

Exploring Learning Obstacles in Extraction: A Qualitative Analysis for Systems Thinking-Based Didactical Design

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Abstract

Despite the fundamental role of extraction in chemical analysis, pre-service chemistry teachers often struggle to move beyond procedural understanding toward a holistic grasp of the chemical system. Traditional instruction frequently overlooks the complex interdependencies within extraction processes, creating significant learning barriers. This qualitative preliminary study analyzes learning obstacles (ontogenic, epistemological, and didactic) in the extraction material as a critical step in developing a Systems Thinking-based didactical design. The study also aims to identify how these barriers hinder students' ability to connect conceptual, procedural, and representational aspects of extraction processes, as well as to provide an empirical foundation for designing more integrative and meaningful chemistry learning experiences. By exploring students' cognitive difficulties and instructional challenges, this research seeks to support the development of pedagogical strategies that promote system thinking, conceptual integration, and contextual understanding in analytical chemistry education. Data was collected through in-depth interviews with eight pre-service chemistry teachers who had completed Analytical Chemistry courses. The findings reveal that ontogenic obstacles, characterized by fragmented prerequisite knowledge and cognitive unreadiness, are the primary inhibitors of systems thinking. Specifically, students fail to visualize extraction as a dynamic system, leading to a disconnect between macroscopic observations and sub-microscopic interactions (epistemological barriers). Furthermore, didactic obstacles stemming from linear instructional methods were found to reinforce these fragmented mental models. This study concludes that overcoming these complex barriers requires a shift toward system-oriented pedagogical frameworks. Implementing learning-based problem integration and student-centered learning with a visualization map is recommended to facilitate the visualization of complex chemical interconnections and to foster contextual problem-solving skills in chemistry education.

Keywords: didactical design, extraction, learning obstacles, pre-service chemistry teachers, systems thinking

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1. Introduction

Systems thinking is a skill required to understand and interpret complex problems. Orgill et al. (2019) stated that chemistry serves as a tool to address several pressing global challenges, such as sustainability, pollution, climate change, and poverty. Therefore, by cultivating systems thinking skills, students are

expected to connect chemical content with context (real-world issues) and apply chemical concepts to solve problems systematically and holistically, considering all related components, the interrelationships among them, and logical steps aligned with specific goals. In this context, integrating systems thinking into chemistry education directly supports the United Nations' Sustainable

Development Goal 4 (Quality Education) by ensuring that pre-service teachers possess the holistic competencies needed to promote sustainable development. According to UNESCO (2017), quality education in the 21st century must shift from mere knowledge transmission to the development of cross-cutting functional competencies, such as systemic reasoning, which allows students to navigate the complexities of chemical processes and their environmental impacts. This is one way to promote meaningful learning.

Meaningful learning occurs when students can connect new information to their real-world applications. Chemistry is closely linked to other scientific disciplines and is often referred to as "the central science." Its applications in daily life are extensive, particularly in industrial processes. Similarly, Jasper-Abowey (2023) emphasized that educators must present information appropriately to ensure contextual and comprehensive learning. To achieve meaningful learning, educators must help students connect new information to their prior knowledge and integrate that knowledge into relevant contexts. One chemistry topic relevant to industrial applications is extraction, as it is a separation technique used in a preliminary step of research to obtain crude extracts containing active components from natural sources, enabling subsequent work in separation, purification, and analysis (Zhang et al., 2023). Extraction techniques are studied in analytical chemistry courses. According to Jakubčinová et al. (2024), the extraction topic is crucial in chemistry education because it involves the separation and purification of chemical compounds from mixtures. Understanding these concepts is necessary not only in theory but also in practice, especially in real-world contexts. Integrating real-world problems into chemistry instruction can support meaningful learning by enabling students to reinforce fundamental chemical concepts (e.g., chemical equilibrium, solubility and distribution laws, polarity of compounds and solvents, chemical bonding and molecular interactions, temperature, and pH).

By challenging students to examine how a change in one parameter (such as pH or solvent polarity) affects the entire extraction system, the study of extraction uses a systems-thinking lens that goes beyond mastery of isolated variables and develops higher-order reasoning abilities. With this method, the educational focus shifts from result-oriented learning, in which the yield of a crude extract is the main objective, to process-oriented learning. Students are encouraged to externalize their mental models and to understand the "why" and "how" underlying chemical processes rather than merely the "what," according to York & Orgill (2020). This approach allows students to expand their foundational knowledge and apply theoretical chemistry to complex experimental situations. By starting the learning process with such authentic problems, educators can more effectively engage students' cognitive processes and foster the development of a 'systems-view' early on.

Extraction is significant not only in chemistry but also in cross-disciplinary applications. Teaching extraction provides students with opportunities to visualize the broader picture and the practical applications of chemical concepts across environmental and other domains. Thus, extraction is a broad topic in chemistry that poses challenges for pre-service chemistry teachers to understand and apply it to real-world problems. Moreover, the lack of prior research linking extraction teaching to real-world issues supports the need for this study. This challenge aligns with the need to equip pre-service chemistry teachers and chemists with systems thinking skills to prepare future scientists capable of addressing global challenges, such as sustainability, and to foster evidence-based decision-making in both everyday life and public science policy (Mahaffy et al, 2019). However, the competence of pre-service chemistry teachers, who serve as the main facilitators of scientific literacy, is crucial to the success of this systematic approach. The objective of creating a culture that is aware of sustainability will remain unattainable if these future educators continue to have a

fragmentary understanding of chemical processes. This concern is echoed by Eilks & Hayes (2015) who noted that most students do not realize the importance of learning chemistry because they are not exposed to its relevance or real-world applications. This lack of awareness contributes to learning difficulties among pre-service chemistry teachers and hinders the development of chemists with system thinking capabilities.

According to Suyadi (2023), learning obstacles include ontogenic (mental readiness to learn), epistemological (limitations in the context used during learning or understanding specific concepts), and didactical (instructional methods used by educators). Ontogenic obstacles can be classified into three types: psychological (unreadiness due to psychological factors), instrumental (technical difficulties due to a lack of understanding of core concepts), and conceptual (mismatches between the learning design and students' prior experiences).

Suryadi (2023) stated that the quality of information delivery significantly affects the learning process. A didactic design that prioritizes quality learning by considering instructional strategies and the relationship between students and the learning material can support students' understanding. After identifying and analyzing the learning obstacles aspect, educators can develop predictions of student responses and design appropriate didactic-pedagogical anticipations (Anticipatory Didactic Pedagogy – ADP).

Purba (2024) found that didactic design can enhance scientific literacy and address student learning obstacles, particularly on the topic of bioplastics. Similarly, Muyassaroh (2025), developed a didactic design based on Project-Based Learning (PjBL) informed by identified learning obstacles, which resulted in improved student content knowledge, competencies, and scientific identity. Likewise, Sulistyowati (2025) assessed students' systems thinking using a PjBL-based didactic design on edible coating, developed after analyzing learning

obstacles. The study revealed that a didactic design incorporating scaffolding techniques could enhance students' systems-thinking skills to the mastery level.

Despite these advancements in didactical design research, a significant gap remains in understanding the structural origins of learning obstacles, particularly in extraction. While previous research has identified that students find analytical chemistry challenging, most existing studies describe these errors descriptively without tracing them back to their ontogenic, epistemological, or didactical roots. Furthermore, the integration of a Systems Thinking approach to specifically analyze these obstacles, rather than just as an outcome of an intervention, remains largely unexplored in pre-service teacher education. Without identifying these fundamental barriers, the development of didactical designs risks being superficial and failing to address the core cognitive gaps that prevent students from seeing extraction as an interconnected chemical system.

Therefore, to achieve contextual, high-quality learning on extraction, it is essential to identify student learning obstacles as the initial step in developing a didactic design for the extraction topic using a systems-thinking approach. Accordingly, this study aims to analyze the learning obstacles experienced by pre-service chemistry teachers during the extraction process. To achieve this objective, the study addresses the following research questions: (1) What are the predominant ontogenic, epistemological, and didactical obstacles faced by pre-service chemistry teachers in understanding the extraction topic?; (2) How do these identified obstacles hinder the development of students' systems thinking skills in the context of analytical chemistry? and (3) what are the pedagogical implications for developing a didactical design that effectively addresses these barriers?.

2. Research Method

The study was conducted at a State University located in Bandung, West Java, Indonesia. This

research employs a qualitative case study method. As outlined by Gammelgaard (2017), case study is a research approach that aims to understand the depth, uniqueness, and complexity of a "case" in its real-life context. Case studies are used to gain a deep understanding of a particular phenomenon, in this case, learning experiences.

A purposive sampling technique was used to select participants who met specific criteria deemed relevant to the study (Fraenkel et al., 2012). The participants were eight pre-service chemistry teachers from the 2023 cohort who had completed the Analytical Chemistry I course. The sample included students with high, moderate, and low academic performance in the subject. This selection aligns with Creswell's (2015) recommendation that qualitative research participants should be individuals with rich, relevant, and informed experiences concerning the phenomenon under investigation.

Data on students' learning obstacles were collected through semi-structured, in-depth interviews and audio recordings. Academic supervisors validated the interview guide to ensure the items were accurate and relevant. One-on-one interviews were conducted, allowing participants to speak freely and comfortably about their experiences (Creswell, 2015). Audio recordings were then transcribed for further analysis.

Data analysis followed the framework proposed by (Miles et al., 2014). The stages are shown in Figure 1.

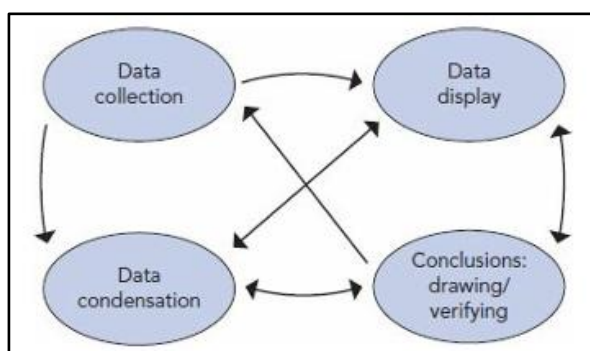


Figure 1. Interactive Model of Data Analysis Components

According to Figure 1, which consists of four interactive and cyclical components: data collection, data condensation (simplifying and organizing the data), data display (presenting the data visually or descriptively), and drawing/verifying conclusions. This iterative process allows for continuous refinement and interpretation throughout the analysis phase.

3. Result and Discussion

The questions used in the semi-structured in-depth interview instrument were designed around several sub-themes, including initial understanding of the extraction material, identification of learning obstacles, connections to systems-thinking concepts, the context of bioactive compounds from fruit peel waste, green chemistry in waste utilization, and recommendations for learning. Learning obstacles were identified across all interviews sub-themes by analyzing students' misconceptions in their responses and their verbal and nonverbal reactions to the questions. The interview topics and corresponding question numbers are described in the table below:

Table 1. Interview Topic and The Number on The Interview Sheets

Interview topic	Questions' Number
Initial understanding of the extraction material	1, 2, 3
Learning barrier identification	4, 5, 6, 7
Relation to the concept of systems thinking	8, 9, 10, 11, 12
Context (bioactive compounds in fruit peel waste) in the utilization of fruit peel waste	12, 13, 14, 15, 16, 17, 18
Learning recommendation	19, 20, 21, 22

After conducting interviews with participants based on the five topics and analyzing the data qualitatively, following the stages proposed by Miles et al. (2014) five categories

were identified, reflecting the learning obstacles experienced by pre-service chemistry teacher students. These five categories were then grouped into three main themes based on the types of obstacles outlined by Brousseau in Suryadi (2023): ontogenic, epistemological, and didactical obstacles.

Table 2. Interview's Categories and Themes

Categories	Themes
Weak understanding of basic concepts and prerequisites: weak chemistry foundation in high school, forgetfulness, difficulty connecting and elaborating concepts)	<ul style="list-style-type: none"> • Ontogenic Obstacle (Instrumental and Conceptual) • Epistemologic Obstacles
Psychological and Motivational Factors: pessimism, lack of confidence, fear, passive learning, drowsiness, low interest, feeling left behind)	Ontogenic Obstacles (Psychology)
Technical and Theoretical Gap: Difficulty with Calculations and Technical Concepts Lack of real-world application and context	Ontogenic Obstacles (Instrumental) Epistemological Obstacles
Instructional Learning: Lack of interactive learning models and media, teacher-centered methods, and non-interactive media.	Didactic Obstacles

3.1. Ontogenic Obstacles: Limitations of Cognitive Readiness and Preconceptions

Interview results indicate that most pre-service chemistry teacher students experience ontogenic obstacles in understanding the extraction material. One of the most prominent forms of ontogenic obstacles is cognitive unpreparedness, which stems from a weak mastery of basic chemical concepts. This is reflected in participant statements such as:

"I've heard of the partition coefficient, but I forgot, Ma'am." (I-1)

"Since my background is only from high school, I don't really understand chemistry in depth, Ma'am... rather than my friends who already come from a chemistry vocational high school. I have zero knowledge of analytical chemistry, even until now." (I-2)

"It was difficult at first. Thinking back to high school, my theoretical chemistry grades weren't very good, Ma'am, so it's quite hard to understand." (I-8)

According to Brousseau (as cited in Suryadi, 2023), these statements reflect ontogenic conceptual obstacles, defined as the gap between students' current cognitive maturity and the conceptual demands of the subject matter. When students lack understanding of fundamental concepts such as polarity, solubility, or the distribution law (which relates to the extraction topic), they struggle to grasp the principles of extraction.

Furthermore, students also experienced instrumental obstacles, which refer to difficulties in applying chemical concepts to solve problems. For example:

"I'm confused about how to determine the organic phase and the aqueous phase, Ma'am." (I-1)

"...I don't understand why the solution separates into top and bottom layers." (I-3)

"It's difficult, Ma'am. The theory is hard, including the calculations." (I-2)

These statements indicate that even though some students are familiar with basic concepts, they still struggle to apply them procedurally within the context of extraction. This instrumental obstacle is further supported by I6's statement:

"Then I was confused about why it separates, Ma'am." (I-6)

This reveals a lack of understanding of the principle of separation based on polarity differences, which is a fundamental concept in the extraction process. This aligns with Natalia et al (2023) who explain that ontogenic obstacles emerge from a mismatch between students' current cognitive abilities and the conceptual demands of the subject matter.

In addition, several participants reported difficulty in integrating interrelated concepts, as illustrated by the following statements:

"There are so many interconnected concepts, Ma'am, so it's hard to link them together." (I-2)

"I have difficulty connecting one concept to another, even though we are expected to integrate the concepts on our own." (I-7)

These challenges indicate a weakness in students' systems-thinking skills, a critical component of cognitive readiness required to understand complex subject matter. As emphasized by Orgill et al., (2019) systems thinking skills are essential for recognizing and understanding the interrelationships among concepts, particularly in complex chemistry topics such as extraction.

Beyond conceptual and instrumental barriers, interview findings also revealed that students encountered psychological ontogenic obstacles—learning difficulties rooted in mental, emotional, or attitude conditions that hinder the learning process. These obstacles included low self-confidence, lack of motivation, social anxiety, and mismatches between students' learning styles and the instructional methods used.

Several students expressed feelings of insecurity and inferiority when learning extraction content, particularly when comparing themselves to peers with stronger chemistry backgrounds:

"At the beginning of the course, I basically had zero knowledge of analytical chemistry,

even until now, Ma'am. Meanwhile, my classmates who had a background in analytical chemistry had already studied the material and completed lab work." (I-2)

"I felt embarrassed compared to my classmates." (I-6)

"...because I wasn't confident, Ma'am..." (I-8)

This condition reflects a sense of inferiority and social pressure, which hinders students from actively asking questions, engaging in discussions, or pursuing a deeper understanding. As expressed by one participant:

"Sometimes we feel hesitant and afraid to ask questions because the lecturer puts pressure on us..." (I-7)

This reluctance to ask questions during learning activities creates a disconnect between students and the learning resources, ultimately affecting their comprehension of the material.

Bhati (2022) states the following the self-efficacy theory, an individual's belief in their own ability, plays a critical role in learning success. When students lack confidence in their capabilities, they tend to avoid challenges and are less likely to engage with difficult material. This is evident in the psychological barriers expressed by several participants. In addition to low self-efficacy, lack of motivation, and passive attitudes also emerged as significant psychological obstacles:

"Internally, I'm just too lazy to read the book, Ma'am..." (I-4)

"...I lack the motivation to study, Ma'am." (I-6)

"At first, I was confused, Ma'am, but I just went with the flow." (I-5)

Such passive behavior reflects limited active engagement in the learning process, which

aggravates the gap in conceptual understanding. Students who adopt this mindset not only struggle with the material but also demonstrate minimal effort to seek solutions or overcome learning difficulties. Furthermore, psychological barriers were also linked to mismatches between students' preferred learning styles and the instructional methods used:

"I can't study just by reading a book, because I'm an audio-visual learner..." (I-7)

"I'm the kind of learner who doesn't immediately understand things in class..." (I-8)

These statements highlight the need for pedagogical interventions that promote belief in chemistry learning, not just the transfer of content, and for safety-learning environments that accommodate diverse learner profiles, especially when addressing complex topics like chemical extraction.

Learning styles that are not accommodated can leave students feeling left behind and demotivated. Hattie (2025) said everyone has different learning style preferences (visual, auditory, kinesthetic), and failure to adapt learning methods to students' learning styles can be a source of cognitive and emotional stress.

3.2. Epistemological Obstacles: Difficulty Understanding Conceptual and Abstract Nature

Epistemological obstacles among pre-service chemistry teacher students are reflected in their difficulty in connecting previously learned fundamental chemical concepts with the new concepts introduced in the extraction topic. Students struggled to integrate these concepts due to the material's interconnected, abstract nature. Participant statements such as:

"There are many interconnected concepts, so it's hard to connect them." (I-2)

"It was only presented and introduced briefly." (I-3)

It indicates that their conceptual understanding is shallow and unstructured. Moreover, the absence of real-life applications in the learning process further weakens the conceptual linkage:

"There were no application examples, so it was difficult to understand." (I-4)

These findings underscore the need for contextual and application-based instruction to support deeper conceptual integration and overcome epistemological obstacles.

According to the interview's topic, students' failure to link solvent polarity to the extraction outcome indicates a 'fragmented mental model'. In a systems-thinking framework, this means students see extraction as a linear sequence of steps rather than as a dynamic equilibrium in which changing one component affects the entire network of interactions. This difficulty highlights a weak cognitive structure in the construction of conceptual understanding, reinforcing the need for context-based and experiential learning. This aligns with Novak & Gowin (1984), who argue that meaningful learning requires integrating new knowledge with the learner's existing cognitive framework.

3.3. Didactic Obstacles: The Influence of Instructional Methods

Didactic barriers emerge from instructional practices that tend to be conventional and teacher-centered, providing limited opportunities for meaningful interaction between students and the content. Learning processes dominated by lectures, text-heavy PowerPoint slides, and a lack of variety in teaching media contribute to student disengagement and hinder deep understanding. Several participant quotes illustrate this issue:

"It was only lectures and reading PowerPoints, so it was boring and difficult to understand." (I-4)

"There was a lack of innovation in the teaching, Ma'am." (I-6)

Such monotonous methods may reduce students' motivation to learn and lead to cognitive overload, particularly when content is delivered in lengthy textual formats without supporting visual elements or interactive activities. Additionally, instructional strategies that involve students presenting material without sufficient understanding can exacerbate confusion rather than facilitate learning:

"Students who didn't understand were asked to explain, so I became even more confused." (I-4)

This indicates that the instructional design did not adequately incorporate scaffolding, leaving students unprepared to explain concepts they had not yet mastered. In addition to the lecture method, students also expressed concerns about the lack of variety in instructional delivery:

"There's a lack of innovation in the learning process, Ma'am." (I-6)

"The lecturer tells too many stories... even though it's enjoyable, it can also become boring without variation." (I-7)

This indicates that although narrative or storytelling methods can be engaging, without being balanced by interactive and multimodal approaches, the effectiveness of learning decreases. Students require a learning environment that is varied, adaptive to individual learning styles, and that encourages active engagement, rather than passive listening.

3.4. Solutions to Learning Obstacles

This study shows that ontogenetic, epistemological, and didactic barriers in the extraction process are not isolated phenomena but form an interconnected system that shapes how pre-service chemistry teachers interact with analytical chemistry. When students enter the course with weak

prerequisite knowledge and fragile conceptual structures, ontogenetic barriers such as low cognitive readiness and misconceptions make it difficult for them to follow instructions. Furthermore, the abstract and relational nature of extraction knowledge creates epistemological challenges, especially when concepts such as partition coefficients, polarity, and phase equilibrium are taught symbolically and out of context. These challenges are made worse by pedagogic patterns that limit students' possibilities to reorganize their thinking, such as narrative, lecture-based learning, limited technique diversity, and peer presentations without sufficient coaching. This pattern is in line with research on learning barriers carried out in the context of Didactic Design Research (DDR) in science and mathematics, where didactic barriers, psychological and instrumental ontogenic barriers, and epistemological barriers usually coexist and interact dynamically rather than independently.

From a broader perspective in chemistry education, the ontogenic barriers identified in this study are closely related to how aspiring chemistry teachers typically approach complex topics, such as extraction. Interview data showed that many participants relied on memorized procedures without being able to explain why each step was necessary, what drove solute transfer between phases, or how solute and solvent properties affected the extractions' result/yield. This procedural pattern, lacking a coherent conceptual framework, reflects students' own descriptions of feeling "confused when many factors are intertwined" and "not really understanding chemistry in depth." In this study, the difficulties in explaining why two layers form, which layers are organic or aqueous, or why the distribution of solutes changes with polarity and mixing time reflect the same fundamental problem: basic ideas such as polarity, intermolecular interactions, and equilibrium have not been organized into stable mental models. Thus, the learning barriers observed in the extraction topic are not isolated errors, but rather part of a broader problem of how basic chemical concepts are

constructed, connected, and used by prospective teachers when they are confronted with interacting component systems.

Moreover, these findings also have important implications for the development of pre-service teachers' pedagogical content knowledge (PCK), particularly regarding separation techniques and analytical chemistry. When content knowledge is presented in a fragmented format, pre-service teachers may struggle to anticipate the difficulties their students will encounter in learning extraction. For example, selecting a solvent, interpreting layer appearance, or explaining why repeated extractions can increase yield. They are also less likely to design tasks that highlight the relationship between macroscopic observations (visible layers and color changes), sub-microscopic models (particle-level interactions), and symbolic representations (equations, distribution ratios, and partition coefficients). In the context of this study, if misconceptions about extraction, equilibrium, and phase behavior are not addressed in pre-service chemistry teachers, there is a risk that these barriers will be passed on to the next generation of learners through oversimplified explanations or the avoidance of complex concepts. Therefore, mapping learning barriers in students is not only diagnostic to understand students' current difficulties, but also strategic to strengthen their PCK in the future so that they can design more meaningful and system-oriented learning experiences about extraction in their own classes.

Furthermore, this study's contribution lies in the direct link between learning barriers and systems thinking in chemistry education. The IUPAC Systems Thinking in Chemistry Education (STICE) project and related research argue that chemistry curricula need to support students in connecting molecular-level processes to larger systems and sustainability issues (Mahaffy et al., 2019). Nevertheless, most of the existing literature focuses on conceptualizing systems thinking (Mahaffy et

al., 2018; Orgill et al., 2019), providing frameworks (Nagarajan & Overton, 2019; Szozda et al., 2023; Talanquer & Szozda, 2024), or designing exemplary tasks (Talanquer, 2019), while relatively few studies map specific cognitive and didactic barriers that do not engage students in systems thinking. By demonstrating that pre-service chemistry teachers struggle not only with individual concepts but also with viewing extraction as a network of components, relationships, and contexts, this study fills the gap between theoretical support for systems thinking and the empirical reality of student difficulties. In other words, the analysis of learning barriers here provides a missing diagnostic layer that can inform more realistic and responsive systems thinking-based design.

By demonstrating that pre-service chemistry teachers struggle not only with individual concepts but also with viewing extraction as a network of components, relationships, and contexts, this study fills the gap between theoretical support for systems thinking and the empirical reality of student difficulties. In other words, the analysis of learning barriers here provides a missing diagnostic layer to inform more realistic and responsive systems-thinking-based design.

These results also strengthen the argument that DDR is an appropriate methodological framework for bridging the gap between learning barrier analysis and didactic innovation. Previous DDR studies in mathematics have demonstrated how prospective analysis of learning barriers, followed by metapedagogical monitoring and retrospective analysis, can be used to iteratively build and refine didactic designs that significantly reduce barriers and improve students' understanding of abstract concepts such as numbers, fractions, and limits (Pauji et al., 2023).

In this study, the identification of psychological ontogenic barriers (low self-confidence, passive learning habits), instrumental and conceptual ontogenic barriers, and epistemological and didactic

barriers on the topic of extraction can serve as prospective analytical layers for future DDR cycles in analytical chemistry. By explicitly articulating how these barriers manifest in student interview results, this study provides a concrete basis for predicting student responses and designing anticipatory scaffolding.

Regarding teaching strategies, recommendations for integrating student-centered models (Problem-Based Learning and Project-Based Learning), scaffolding questions, visualization map (for instance: SOCME (Systems-oriented Concept Map)) and addressing contextual issues can now be more precisely interpreted considering the identified barriers. PBL and PjBL can overcome motivational and psychological barriers by positioning students as active problem solvers rather than passive recipients (listeners) and by providing a concrete context that helps transform abstract ideas into meaningful knowledge. At the same time, structured scaffolding questions (Vygotsky, 1978) can directly address epistemological barriers by guiding students to make specific connections between macroscopic observations, submicroscopic models, and symbolic representations.

Furthermore, systems-oriented concept mapping tools such as visualization maps, or in IUPAC already introduced SOCME (Systems-Oriented Concept Map), which can help students externalize their systems thinking, facilitating discussion and revision of the relationships among components, processes, and contextual factors. In line with Husna et al. (2024) whose findings emphasize the need to coordinate multiple relationships within a chemical system. Recent research in systems thinking and chemistry education suggests that such mapping-based approaches can support students in visualizing complex systems and reflecting on how their understanding evolves over time (Mahaffy et al. 2020).

Finally, the study has implications for how extraction is positioned within the broader

curriculum of pre-service chemistry teacher education. Traditionally, extraction is treated as one of many separation methods in analytical chemistry, often presented after distillation or chromatography and framed primarily as a preliminary technique. The present findings suggest that, when approached through DDR and systems thinking, extraction can become a rich integrative context for developing not only conceptual understanding (polarity, equilibrium, partitioning) but also higher-order competencies such as systems thinking, scientific literacy, and sustainability awareness (Flynn et al., 2019). By using contexts such as waste valorization, green solvent design, or environmental analysis (Kisworo et al., 2023). Didactical designs on extraction can simultaneously address ontogenic, epistemological, and didactic obstacles while aligning with global efforts to reimagine chemistry education for sustainability. In this sense, the learning obstacles documented in this study are not merely "problems" to be fixed, but valuable resources for designing more responsive, future-oriented learning environments for pre-service chemistry teachers.

4. Conclusion

This study identified ontogenic, epistemological, and didactical obstacles that hinder pre-service chemistry teachers' understanding of extraction. Ontogenic obstacles were found to be the most dominant, particularly in the form of inadequate prerequisite knowledge, difficulties in connecting related chemical concepts, low cognitive readiness, and limited confidence in learning. These challenges were accompanied by epistemological obstacles, reflected in fragmented conceptual understanding and difficulties linking macroscopic, submicroscopic, and symbolic representations, as well as didactical obstacles arising from teacher-centered and procedure-oriented instructional practices. As a result, students tended to perceive extraction as a

sequence of procedures rather than as an interconnected chemical system.

The findings highlight the need for more integrative and systems-oriented chemistry instruction through contextual learning, scaffolding, student-centered approaches, and visualization tools that support systems thinking. Future research should focus on developing and implementing a Systems Thinking-based didactical design for extraction and evaluating its effectiveness in improving students' conceptual understanding, systems thinking skills, and pedagogical content knowledge in analytical chemistry.

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