Volume 4, Issue 3 (2026) 334-342

EQUATOR SCIENCE JOURNAL (ESJ)
e-ISSN: 2988-3881
Journal homepage:
https://ejournal.edukhatulistiwa.com/index.php/ESJ

Students' Thinking Processes in Connecting Abstract Cell Biology Concepts to Socio-scientific Reasoning through Biological Contexts

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Received: August 8, 2026 | Revised: September 2, 2026 | Accepted: September 18, 2026
First Available Online: September 22, 2026 | Publication Date: October 31, 2026
DOI: https://doi.org/10.61142/esj.v4i3.482

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***Keywords**:*
Cell biology;
Socio-scientific reasoning;
Biological contexts;
Context-based learning;
Thinking processes

ABSTRACT

Learning cell biology requires not only mastery of concepts but also thinking processes that enable students to connect abstract concepts with biological contexts. However, how these thinking processes develop in socio-scientific learning remains underexplored. This study aimed to explore students' thinking processes in connecting abstract Cell Biology concepts with socio-scientific reasoning through biological contexts. An exploratory qualitative case study was conducted involving 32 female students enrolled in a Biology Education program at a private university in Bandung, Indonesia. Data were collected through context-based written tests, student activity sheets, and learning reflection journals. The data were analyzed using framework analysis and descriptive statistics to identify students' thinking process profiles. The findings showed that students' thinking processes developed through three phases: Conceptual Development, Transition to Socio-scientific Reasoning, and Socio-scientific Reasoning. This development indicated that students were more capable of connecting Cell Biology concepts, evaluating evidence, and constructing arguments than problematizing socio-scientific issues. The Issue Problematization stage emerged as the most critical transition phase in connecting conceptual understanding with socio-scientific reasoning. These findings provide a thinking process framework with implications for developing biological context-based Cell Biology learning to facilitate students' socio-scientific reasoning.

INTRODUCTION

One of the main challenges in Cell Biology learning in higher education is no longer students' ability to recall cellular concepts, but rather their ability to use these concepts to understand and explain complex biological phenomena. This ability requires students to integrate multiple Cell Biology concepts when addressing a biological context, rather than mastering concepts in isolation. In this process, students need to identify relevant concepts, establish relationships among concepts, explain causal relationships, and interpret scientific information as a basis for understanding a given problem (Kopp et al., 2024; Momsen et al., 2022). However, research has shown that students tend to develop fragmented understandings of Cell Biology, making it difficult for them to connect concepts across levels of biological organization into coherent biological explanations (Flowers et al., 2023; Shiroda et al., 2024). Several studies have also reported difficulties in integrating relationships among concepts and transferring conceptual understanding to explain biological phenomena in real-life contexts (Kiselyonv & Schunn, 2022; Zúñiga et al., 2025)

One approach to bridging the gap between abstract concepts and real-world phenomena is to incorporate relevant biological contexts into learning. Biological contexts provide students with opportunities to use Cell Biology concepts to understand and explain phenomena encountered in everyday life (Leite et al., 2017; Pestes et al., 2018) Context-based science learning has also been reported to enhance learning relevance, student engagement, and scientific literacy, while helping students connect scientific knowledge with real-world experiences and problems (Giamellaro et al., 2025; Hüfner et al., 2025; Picardal & Sanchez, 2022) Thus, biological contexts can serve not only as illustrations of concepts but also as spaces in which students use and connect conceptual knowledge when addressing biological problems.

These thinking processes become increasingly complex when biological contexts involve not only scientific problems but also social, ethical, health, economic, and policy considerations. Issues such as cancer, gene therapy, vaccination, genetic engineering, and stem cell technologies are examples of *socio-scientific issues* (SSI) that require individuals to draw on scientific knowledge while also considering multiple dimensions beyond science (Dauer et al., 2025; Kumar et al., 2024). When addressing such issues, students need to do more than identify relevant concepts; they must evaluate evidence, recognize the complexity of the issues, consider multiple perspectives, and justify the decisions they make. These abilities are central to socio-scientific reasoning, which enables individuals to reason about complex issues that do not necessarily have a single definitive answer (Zeidler et al., 2019).

Although previous studies have extensively explored context-based learning and Socio-scientific Issues (SSI), most have focused on learning outcomes, such as conceptual understanding, scientific literacy, argumentation, learning engagement, and decision-making skills (Puspitarini et al., 2025; Badeo & Duque, 2022; Dewi et al., 2023; Dusturia et al., 2024). In contrast, relatively few studies have examined how students' thinking processes develop when they use Cell Biology concepts to understand biological phenomena and connect them to socio-scientific issues (Maryanti et al., 2025). Consequently, it remains unclear how students move from using conceptual knowledge to evaluating evidence, considering multiple perspectives, and reasoning about socio-scientific issues. Understanding these thinking processes is important for revealing how Cell Biology knowledge is mobilized to address complex biological problems in real-world contexts (Dauer et al., 2025).

Some students demonstrated variations in their thinking processes when connecting Cell Biology concepts with socio-scientific issues. While some students were only able to identify relevant concepts, others were able to connect multiple concepts, explain biological mechanisms, use evidence, and construct reasoning before making decisions (Maryanti et al., 2025; Flowers et al., 2023). In this study, the socio-scientific issue was presented through the context of breast self-examination (BSE) as an approach to the early detection of breast cancer. This context provided students with opportunities to connect the concept of cell division with cellular changes and cancer development, and subsequently relate these concepts to the importance of early detection through BSE. Through this context, students used Cell Biology concepts to understand breast health issues, consider scientific evidence, and construct reasoning before making decisions.

To explore the development of these *thinking processes*, this study employed a conceptual approach synthesized from the literature on *context-based learning*, *mechanistic reasoning*, *socioscientific reasoning*, and *Socio-scientific Issues in the Classroom*. This conceptual approach was synthesized into dimensions of thinking processes that were used to trace the development of students' thinking, ranging from identifying relevant concepts and connecting concepts to biological contexts to using scientific evidence and constructing reasoning about socio-scientific issues. Based on these dimensions of thinking processes, the study identified nine indicators of *thinking processes* as the basis for analysis throughout the learning process.

Previous studies have focused predominantly on learning outcomes, such as critical thinking, argumentation, and socioscientific reasoning. However, how students use and develop abstract Cell Biology concepts when engaging with socio-scientific issues remains underexplored. Therefore, this study aimed to analyze students' thinking processes in connecting abstract Cell Biology concepts with *socioscientific reasoning*. The analysis was conducted at each stage of the learning process to examine how students used concepts, scientific evidence, and reasoning to understand the issue presented through the BSE context. Accordingly, the research question was: How do students' thinking processes develop as they connect abstract Cell Biology concepts with *socioscientific reasoning* through an SSI context presented in learning?

METHOD

This study employed an exploratory qualitative case study to explore students' thinking processes in connecting abstract Cell Biology concepts with *socioscientific reasoning*. The case was bounded by the students' thinking processes during Cell Biology learning within a single class. The learning context referred to Cell Biology instruction that used breast self-examination (BSE) as a socio-scientific issue. This context was used to help students connect Cell Biology concepts, particularly cell division and its relationship to cancer, with health-related issues that are relevant to everyday life.

A case study was selected to gain an in-depth understanding of how students use Cell Biology concepts, connect these concepts to the issues presented, use scientific evidence, and construct *socioscientific reasoning*. Qualitative data served as the primary source for analyzing students' thinking processes, while descriptive quantitative data were used as supporting data to provide an overview of conceptual understanding and *socioscientific reasoning*. The study did not aim to test the effectiveness of an intervention but rather to explore students' thinking processes during learning.

This study involved 32 female students enrolled in a Cell Biology course in the Biology Education Program at a private university in Bandung, Indonesia. All students in a single class were included as participants because the class consisted entirely of female students. Thus, participants were not selected based on gender. The class was selected purposively because the students had previously studied the basic Cell Biology concepts required to connect abstract Cell Biology concepts with *socioscientific reasoning*. The class was designated as the focus of the study to enable an in-depth exploration of students' *thinking processes* during learning.

Learning was conducted using a digital Cell Biology module designed to facilitate students in connecting abstract Cell Biology concepts with biological contexts. The module presented visual representations, conceptual materials, and learning activities that encouraged students to use their Cell Biology knowledge to analyze socio-scientific issues.

After studying the Cell Biology concepts, students were presented with a socio-scientific issue related to breast self-examination (BSE) as an approach to the early detection of breast cancer**.** The issue was used to connect Cell Biology concepts, particularly cell division, with breast health concerns. Through this issue, students were asked to identify the problem, connect relevant concepts, interpret scientific evidence, consider multiple perspectives, construct arguments, and make decisions.

Data were collected from multiple sources to explore students' thinking processes in connecting abstract Cell Biology concepts with socio-scientific reasoning through biological contexts. The primary data source consisted of students' written responses to biological context-based tasks designed to elicit the use of concepts, interpretation of evidence, consideration of multiple perspectives, argumentation, and decision-making.

As supporting data, the study used student activity sheets, learning reflections, and conceptual understanding test results. All data sources were analyzed in an integrated manner to identify students' thinking processes, while the use of multiple data sources enabled triangulation in interpreting the research findings.

The research instruments consisted of a context-based written test, student activity sheets, and learning reflection journals. The written test was developed based on nine *thinking process* indicators formulated through a synthesis of the literature described in the preceding section**.** The nine indicators comprised *Conceptual Grounding, Contextual Encounter, Concept–Context Connection, Biological Sense-Making, Evidence Engagement, Issue Problematization, Multiple-Perspective Reasoning, Argumentation and Evaluation*, and *Evidence-Based Decision Making*. Students' responses were analyzed as *evidence of thinking* based on the arguments and justifications expressed for each indicator. Before being administered, the instruments were reviewed and validated by Biology education experts to assess the alignment among the indicators, the concepts being measured, the socio-scientific issue context, and the research objectives.

Data analysis was conducted in two stages. The first stage employed framework analysis to identify students' thinking processes based on the nine research indicators. The second stage converted the coding results into rubric scores, which were analyzed descriptively using the mean, standard deviation, minimum–maximum values, and frequency and percentage distributions. The results were used to describe students' thinking process profiles in connecting abstract Cell Biology concepts with socio-scientific reasoning through biological contexts.

RESULTS AND DISCUSSION

To address the research question, students' thinking processes were analyzed based on their written responses to biological context-based tasks using the assessment rubric presented in Figure 1.

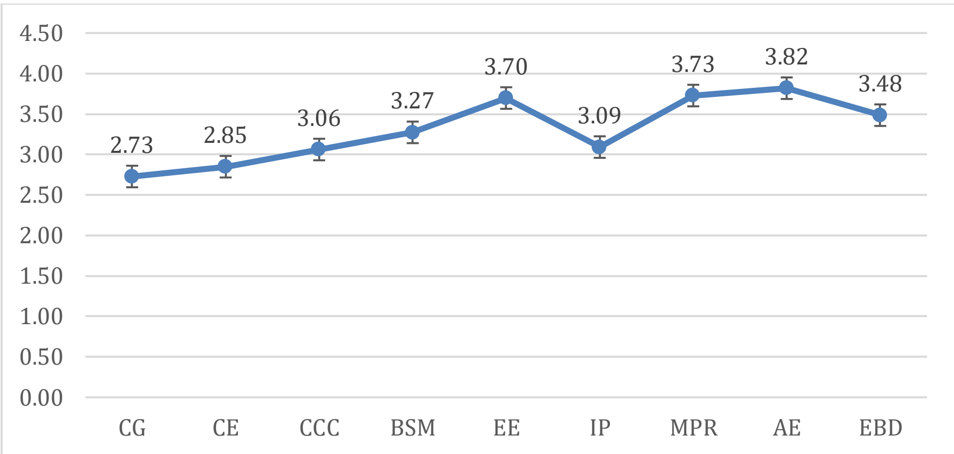


Fig.1. Students' thinking processes in connecting abstract cell biology concepts to socio-scientific reasoning through biological contexts

Note: 1. CC (Conceptual Grounding), 2. CE (Contextual Encounter), 3. CCC = (Concept–Context Connection), 4. BSM (Biological Sense-Making), 5. EE (Evidence Engagement), 6. IP (Issue Problematization), 7. MPR (Multiple-Perspective Reasoning), 8. AE (Argumentation and Evaluation), 9. EBD (Evidence-Based Decision Making)

Figure 1 shows that students' thinking processes in connecting abstract Cell Biology concepts with socio-scientific reasoning through biological contexts developed across three main phases: Conceptual Development, Transition to Socio-scientific Reasoning, and Socio-scientific Reasoning. This developmental pattern was not linear. The initial stages showed a gradual increase as students established connections between Cell Biology concepts and biological contexts, followed by a decline at the Issue Problematization stage, before increasing again through the reasoning stages up to Argumentation and Evaluation, with a slight decline at Evidence-Based and Decision Making.

In the Conceptual Development phase, students' performance increased progressively from Conceptual Grounding (2.73) and Contextual Encounter (2.85) to Concept–Context Connection (3.06) and Biological Sense-Making (3.27). The findings indicate a development in students' thinking processes as they used their Cell Biology knowledge when engaging with the socio-scientific issue, particularly the BSE context. This development was evident in the progression from activating prior knowledge and understanding the issue to connecting concepts with the issue and explaining the underlying biological processes.

This pattern was reflected across the four processes. In *Conceptual Grounding*, students identified and activated their prior knowledge of cell division concepts that they had previously learned. This prior knowledge provided a foundation for understanding the issue of breast cancer and the importance of BSE as an approach to early detection. In the *Contextual Encounter* stage, students began to recognize the health problem presented through the issue. Subsequently, in *Concept–Context Connection*, students began to connect Cell Biology concepts with the issue, particularly by relating cell division and cell-cycle regulation to cellular changes associated with cancer development. This process progressed to *Biological Sense-Making*, in which students used the concepts they had acquired to explain the biological processes underlying the issue of breast cancer. Thus, the *Conceptual Development* phase indicates that students' thinking processes developed from activating prior knowledge and understanding the issue toward constructing more comprehensive biological explanations.

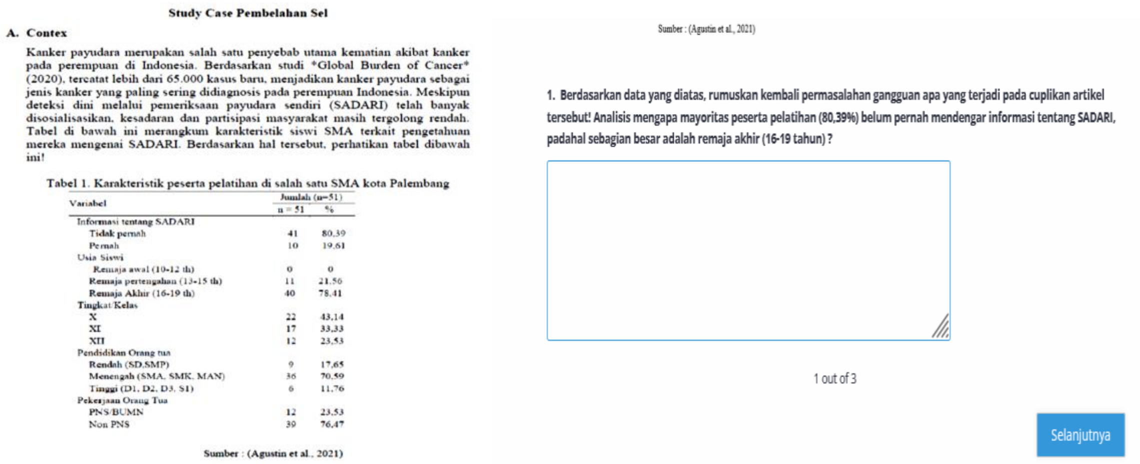
Thus, the SSI context can help students use abstract Cell Biology concepts to understand biological problems. This finding is consistent with Li et al. (2021), who showed that Cell Biology learning can connect molecular-level concepts with their implications for health, including cancer development. Context-based learning can also help students integrate scientific concepts with real-world situations, making the concepts they learn more meaningful and relevant (King & Henderson, 2018; Sevian et al., 2018; Appiah-Adjei et al., 2025). These findings are further supported by a bibliometric study by Fayzullina et al. (2023), which showed that context-based learning in science education can enhance students' understanding and application of authentic concepts while also increasing their engagement.

This development continued into the *Transition to Socioscientific Reasoning* phase, which was characterized by a relatively high score for *Evidence Engagement* (3.70), followed by a lower score for *Issue Problematization* (3.09). These findings indicate that students were relatively capable of using scientific evidence to understand the issue; however, this ability had not yet fully developed into the capacity to identify and articulate the complexity of the issue.

In the context of breast cancer and early detection through BSE, students tended to use Cell Biology concepts to explain the biological mechanisms underlying cancer. However, they did not frequently connect these mechanisms to other aspects, such as health literacy, education, family support, access to information, and social conditions. This pattern indicates that the ability to use scientific evidence was not yet fully accompanied by the ability to problematize the issue. Students tended to use evidence to explain the biological aspects of cancer, while their ability to identify the broader and more complex dimensions of the BSE issue remained limited.

These findings are consistent with Högström et al. (2025), who showed that SSI-based learning involves not only the use of scientific evidence but also requires students to explore issues through multiple scientific and social dimensions. This finding also reinforces the view that *socioscientific reasoning* requires the ability to consider the complexity of an issue and multiple perspectives when understanding it, which is a key characteristic of *socioscientific reasoning* (Zeidler et al., 2005 ; Zeidler et al., 2019).

Entering the *Socioscientific Reasoning* phase, students' performance increased again in *Multiple-Perspective Reasoning* (3.73) and reached its highest score in *Argumentation and Evaluation* (3.82), before declining slightly in *Evidence-Based Decision Making* (3.48). In the BSE issue context, most students were able to construct arguments that early detection is necessary to increase the likelihood of successful breast cancer treatment and should be supported by broader health education. However, when asked to determine the most appropriate decision, some students still tended to provide general solutions, such as increasing public awareness or health education, without considering various factors that influence the implementation of BSE, including the target age group, health literacy, family support, access to information, and sociocultural conditions. These findings indicate that decision-making in socio-scientific issues requires the integration of conceptual knowledge, evidence evaluation, and consideration of multiple perspectives and the consequences of each decision alternative, making it a more complex process than constructing an argument (Klosterman & Sadler, 2010; Sadler & Zeidler, 2009). Figure 2 presents the biological context used as a learning stimulus to facilitate students' *thinking processes* in connecting abstract Cell Biology concepts with *socioscientific reasoning*.



Study Case Pembelahan Sel

A. Contex

Kanker payudara merupakan salah satu penyebab utama kematian akibat kanker pada perempuan di Indonesia. Berdasarkan studi *Global Burden of Cancer* (2020), tercatat lebih dari 65.000 kasus baru, menjadikan kanker payudara sebagai jenis kanker yang paling sering didiagnosis pada perempuan Indonesia. Meskipun deteksi dini melalui pemeriksaan payudara sendiri (SADARI) telah banyak disosialisasikan, kesadaran dan partisipasi masyarakat masih tergolong rendah. Tabel di bawah ini merangkum karakteristik siswi SMA terkait pengetahuan mereka mengenai SADARI. Berdasarkan hal tersebut, perhatikan tabel dibawah ini!

Tabel 1. Karakteristik peserta pelatihan di salah satu SMA kota Palembang

Variabel	Jumlah (n=51)	
	n = 51	%
Informasi tentang SADARI		
Tidak pernah	41	80,39
Pernah	10	19,61
Usia Siswi		
Remaja awal (10-12 th)	0	0
Remaja pertengahan (13-15 th)	11	21,56
Remaja Akhir (16-19 th)	40	78,41
Tingkat/Kelas		
X	22	43,14
XI	17	33,33
XII	12	23,53
Pendidikan Orang tua		
Rendah (SD,SMP)	9	17,65
Menengah (SMA, SMK, MAN)	36	70,59
Tinggi (D1, D2, D3, S1)	6	11,76
Pekerjaan Orang Tua		
PNS/BUMN	12	23,53
Non PNS	39	76,47

Sumber : (Agustin et al., 2021)

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1. Berdasarkan data yang diatas, rumuskan kembali permasalahan gangguan apa yang terjadi pada cuplikan artikel tersebut! Analisis mengapa mayoritas peserta pelatihan (80,39%) belum pernah mendengar informasi tentang SADARI, padahal sebagian besar adalah remaja akhir (16-19 tahun) ?

1 out of 3

Selanjutnya

Fig.2. Biological context used to facilitate students' thinking processes in connecting abstract cell biology concepts to socio-scientific reasoning

Overall, the findings indicate that students' thinking processes developed progressively from Conceptual Development to Transition to Socio-scientific Reasoning and ultimately to Socio-scientific Reasoning; however, this development was not linear. The main difficulty emerged at the Issue Problematization stage, when students began to move from using scientific evidence toward recognizing the complexity of the issue. This finding does not suggest that the SADARI issue was insufficiently problematic; rather, it indicates that students tended to perceive the issue as a problem with a straightforward solution, namely increasing health education. From a socio-scientific reasoning perspective, however, the issue also involves biological, health, educational, cultural, information-access, and psychological dimensions that require deeper analysis.

Thus, this study demonstrates that the main challenge in connecting abstract Cell Biology concepts with socio-scientific reasoning lies not in the use of scientific evidence but in students' ability to problematize the issue before constructing arguments and making decisions. These findings extend the understanding of how thinking processes develop through biological contexts and identify Issue Problematization as the most critical transition stage in connecting conceptual knowledge with socio-scientific reasoning.

CONCLUSION AND SUGGESTION

This study shows that students' thinking processes in connecting abstract Cell Biology concepts with socio-scientific reasoning through biological contexts developed progressively across three phases: Conceptual Development, Transition to Socio-scientific Reasoning, and Socio-scientific Reasoning. These three phases demonstrate that biological contexts not only support students in developing conceptual understanding but also facilitate the use of Cell Biology concepts to understand real-world problems.

The findings indicate that the main challenge lies not in using concepts or scientific evidence but in students' ability to problematize issues before constructing arguments and making decisions. This suggests that the development of thinking processes toward socio-scientific reasoning is not linear but requires students to integrate conceptual knowledge, scientific evidence, and relevant perspectives when addressing biological and social issues.

Theoretically, this study contributes by proposing a thinking processes framework that explains how students move from conceptual understanding toward socio-scientific reasoning through biological contexts. This framework extends understanding of the role of biological contexts in Cell Biology learning, not only as a means of enhancing conceptual understanding but also as a context for developing reasoning about issues at the intersection of science and society.

Practically, these findings suggest that Cell Biology learning in higher education should incorporate biological contexts designed not only to help students understand biological mechanisms but also to encourage them to explore issue complexity, evaluate multiple perspectives, and make evidence-based decisions. In this way, Cell Biology learning can become more relevant in preparing students to address emerging biological and health-related issues in society.

Future research should examine this thinking processes framework across diverse biological contexts and socio-scientific issues, involve more diverse and larger participant groups, and combine qualitative and quantitative approaches to obtain a more comprehensive understanding of the development of students' thinking processes toward socio-scientific reasoning.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, C.T. and M.H.; methodology, C.T. and M.H.; formal analysis, C.T.; investigation, C.T. and M.H.; writing—original draft preparation, C.T. and A.A.,; writing—review and editing, C.T., M.H., and A.A.; supervision, M.H. and A.A.,; and project administration, C.T. and M.H. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support and contributions of all individuals and institutions involved in the completion of this research and the preparation of this manuscript.

DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this work, the authors used ChatGPT 4.0 (Artificial Intelligence) for language refinement and assistance with structuring certain sections of the manuscript. Following the use of this tool, the authors thoroughly reviewed, edited, and validated the content to ensure accuracy and academic integrity. The authors take full responsibility for the final content of the publication and declare that the core research, data analysis, and interpretations were conducted without the aid of artificial intelligence.

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