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PROFILING CHEMISTRY STUDENTS' SYSTEMS THINKING SKILLS IN RESPONDING TO 21ST-CENTURY CHALLENGES

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ABSTRACT

This study analyzes the profile of chemistry students' systems thinking skills as a key competency for addressing the complex challenges of the 21st century. Systems thinking is essential for understanding the dynamic interrelationships among components within a system in an integrated and holistic manner. A descriptive quantitative approach was employed involving 108 chemistry education students from seven universities across Indonesia, consisting of 58 from rural areas and 50 from urban areas. Data were collected using the Dorani Systems Thinking Skills Test (D-STST), which was adapted to the higher education chemistry context. The results showed that students from urban areas achieved a higher mean score (M = 38.5) than those from rural areas (M = 34.91), indicating differences in systems thinking proficiency based on students' residential backgrounds. These disparities are likely influenced by learning environments, access to educational resources, and academic experiences. The findings underscore the importance of implementing contextual, inquiry-based, and student-centered learning strategies to strengthen systems thinking skills and better prepare students for the demands of 21st-century education and global challenges.

Keywords: *system thinking skills; 21st-century competencies; contextual learning.*

INTRODUCTION

Science, technology, and socioeconomic development have evolved rapidly in the twenty-first century, reshaping the ways in which people think, learn, and work. Higher education institutions are now expected to prepare graduates who not only possess strong disciplinary knowledge but also demonstrate higher-order thinking skills to navigate an increasingly complex and interconnected world (Redhana, 2023). Among these skills, systems thinking has emerged as a core competence that enables individuals to understand and analyze the interrelationships, feedback loops, and dynamics within complex systems (Vuorio et al., 2024). This competency allows learners to move beyond linear cause–effect reasoning toward a more holistic and integrated understanding of real-world problems.

In chemistry education, systems thinking provides a framework for connecting scientific concepts to global challenges such as sustainability, climate change, and the circular economy (Pilcher, 2024; Vuorio, Pernaa, & Aksela, 2024). It encourages students to recognize how molecular-level phenomena relate to broader environmental and social systems, thereby strengthening their capacity to apply chemical knowledge in authentic contexts. This aligns with current international education reforms emphasizing the need to integrate systems thinking into STEM learning as a means of promoting sustainability-oriented science education (Assaraf et al., 2020; IUPAC STCS Consortium, 2024).

Despite its importance, the development and assessment of systems thinking skills in higher education, particularly in chemistry, remain inconsistent across regions and institutions. Many chemistry programs still emphasize algorithmic and content-based learning rather than systemic reasoning, limiting students' ability to apply knowledge in interdisciplinary and societal

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contexts. As a result, there is a growing need to explore how students develop systems thinking skills and what contextual factors—such as learning environments, institutional resources, and teaching approaches—affect these outcomes (Demssie, Biemans, Wesselink, & Mulder, 2023).

Recent studies have demonstrated that context-based and inquiry-driven instruction can significantly enhance systems thinking competencies. Amida et al. (2024), for instance, reported that integrating local scientific contexts—such as the phylogenetic analysis of Bengkulu oranges through DNA sequencing—can effectively foster chemistry students' systemic understanding. Laboratory activities that embed social, environmental, and technological dimensions promote deeper conceptual integration and relevance, helping students perceive chemistry as part of a larger system of interdependent processes. These findings underscore the pedagogical value of designing chemistry learning experiences that connect theoretical knowledge to authentic, context-rich problems.

However, empirical studies that map the profile of chemistry students' systems thinking skills remain limited, especially those that examine variations across different demographic and geographical backgrounds. Differences between urban and rural students may stem from disparities in learning environments, access to educational resources, and exposure to interdisciplinary experiences (Birru, 2024; Suryaningsih et al., 2024). Investigating such differences is crucial for ensuring equitable learning opportunities and for informing national education policies that promote inclusive and sustainable chemistry education across diverse contexts.

In addition, the integration of 21st-century skills—such as critical thinking (Unwakoly & Munawaroh, 2024), creativity, collaboration, and digital literacy (Dingli & Baldacchino, 2018; Hobbs & Coiro, 2016)—has been widely recognized as essential for higher education reform (Kivunja, 2022). Systems thinking aligns closely with these competencies, as it involves complex reasoning, multidimensional problem-solving, and the ability to synthesize information across disciplines (Hernandez et al., 2023). Nonetheless, universities in many developing countries, including Indonesia, face challenges in systematically embedding these skills into curricula, largely due to gaps in instructional design and limited access to technology-enhanced learning environments (Rahman et al., 2023).

Furthermore, the International Union of Pure and Applied Chemistry (IUPAC) Systems Thinking in Chemistry Education (STCS) Consortium (2024) has emphasized the importance of integrating systems thinking into undergraduate chemistry curricula worldwide. Their framework advocates for chemistry education that fosters interconnected understanding across chemical, environmental, and societal systems. This global initiative provides a timely reference for Indonesian higher education institutions seeking to modernize chemistry instruction in line with international standards and sustainability goals (Martin, 2019).

Based on these considerations, this study aims to analyze the profile of chemistry students' systems thinking skills in addressing the challenges of the 21st century. The research focuses on comparing students from rural and urban universities in Indonesia to identify potential disparities and contributing factors. The results are expected to inform the design of more contextualized, adaptive, and student-centered learning strategies that promote systems thinking as a foundational competence for chemistry education and for preparing graduates to address complex global challenges.

RESEARCH METHOD

This study used a descriptive quantitative research approach to examine the profile of chemistry students' systems thinking skills when facing 21st-century concerns (Chien, Su, Chou, & Wang, 2021). The descriptive approach was chosen to provide a detailed overview of students' current competencies and to identify potential differences between groups with different educational and geographical backgrounds. This study included 108 chemistry education students from seven Indonesian universities, with 58 from rural and 50 from urban institutions. Purposive sampling was used to ensure that the participants represented a variety of institutional contexts and learning situations.

The Dorani Systems Thinking Skills Test (D-STST) served as the primary data collection tool in this study. The D-STST was developed for usez in higher education chemistry to assess

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students' capacity to identify system components, understand interrelationships and feedback loops, and solve issues from many perspectives. Three experts in science education evaluated the revised instrument's content validity and confirmed its usefulness for assessing systems thinking in chemistry learning. The instrument's reliability was confirmed by pilot testing, which yielded a Cronbach's alpha coefficient of 0.87, showing strong internal consistency and reliability.

Data were acquired via an online questionnaire emailed to students who volunteered to participate with informed consent. Participants took about 45 minutes to complete the D-STST. The data were evaluated using descriptive statistics (mean, standard deviation, and percentage) to summarize the students' overall systems thinking profile. To investigate differences based on residential background, an independent samples t-test was performed by comparing the mean scores of rural and urban groups. The study also looked at contextual elements that could influence students' systems thinking growth, such as institutional learning environments, access to laboratory facilities, and prior academic experiences.

RESULTS AND DISCUSSION

The results of this descriptive quantitative study reveal substantial variation in chemistry students' systems thinking skills across universities and geographical backgrounds. Data collected from 108 students at seven Indonesian universities demonstrated a wide range of average scores on the Systems Thinking Skills Test. As summarized in Table 1, students from University 1 achieved the highest mean score (M = 53.13), followed by University 7 (M = 50.00). Meanwhile, University 6 recorded the lowest mean score (M = 7.50). These results suggest that institutional factors—such as curriculum design, access to learning facilities, and pedagogical orientation—may significantly influence students' ability to think systemically.

Table 1. Average Pre-Test Scores of Students' Systems Thinking Skills

University	Mean Score
1	53,13
2	34,42
3	35,00
4	38,89
5	37,50
6	7,50
7	50,00

When the data were analyzed based on residential background, students from urban universities demonstrated higher systems thinking skills (M = 38.50) than their counterparts from rural universities (M = 34.91). To determine whether this difference was statistically significant, an independent samples t-test was performed. Based on the estimated pooled standard deviation of 9.38, the test revealed a significant difference between urban and rural students ($p < .05$). This indicates that, on average, students studying in urban areas possess moderately higher systems thinking skills than those from rural regions.

Table 2. Comparison of Urban and Rural Students' Mean Scores

Group	n	Mean Score (M)
Urban	50	38,50
Rural	58	34,91

The uneven distribution of systems thinking skills across universities reflects disparities in educational environments, learning opportunities, and access to academic resources. Students enrolled in urban universities often benefit from well-equipped laboratories, exposure to interdisciplinary projects, and the integration of digital learning technologies—all of which

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enhance complex reasoning and systems-based understanding (Vuorio et al., 2024; Reynders et al., 2025). Conversely, students from rural institutions may face constraints related to laboratory access, learning materials, and exposure to real-world chemical contexts, leading to less developed systemic reasoning skills (Redhana, 2023).

These differences can also be attributed to the pedagogical environment. Studies have shown that inquiry-based and context-rich learning environments foster systems thinking by encouraging students to analyze interrelated processes and feedback mechanisms (Assaraf et al., 2020; Lavi et al., 2021). In contrast, traditional lecture-based instruction tends to emphasize procedural problem solving, limiting students' ability to see connections among chemical, environmental, and social systems. This finding echoes prior studies suggesting that the level of contextualization in chemistry learning directly correlates with systems thinking performance (Pilcher, 2022; Amida et al., 2024).

Furthermore, the disparities observed between institutions suggest that curriculum implementation may not be uniform across Indonesian higher education. Universities located in metropolitan regions may have adopted modern educational reforms more effectively, particularly those emphasizing 21st-century competencies (González-Pérez & Ramírez-Montoya, 2022) such as critical thinking, collaboration, and digital literacy (Kivunja, 2022; Birru, 2024). The integration of technology-enhanced tools and authentic laboratory experiences promotes the synthesis of chemical knowledge and systems-based problem solving (Rahman et al., 2023).

The results align closely with research by Amida et al. (2024), who demonstrated that contextual laboratory instruction, such as DNA sequencing of local Bengkulu citrus, significantly enhanced chemistry students' systems thinking. The inclusion of authentic, place-based investigations encouraged students to connect molecular processes to ecological and societal systems. Similarly, studies in Finland and South Korea reported that contextualized systems thinking curricula promote deeper understanding of chemical interactions across multiple scales (Vuorio et al., 2024).

In addition, findings from Vuario et al. (2025) emphasized the role of digital learning environments in fostering systems thinking. Interactive simulations, modeling software, and virtual laboratories help learners visualize complex system dynamics and test cause–effect relationships in chemical processes. This form of digital scaffolding allows students, particularly those in resource-limited settings, to develop integrative thinking without full reliance on physical laboratory access. Therefore, incorporating digital pedagogies can bridge systemic learning gaps between rural and urban contexts.

From a pedagogical perspective, the study reinforces the value of systems thinking as a bridge between scientific literacy and sustainability education. Systems thinking promotes students' capacity to understand chemical phenomena within societal and environmental frameworks, supporting the United Nations' Sustainable Development Goals (SDGs) (IUPAC STCS Consortium, 2024; Hernandez et al., 2023). Chemistry educators are thus encouraged to design learning activities that highlight the interdependence between chemical reactions, resource use, and global environmental issues such as pollution and climate change.

Moreover, the observed performance gap underscores the need for capacity building in rural universities. Teacher professional development programs, collaborative research networks, and partnerships with urban institutions can enhance rural faculty's expertise in implementing systems-based pedagogy. By strengthening institutional infrastructure and promoting cross-campus collaboration, Indonesian higher education can create more equitable opportunities for developing students' systemic reasoning skills.

The study also has implications for curriculum policy and assessment. Developing systems thinking requires sustained exposure to integrated, cross-disciplinary learning experiences rather than one-off laboratory activities. This supports calls from the IUPAC STCS Consortium (2024) and UNESCO (2023) for chemistry curricula to incorporate complex systems modeling and interdisciplinary project-based learning. Assessment frameworks should likewise evolve to evaluate students' ability to recognize feedback loops, interdependencies, and emergent behaviors in chemical systems.

Overall, this research underscores the urgency for universities—particularly those in developing and rural regions—to adopt learning strategies that promote systems thinking through contextual, inquiry-based, and technology-supported methods. Providing equitable

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access to laboratory experiences, digital tools, and interdisciplinary projects can help close the systems thinking gap and better prepare students to address global sustainability challenges (Suryaningsih et al., 2024).

Finally, future studies should expand this line of research by exploring longitudinal changes in students' systems thinking skills, incorporating qualitative measures such as interviews or reflective journals, and testing the efficacy of digital-based interventions. Such approaches could provide deeper insight into how systems thinking evolves across different learning contexts and how it contributes to preparing chemistry graduates for the complexity of the 21st century.

CONCLUSION

This study concludes that the systems thinking skills of chemistry students in Indonesia vary considerably across universities and residential backgrounds, with urban students demonstrating higher proficiency than those from rural areas. These differences indicate that access to learning resources, laboratory experiences, and technology-based instruction significantly influences the development of systems-oriented reasoning. Overall, students' ability to understand interconnections and feedback loops within chemical systems remains moderate, reflecting limited integration of systems thinking in chemistry education. Therefore, to address this gap, universities—particularly in rural settings—should adopt contextual, inquiry-based, and technology-enhanced learning approaches to foster systems thinking as a core 21st-century competency and better prepare students to tackle complex scientific and societal challenges.

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