan City, Zamboanga del Norte, Philippines. The school is one of ten public secondary schools in Dapitan City and serves learners from diverse socio-economic backgrounds. A purposive sampling technique was employed to select participants based on enrollment in the Senior High School STEM strand and exposure to chemistry topics involving gases. A total of 50 Senior High School STEM learners participated in the main phase of the study.

Instrumentation. Two research instruments were utilized. The first was a researcher-developed 30-item multiple-choice test designed to assess learners' content proficiency in chemistry, specifically focusing on gas-related competencies aligned with the Department of Education's Most Essential Learning Competencies (MELCs). The instrument underwent expert validation to establish content validity and was pilot tested to assess clarity and reliability. Revisions were made based on pilot-test results prior to its final administration.

The second instrument was a 15-item technological proficiency questionnaire adapted from Garma et al. (2024). This tool measured learners' technological fluency across three domains: software application skills, web navigation skills, and online safety and security skills. The adapted instrument was reviewed for contextual appropriateness and internal consistency.

Pilot Testing and Instrument Validation. Prior to data collection, pilot testing was conducted among Senior High School STEM learners from Dapitan City National High School, who were not included in the main study. These learners had prior exposure to the chemistry concepts under investigation, making them suitable for evaluating the instruments. Data obtained from the pilot test were analyzed to determine reliability and inform necessary revisions, ensuring that the instruments were valid and reliable for the target population.

Table 1. Interpretation of Learners' Performance in the Chemistry Test

Percentage	**Remarks**
90-100	Passed
85-89	Passed
80-84	Passed
75-79	Passed
Below 75	Failed

(DepEd Order No. 8 s, 2015)

Table 2. Content Proficiency Scale Range and Interpretation

Level of Proficiency	**Equivalent Numerical Value**
Novice	74% and below
Developing	75%-79%
Approaching Proficient	80%-84%
Proficient	85%-89%
Advance	90% and above

(DepEd Order No. 31 s, 2012)

Table 3. Technological Proficiency Scale Range and Interpretation

Level of Proficiency	**Equivalent Numerical Value**
Advanced	3.25-4.00
Proficient	2.50-3.24
Developing	1.75-2.49
Novice	1.00-1.74

(Garma et al., 2024)

Data Analysis. To examine the relationship between learners' chemistry content proficiency and technological proficiency, the Pearson product–moment correlation coefficient was employed. This statistical procedure was selected to determine both the strength and direction of the association between the two continuous variables. Statistical significance was evaluated at the 0.05 alpha level to ascertain whether the observed correlation exceeded what could be expected by chance. The use of Pearson's r provided an objective and robust measure of the relationship between learners' academic performance in chemistry and their level of technological fluency.

Ethical Considerations. This study was conducted in strict adherence to established ethical standards for research involving human participants. Prior to data collection, formal approval was obtained from the Schools Division Superintendent and the School Principal of Sulangon National High School. Coordination with designated science teachers ensured the appropriate and orderly administration of the research instruments.

Participants were informed of the purpose and procedures of the study and were assured that all data collected would be treated with confidentiality and used solely for academic and research purposes. To preserve anonymity, no personally identifiable information was collected. Participation was entirely voluntary, and learners were informed of their right to decline participation or withdraw from the study at any point without academic repercussions.

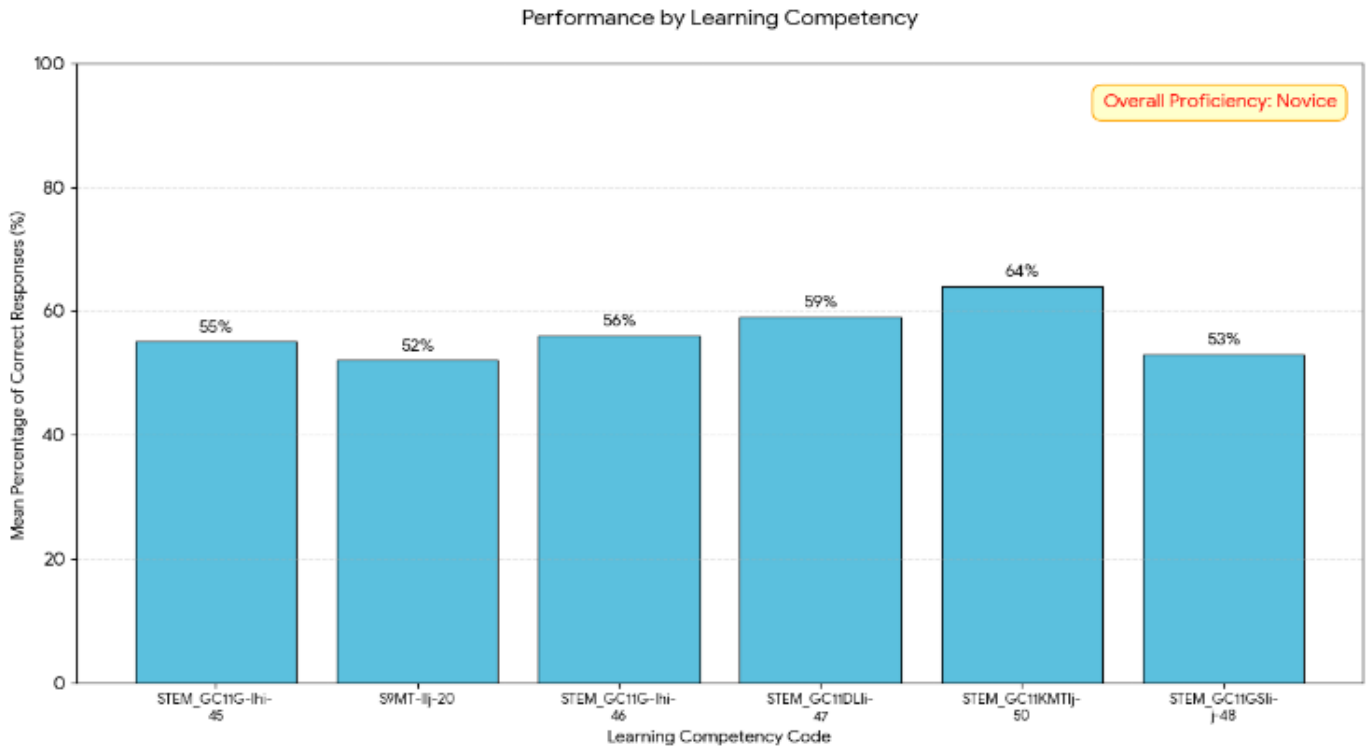
All research procedures were non-intrusive and posed no risk of physical, emotional, or psychological harm. The study complied with ethical guidelines prescribed by the Department of Education and recognized standards for educational research, thereby safeguarding the rights, welfare, and dignity of all participants.

RESULTS AND DISCUSSION

This section presents Senior High School Stem Learners' Content Proficiency in Chemistry Competencies and their Technological Proficiency.

A. Content Proficiency in Chemistry Competencies

Figure 1. Senior High School STEM Learners' Level of Proficiency in Chemistry Competencies (Gases)

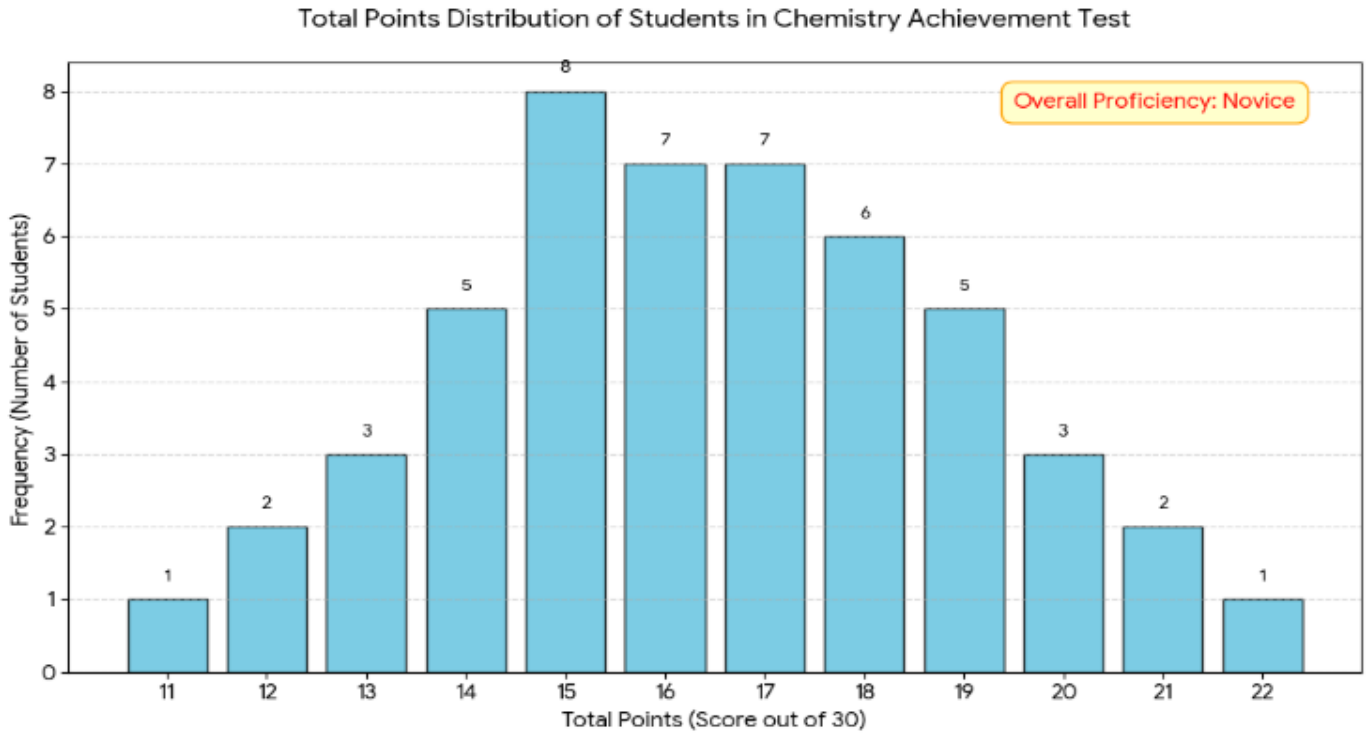


The findings reveal a persistently low level of proficiency among Senior High School STEM learners in chemistry competencies related to gases. The overall mean percentage score of 56.5% across all assessed items places learner performance within the Novice proficiency level, based on the classification set forth in DepEd Order No. 31, s. 2012. Notably, none of the assessed competencies reached the 75% mastery benchmark, indicating that foundational chemistry concepts in this domain have not been adequately mastered. This pattern suggests a cumulative deficiency in conceptual understanding that likely originates in earlier grade levels and persists through Senior High School, reflecting systemic challenges in learners' progression across the chemistry curriculum.

A closer examination of individual competencies highlights areas of pronounced difficulty. The lowest mastery level was recorded for competency S9MT-IIj-20, with a mean percentage score of 52%, followed closely by STEM_GC11G-Ihi-45 at 55% and STEM_GC11GSIi-j-48 at 53%. Although STEM_GC11KMTIj-50 yielded a comparatively higher score of 64%, it nonetheless remained within the Novice proficiency category. These results indicate pervasive challenges in both knowledge retention and the application of core concepts, underscoring learners' difficulty in integrating theoretical understanding with problem-solving tasks.

The high incidence of incorrect responses across several competencies indicates persistent learning gaps in gas-related chemistry topics. These findings suggest that, within the context of this study, existing instructional approaches may not sufficiently support deep conceptual understanding. Thus, the use of targeted strategies such as differentiated instruction, guided remediation, and well-designed intervention materials is recommended to address identified gaps and support improved learning outcomes in chemistry.

Figure 2. Performance of the Learners on the Achievement Test



The distribution of scores obtained by the 50 Senior High School STEM learners on the Chemistry achievement test covering gas-related concepts indicates a pronounced clustering below the established mastery criterion. The 30-item assessment yielded a mean score of 16.95, corresponding to a mean percentage score of 56.5%, which falls within the Novice (Not Mastered) category based on the minimum proficiency threshold of 75%. The score distribution approximates a normal curve, with the majority of learners scoring between 15 and 18 points and the highest frequency occurring within the 16–17 point range. This pattern reflects widespread difficulty in applying more advanced conceptual and thermodynamic principles associated with gases.

Individual scores were largely confined to a range of 11 to 22 points, with no learner attaining scores within the high-proficiency bracket (27–30 points). Notably, none of the participants reached the 22.5-point benchmark required for mastery. The concentration of scores in the lower-to-middle range suggests that while learners demonstrate rudimentary familiarity with gas-related concepts, they experience substantial challenges in analytical reasoning, quantitative problem-solving, and the application of abstract principles. These findings underscore the need for targeted remedial instruction and the implementation of pedagogical strategies that emphasize conceptual coherence, scaffolded problem solving, and the integration of quantitative reasoning to address persistent learning gaps.

Senior High School STEM Learners' Level of Technological Proficiency

This section presents the results of Senior High School STEM learners' technological proficiency across three domains: software application skills, web navigation skills, and online security skills.

Table 1. Learners' level of technological proficiency in terms of software skills

Indicators	Mean	Interpretation
I can prepare and give presentations using PowerPoint, Google Slides, Prezi, etc.	3.02	Proficient
I can utilize Canva and other editing apps in making and submitting my learning task.	3.14	Proficient
I can work collaboratively on a shared online document using Google Docs, etc.	2.76	Proficient
I can create a report using Excel and spreadsheets for my assigned learning tasks.	2.66	Proficient
I can compose my assignments and other learning tasks using Microsoft Word, Google Docs, etc.	2.88	Proficient
Total Mean	**2.89**	**Proficient**

Senior High School STEM learners demonstrated an overall Proficient level of technological proficiency in terms of software skills, with a composite mean score of 2.89. Learners exhibited the strongest performance in tasks involving creative and visual applications, as evidenced by the highest mean score for the use of design and editing platforms such as Canva (M = 3.14), followed by the preparation of digital presentations (M = 3.02). These results indicate a well-developed capacity for visual communication and content creation within digital learning environments.

Conversely, although still classified within the Proficient range, lower mean scores were observed for more technical and data-oriented tasks. Collaborative work using shared digital documents (M = 2.76) and the creation of reports using spreadsheet applications (M = 2.66) emerged as the least developed competencies. This disparity suggests that while learners are comfortable with visually oriented digital tools, they experience greater difficulty with tasks requiring data management, numerical analysis, and collaborative document processing. These findings underscore the need for targeted instructional support to strengthen learners' analytical and data-handling skills, which are essential for higher-level academic work and future STEM-related professional contexts.

Table 2. Learners' level of technological proficiency in terms of web navigation

Indicators	Mean	Interpretation
I can navigate and conduct research using Google, Yahoo, Bing and other online search engines.	2.92	Proficient
I can easily find primary sources of information for my learning task.	3.06	Proficient
I can keep track of the sites and information I have searched using online bookmarks.	2.88	Proficient

I can recognize false information available online.	3.08	Proficient
I can identify if a website is safe to navigate.	3	Proficient
Total Mean	**2.99**	**Proficient**

The results presented in Table 2 indicate that Senior High School STEM learners exhibit a Proficient level of technological proficiency in terms of web navigation, with a composite mean score of 2.99. Learners demonstrated particularly strong competencies in evaluating the credibility and reliability of online information, as reflected in the highest mean scores for identifying false or misleading content (M = 3.08) and locating primary or authoritative sources for academic tasks (M = 3.06). These findings suggest well-developed digital literacy and critical evaluation skills, which are essential for effective engagement with online academic resources.

Although proficiency was observed across all indicators, relatively lower mean scores were noted for organizational and routine search-related tasks. Specifically, identifying secure and reliable websites (M = 3.00) and using online bookmarking tools to organize digital information (M = 2.88) represented the lower range of reported competence. Despite these minor variations, the overall proficiency level indicates that learners are generally well-equipped to conduct independent online research and navigate digital environments safely. Such foundational web navigation skills are increasingly vital in science education, where the ability to discern credible scientific information from misinformation is critical to academic success.

Table 3. Learners' level of technological proficiency in terms of online security skills

Indicators	Mean	Interpretation
I am fully aware of the risk of spam and phishing attempts when utilizing social media.	3.2	Proficient
I always reconsider the pros and cons before joining as a participating member of an online community.	3.1	Proficient
I am knowledgeable about the ambiguous copyright and intellectual property issues rampant in social media.	3	Proficient
I conduct fact-checking on the information I share on social media.	3.08	Proficient
I always make sure that my post online will not go against the community guidelines.	3.28	Advanced
Total Mean	**3.13**	**Proficient**

The results indicate that Senior High School STEM learners demonstrate an overall Proficient level of online security skills, with a composite mean score of 3.13. Learners exhibited an Advanced level of competence in digital ethics, particularly in ensuring that online posts comply with established community guidelines (M = 3.28). High levels of awareness were also observed in relation to personal online safety, as evidenced by strong performance in recognizing the risks associated with spam and phishing attempts on social media platforms (M = 3.20).

Although proficiency was evident across all indicators, relatively lower mean scores were recorded for more complex legal and evaluative tasks. Specifically, understanding ambiguous issues related to copyright and intellectual property yielded the lowest mean score (M = 3.00), while the practice of actively verifying the accuracy of shared online information obtained a mean score of 3.08. Overall, these findings suggest that while learners are well-equipped to safeguard their personal security and adhere to appropriate online conduct,

targeted instruction in digital law and systematic information verification may further strengthen their online security competencies.

Relationship Between Content Knowledge and Technological Proficiency

Table 4 presents a mean score of 16.95 for content knowledge and 3.00 for technological proficiency. The computed Pearson product–moment correlation coefficient (r = 0.589) indicates a moderate positive relationship between the two variables.

Table 4. Relationship between Content Proficiency and Technological Fluency of Senior High School STEM Learners

Variable	Mean	r coefficient	p-value	Remarks
Content Knowledge	16.95	0.589	0.000006	Significant
Technological Knowledge	3.00			

This finding suggests that increases in learners' mastery of STEM content are associated with corresponding improvements in their level of technological fluency. The statistical significance of this relationship is supported by a p-value of 0.000006, which is substantially lower than the established alpha level of 0.05. Consequently, the null hypothesis is rejected, confirming that the observed association is statistically significant and unlikely to be due to random variation.

The correlational analysis indicates that content knowledge and technological proficiency among Senior High School STEM learners are significantly associated rather than independent constructs. The findings suggest that stronger foundations in scientific and mathematical concepts are linked to more effective engagement with digital learning tools, while higher technological fluency is associated with improved conceptual understanding through technology-mediated activities. Within the context of this study, technology appears to function as a supportive factor in learning rather than a causal driver of content mastery.

CONCLUSION AND RECOMMENDATIONS

Based on the empirical evidence gathered in this study, it is concluded that content proficiency and technological fluency among STEM learners are significantly associated rather than functioning as isolated domains of learning. The findings indicate that learners with stronger foundations in scientific and mathematical concepts, particularly in chemistry, tend to demonstrate higher levels of technological fluency. This relationship suggests that content knowledge may support learners' capacity to effectively engage with digital tools used in STEM instruction, while technological fluency may, in turn, aid learners' engagement with abstract and complex subject matter.

However, it is important to emphasize that the relationship identified in this study is correlational in nature. While technological fluency appears to be a supportive factor in learners' understanding of chemistry concepts, the findings do not establish a causal or amplifying effect of technology on content mastery. Given the limited sample size of 50 learners from a single school, the conclusions should be interpreted with caution and confined to the context of the study. As such, broad system-level curricular implications are not fully warranted at this stage.

Within these limitations, the findings nonetheless offer practical implications for classroom practice. Educators are encouraged to integrate technological tools within chemistry instruction in ways that directly support conceptual understanding rather than treating technology as a stand-alone skill. Learning activities that require learners to apply digital tools such as simulations, virtual laboratories, or data analysis software to content-rich problems to promote deeper engagement with chemistry concepts while simultaneously developing technological fluency.

School administrators may also consider supporting the purposeful use of digital resources in science classrooms by ensuring access to appropriate technological infrastructure. While this study does not justify large-scale policy reforms, providing teachers and learners with relevant and functional technological tools may enhance instructional delivery when aligned with clear pedagogical objectives.

Finally, future research is strongly recommended to build on the findings of this study by employing larger and more diverse samples across multiple educational settings. Experimental or quasi-experimental research designs should be used to examine the effects of targeted digital interventions on specific chemistry learning outcomes. Additionally, incorporating performance-based measures of technological fluency alongside self-reported data may provide a more robust understanding of how technological skills relate to content proficiency. Longitudinal studies tracking learners over time are also recommended to further explore how the interaction between content proficiency and technological fluency influences academic development within STEM disciplines.

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