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A comparison between preservice science teachers' representational competence and fluency in chemistry and physics

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ABSTRACT
This study examined the representational competence and fluency of preservice science teachers (PSTs) enrolled in a science teacher education program. It compared how these skills influence the understanding of the same cohort of PSTs when teaching concepts in chemistry and physics. Utilising a quantitative descriptive comparative design, the research analyses the participants' ability to effectively use multiple representations (MRs)—comprising graphical, experimental, symbolic, and verbal modes—during lesson presentations. Data from 39 PSTs were collected through video recordings that demonstrate concepts using various representation modes in chemistry and physics. Chi-square statistical analyses revealed significant differences in PSTs' graphical and experimental competence, with no significant differences observed in symbolic and verbal representations. The findings underscore the need for improved pedagogical strategies to enhance representational skills in science education, emphasising the interconnectedness of representational competence and fluency. It calls for targeted approaches in teacher education programs to better equip future educators with the necessary skills to foster effective learning outcomes in science classrooms.

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Introduction

In science education, it is important for PSTs to use multiple representations (MRs) to understand various scientific phenomena, concepts and experiments. These representations can take the form of diagrams, graphs, mathematical equations, or verbal descriptions (Pande & Chandrasekharan, 2021; Tonyali et al., 2023). The ability to effectively navigate and utilise these diverse representations is crucial for PSTs' success in science. Many of them face challenges in interpreting and interacting meaningfully with MRs, which can hinder their understanding and problem-solving abilities (Jannah et al., 2022). They also experience difficulties in understanding basic concepts, analysing images, defining symbols, and calculating accurately (Erniwati et al., 2020).

To facilitate effective teaching and learning in the classroom, science teachers must cultivate diverse pedagogical strategies. When learning materials include MRs, they improve pupil achievement and retention and enhance their understanding of concepts (Alfianti & Kuswanto, 2024;

Hahn & Klein, 2023). When MRs are used in preservice science education, they enhance the understanding of physics concepts and aid the development of scientific literacy and critical thinking skills among future science teachers (Widodo et al., 2023).

The use of MRs in science education must be considered along with the development of PSTs' representational competence and fluency. Representational competence relates to "one's ability to use disciplinary representations for learning, communicating, and problem-solving" (Popova & Jones, 2021, p.733). It also demonstrates the ability to interpret and construct representations, and how and when to use them in a particular context. Furthermore, it goes beyond visual literacy to the interrelationship between representation and the phenomenon depicted. Representational fluency, on the other hand, refers to the ability of individuals to change between different forms of representations to make meaning and engage in problem solving (Handayani & Masrifah, 2024; Moore et al., 2013).

There is a lack of studies that specifically look at how PSTs integrate the use of MRs during their lesson presentations in teacher educations programs in South Africa. This study is focused on PSTs enrolled in such a program at a South African university and compares their representational competence and fluency in chemistry and physics in a Natural Science methods course.

Literature Review

Multiple Representations in Science Education

In science education, multiple representations involve analogies, tables, graphs, models, diagrams, simulations, and text, all of which are designed to enhance understanding and communicate scientific concepts (Daniel et al., 2018; Treagust et al., 2018). Integrating these representations can significantly enhance learners' comprehension and promote deeper learning. This review explores the role of multiple representations in science education, particularly examining their definitions, theoretical frameworks, pedagogical implications, and empirical studies that assess their effectiveness.

Learning from multiple representations occurs when individuals seek to understand information presented across various, distinct representations that differ in symbol systems, formats, or modalities (List et al., 2020, p. 2). These forms of representation are often described as semiotic resources, essential for meaning-making within a discipline (Volkwyn et al., 2020).

Cognitive and socio-cultural perspectives offer differing insights on multiple representations. Rau (2020, p. 17) noted that learners must develop verbal sense-making competencies, nonverbal perceptual fluency with multiple representations, and meta-representational skills. From a socio-cultural standpoint, they acquire representational practices through interactions within scientific, professional, or learning communities.

Through enculturation into scientific communities, preservice teachers can effectively utilise multiple representations and engage in disciplinary discourse. Science teaching must mirror the epistemic practices of the scientific community, using MRs to convey knowledge claims (Kozma, 2020). According to Tang et al. (2014, p. 306), "representations are artifacts that symbolise an idea or concept in science (e.g., force, energy, chemical bonding) and can take the form of analogies, verbal explanations, written texts, diagrams, graphs, and simulations." A combination of these different modes is essential for communicating scientific concepts within scientific discourse and during the process of science learning (Treagust et al., 2018).

Research by Abdurrahman et al. (2019) and Murni et al. (2022), reported in this journal, have highlighted the importance of different teaching strategies to enhance learners' critical thinking and conceptual understanding in science education. The former showed that a multiple representation-based worksheet improved junior high school pupils' critical thinking skills compared with a control group who received a traditional worksheet. The latter found that a structured inquiry-based reaction rate module, integrated with three levels of chemical representation, positively influenced senior high school students' mental models and overall learning outcomes. Both studies utilised a quasi-experimental design which illustrated that diverse teaching and learning approaches that use multiple representations can have constructive outcomes.

Zuhri and Wilujeng (2023) identified a significant gap in systematic research on multiple representation learning in primary science education. They emphasised the need to empower teachers to utilise both semiotic and epistemological representations to enhance students' conceptual understanding and pedagogical effectiveness. Their research demonstrated that diverse representations—such as text, diagrams and digital media—improve reasoning, problem-solving, critical thinking, and overall academic performance in science. Similarly, Yaman and Hand (2022) explored how preservice science teachers develop argumentative and representational skills using a mixed-methods approach to analyse 180 laboratory reports and 20 video recordings. They found that PSTs improved their integration of multiple representations across various levels, particularly in written arguments when they are given continuous opportunities to engage in the discourse and critical reflection.

Hansen and Richland (2020) examined how various visual representations in science education impact learning, particularly in understanding complex concepts such as mitosis and meiosis. The findings revealed that learners performed better with simultaneous representations, especially when self-explanation prompts were included to facilitate connections between the visuals. Kohl and Finkelstein (2017) posited that in physics representations are artefacts or tools that mediate students' cognitive processes, and are mainly verbal, mathematical, graphical, and pictorial. They are used to convey information and support knowledge construction and foster students' understanding of physics (Opfermann et al., 2017; Nieminen et al., 2017). Lesh and Doerr (2003) indicated that the goal of using MRs is to allow an individual to construct and deconstruct meaning as if they were a group of people working together around a table negotiating a stable version of knowledge.

In chemistry, Gilbert and Treagust (2009) identified three types of representations to express chemical ideas:

a) The phenomenological type which includes properties such as mass, density, concentration, pH, temperature, and osmotic pressure.

b) The model type which is used for causal explanations of phenomena such as solids and can be described in terms of packed atoms or molecules.

c) The symbolic type which involves the allocation of symbols to represent atoms, whether of one element or of linked groups of several elements.

Cheng and Gilbert (2009, p.55) have also suggested that "the successful learning of chemistry involves the construction of mental associations among the macroscopic, microscopic and symbolic levels of representation of chemical phenomena using different modes of representation". The symbolic language of chemistry education should be introduced in small quanta and supported by scaffolding, and reinforced through constant practise (Taber, 2009).

In reviewing the existing literature on multiple representations in science education, several potential gaps emerge that warrant further exploration. This includes longitudinal studies, differences in MR development across diverse groups, developing MRs across disciplines, etc. This study is focused on the interplay between representational competence and fluency in Physics and Chemistry in preservice science teacher education which is elaborated upon in the next section.

Representational Competence and Fluency in Science Teacher Education

Representational competence refers to the ability to comprehend and utilise a set of domain-specific representations, such as graphs, models, diagrams and equations, to communicate understandings effectively (Daniel et al., 2018; Parsons, 2018). This competence is crucial for learners as it encompasses not only the interpretation of these representations but also the skill of selecting appropriate representations to convey specific concepts or ideas. In this sense, representational competence is somewhat static; it reflects the capacity of learners to recognise, access and employ various representations in their learning activities.

Representational competence in chemistry education refers to the ability of students to understand and manipulate various representations of chemical concepts. This includes the ability to interpret and utilise different forms of representation, such as molecular models, chemical equations, graphical data, diagrams and symbols (Popova & Jones, 2021). In contrast, representational competence in physics education refers to the ability of pupils to use multiple representations—such as verbal descriptions, mathematical equations, graphs, diagrams, and physical models—to understand and solve physics problems (Küchemann et al., 2021). This skill is crucial because physics concepts often cannot be fully grasped through a single representation alone.

In contrast, representational fluency involves the dynamic process of navigating between different representations to deepen understanding of a concept (Hill & Sharma, 2015; Tang et al., 2019). This fluency allows learners to fluidly move from one representation to another—such as shifting from a graphical representation to an algebraic expression or a physical model—which facilitates a more comprehensive grasp of complex scientific phenomena. Representational fluency is critical for problem-solving and conceptual understanding as it enables learners to relate different forms of information and synthesise their knowledge in meaningful ways. This has also been shown to be significant in mathematics education as highlighted by Lesh, Post, and Behr (1987), whose work emphasised the importance of learners' ability to seamlessly translate between verbal, pictorial and symbolic representations.

Representational fluency in chemistry education pertains to the ability to interpret and use different types of representations, including symbolic, macroscopic, and particulate-level formats (Gkitzia et al., 2020; Hilton & Nichols, 2011; Farida et al., 2009). Learners exhibiting multi-representational fluency can seamlessly transition between various representations—such as linking chemical equations to observable phenomena or particle diagrams. Moreover, educational tools like animations and simulations further enrich this learning experience. In contrast, representational fluency in physics education refers to learners' ability to effectively interact with and shift between various forms of representation—such as graphs, equations, verbal descriptions, and diagrams (Ceuppens et al., 2018; Handayani & Masrifah, 2021, 2024). This skill enhances their comprehension of complex physical concepts and improves their problem-solving abilities. It emphasises the significance of not only understanding each individual representation but also being skilled at translating among them, which ultimately deepens their conceptual understanding.

Thus, while representational competence is foundational and refers to the basic ability to use representations effectively, representational fluency builds upon this foundation by emphasising the importance of adaptability and cognitive flexibility. Learners who exhibit high levels of representational fluency can engage more deeply with the material, fostering a richer and more nuanced understanding of scientific concepts. Together, these two constructs highlight the necessity of developing both the specific skills associated with using representations and the cognitive strategies required to move fluidly between them, ultimately enhancing educational outcomes in science learning.

Purpose and Research Questions

Recent developments in science education research have highlighted the importance of representational competence and fluency in promoting conceptual understanding. However, further research is needed to explore the interplay between these two constructs. This study aimed to investigate the links between representational competence and fluency within the context of science teacher education. Drawing upon theoretical frameworks, empirical evidence, and practical insights, we compared the same cohort of preservice science teachers' representational competence and fluency in chemistry and physics. This study seeks to illustrate effective pedagogical practices that leverage MRs to enhance learning outcomes.

The following main research question is proposed:

• How does the same cohort of preservice science teachers compare in terms of their representational competence and fluency in Chemistry and Physics?

A sub-question that elaborates on the main research question is stated as follows:

• What differences does the same cohort of preservice science teachers show in terms of their competence and fluency when using the graphical, experimental, symbolic and verbal representational modes in Chemistry and Physics?

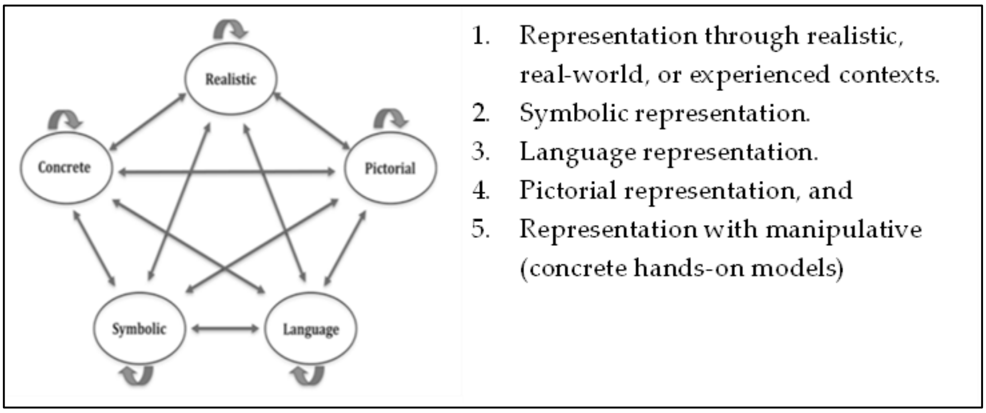
Measuring Representational Competence and Fluency

Numerous studies have sought to assess science students' representational competence (Kozma & Russell, 2005; Halverson & Friedrichsen, 2013; Mishra et al., 2018), primarily within specific contexts such as chemical or biological education. For students to effectively achieve specific objectives, they must be able to choose the appropriate representation for the task at hand (Prain & Tytler, 2013). In Science, Technology, Engineering and Mathematics (STEM) education, representational fluency is essential for engaging in professional discourse. Its promotion requires a collaborative effort among educators and researchers (Parsons, 2018).

Lesh and Doerr (2003) have shown that problem-solving in mathematics involves switching between different representations such as the spoken language, diagrams, equations, tables, etc. This is now referred to as the Lesh Translation Model (LTM) which consists of five nodes (Moore et al., 2018). These are illustrated in Figure 1 below:

Figure 1

The Lesh translation model (LTM)



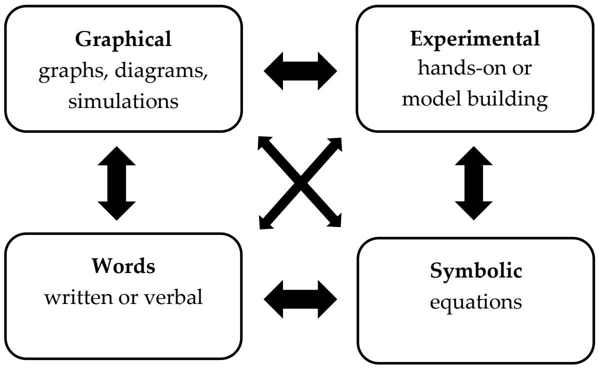
Note. Taken from Moore et al., 2018, p.20.

The LTM highlights that a deep understanding of a concept depends on using five different representations and being able to switch between them. By mastering these translations, learners can develop a more comprehensive grasp of ideas, preparing them to creatively and effectively address new problems. This multidimensional approach not only improves comprehension but also provides students with the skills to adapt their understanding to various contexts for a better learning experience.

This study has adapted the LTM and focuses on four representations and translations between them. These are shown in Figure 2 below:

Figure 2

The four representations adapted from the LTM



The adapted Lesh Translation Model framework provides a comprehensive structure that facilitates understanding and communication across multiple modes of expression—experimental, graphical, symbolic, and words. Each mode serves as a unique lens through which learners can engage with information, enhancing both comprehension and retention. A brief description of each mode is given below:

- Experimental Mode: This mode is centred around hands-on, experiential learning.
- Graphical Mode: This mode utilises visual representations to clarify and communicate information.
- Symbolic Mode: This mode relies on symbols and abstract representations to convey ideas and information.
- Words Mode: The traditional mode of communication that relies on verbal and written language to convey ideas.

The real strength of the adapted Lesh Translation Model lies in how these modes interact. By using multiple modes, educators can cater for diverse learning preferences and enable a more rounded understanding. For instance, a scientific concept can be learned through an experiment (experimental mode), visualised in a graph (graphical mode), expressed through a formula (symbolic mode), and then described in writing or discussion (words mode). When information is processed through various modes, it reinforces learning.

This adapted LTM has been used to compare the same cohort of PSTs' representational competence and fluency in chemistry and physics. Each lesson presentation in chemistry and physics was analysed in respect of the prevalence of the four modes and how they are integrated. This is expanded upon under the research procedure below.

Methodology

Research Design

This study uses a quantitative design which is nonexperimental, and specifically adopts a *descriptive comparative design* (Siedlecki, 2020). Characteristics of a sample population are compared and described without manipulating any variables. Depending on the data collected, the study can include descriptive and inferential statistics – the latter can be parametric or nonparametric (Siedlecki, 2020). The descriptive researcher's job is to focus on the most relevant features of a phenomenon as it exists in a real-world context (Loeb et al., 2017).

Furthermore, this study uses a quantitative research design because the data is numerical which allows for a more objective analysis (Privitera & Ahlgrim-Delzell, 2019). A quantitative study can also be conducted if the research questions, and hypotheses are narrow and measurable (Creswell, 2012). The numerical data that is collected is subjected to statistical analysis which allows for the hypothesis to be rejected when $p < .05$ (Lodico et al., 2010; Tavakol & Sandars, 2014).

Participants

The participants in this study are 39 preservice science teachers enrolled in a second-year level science methods course known as Natural Sciences Education. This is within a 4-year Bachelor of Education degree programme which would allow them to teach grades 4 to 7 once they qualify. The content covers biology, chemistry, geography and physics. This study explores the representational competence and fluency of the 2020 cohort and only focuses on chemistry and physics. These two disciplines were taught by the two researchers.

Data Collection

The second-year PSTs were required to present a physics model using an electricity kit they received. They had to demonstrate that it works and explain how it functions. The students had to submit a videorecording and upload it on the learning platform. Figure 3 below illustrates the use of a simulation to show light bulbs connected in parallel as presented by one of the PSTs. In chemistry, the same cohort of PSTs had to plan a lesson for a grade 7 or 8 class and practically demonstrate and explain the concepts which they chose for the lesson related to the curriculum. This had to be video recorded as well. Figure 4 shows the decomposition of water in the macroscopic, microscopic, and symbolic forms as presented by one of the PSTs. There were no restrictions placed on the PSTs to explain the concepts in both the physics and chemistry content. This allowed for a variety of representational modes to be used during the lesson presentation.

Figure 3

A typical use of a simulation to represent an electric circuit

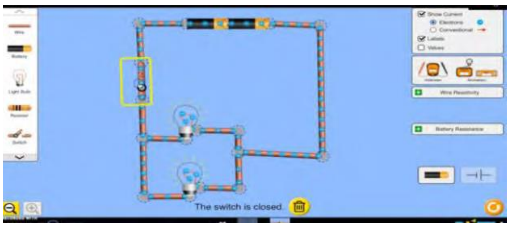
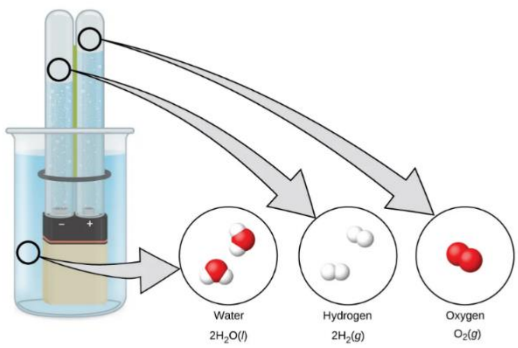


Figure 4

The decomposition of water



Note. Retrieved August 15, 2023, from https://openstax.org/books/chemistry-2e/pages/1-2-phases-and-classification-of-matter.

Sun and Van Es (2015) posited that video can capture the complexity of teaching, can be paused, and reviewed many times. Content presentation and pedagogical practices can also be analysed, whereas complex interactions in the classroom can also be observed (Dalland et al., 2020). The recorded lessons were transcribed after which coding was done of the competency and fluency relating to MRs during the lesson presentation.

Research Procedure

The lesson presentations and topic explanations in chemistry and physics provided by the PSTs were analysed based on their competency and fluency in each representational mode. This analysis was guided by the assessment rubric as developed by the researchers and presented in the Appendix. The competence and fluency in the different representational modes were categorised from low to high level and were assigned codes 1 to 3. The assessment rubric was developed based on the four representation categories in Figure 2 above. An explanation of the rating codes (1,2 and 3) follows while the inter-rater reliability is also indicated under the findings.

From the transcript each mode (graphical, experimental, symbolic, and non-specialist words) was coded as a 0 for no evidence, and 1, 2, or 3 for low-level to high-level of competence or fluency. Competence was analysed either as *inappropriate, partially appropriate,* or *appropriate* use of a specific representational mode as per the assessment rubric, whereas fluency was analysed either as the use of a mode that is *not linked, partially linked,* or *is linked* to other modes of representation.

A code 3 (high-level) was given to a mode of representation for competence and when it was used in conjunction with at least 2 other modes of representation which then promoted fluency. A code 2 (medium-level) was assigned when a partially adequate level of competence was evident, and it was linked to none or only one other representational mode. A code 1 (low-level) was allocated to a representation where no competence or low levels of competence was apparent for an attempt, despite this mode being linked to other modes of representation. A code 0 was given when there was no attempt made at using a specific representational mode.

The codes were captured on a spreadsheet which allowed then for the frequencies of each level for a particular representational mode to be tallied and converted into a percentage. This generated categorical data which allowed for the chi-square test to be applied as shown under data analysis.

Reliability and Validity

Reliability refers to the consistency of scores or a measure, whereas validity focuses on ensuring that the instrument accurately measures what it is supposed to measure (Lodico et al., 2010; Heale & Twycross, 2015). The inter-rater reliability is shown under the findings below.

Data Analysis

In this study, the non-parametric chi-square (χ^2) test is used because the nominal data obtained is in the form of frequencies, and the categories are mutually exclusive and independent (McHugh, 2013). Once the observed frequencies have been counted, they are used to calculate the chi-square statistic from a 4 X 2 contingency table. For a significance of $\alpha = .05$, and degrees of freedom, df = 3, the critical value from the chi-square table is 7.815. The null hypothesis is rejected if χ^2 is greater than the critical value, or if χ^2 is less than or equal to the critical value then we fail to reject the null hypothesis.

When the null hypothesis is rejected, it means that there is a relationship between the PSTs' representational competence and fluency in Chemistry and Physics. The extent of the relationship can be inferred from the extent to which the observed frequencies in a category exceed the expected frequencies and vice versa.

Findings

The content validity of the instrument used to assess the constructs of MR competence and fluency was done by two subject matter experts in Physics and Chemistry. Consensus was reached in terms of the instrument measuring competence and fluency in the different representational modes in Chemistry and Physics.

The inter-rater reliability was determined by calculating the Pearson correlation coefficient of the data. The data was coded independently by two science experts and yielded a value of r = 0.729. This indicates a strong positive correlation between the two sets of data which is illustrated in the scatterplot in Figure 5. The plot also shows a R^2 value of 0.53 which means there is 53% similarity between the data sets.

Figure 5

Scatterplot of data used to calculate Pearson correlation coefficient

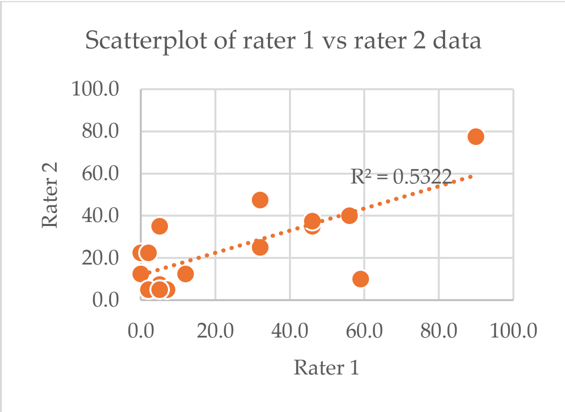


Table 1 shows that there were statistically significant differences between the same cohort of PSTs' representational competence and fluency in Chemistry and Physics on two of the representational modes. These were for the graphical and experimental modes, whereas there were no differences in relation to the symbolic and non-specialist words modes.

Table 1

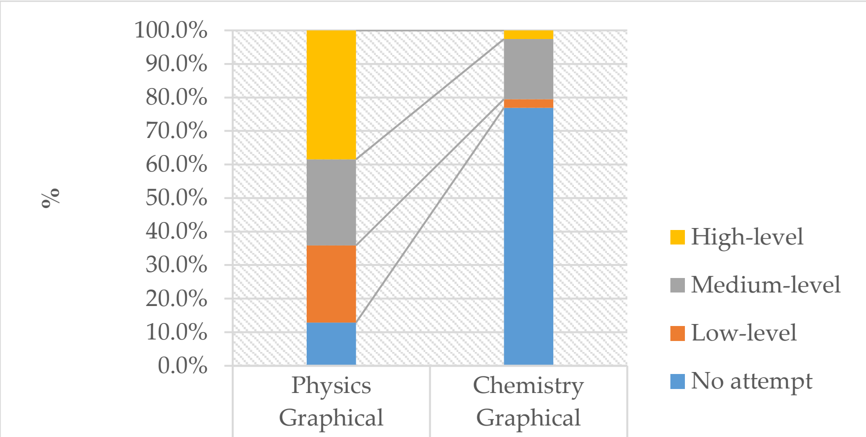
Chi-square statistics for different representational modes

Representational mode	χ^2	p – value	Significant (p < .05)
Graphical	37.04	p < .001	YES
Experimental	9.00	p = .029	YES
Symbolic	3.88	p = .275	NO
Non-specialist words	0.73	p = .867	NO

In Figure 6 the differences in the graphical representational mode for Chemistry and Physics are shown. The largest differences are in the no attempt, low-level and high-level categories.

Figure 6

Graph comparing graphical representation for Physics and Chemistry

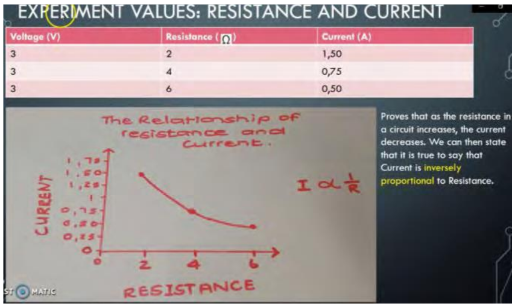


	Physics Graphical	Chemistry Graphical
High-level	38.5%	2.6%
Medium-level	25.6%	17.9%
Low-level	23.1%	2.6%
No attempt	12.8%	76.9%

A typical Physics example that illustrates a high-level of competence and fluency (code 3) is shown in Figure 7. Using a simulation, the student generated experimental data which were tabulated. A graph is then drawn to show the relationship between current and resistance in a direct-current electrical circuit. A symbolic representation of the relationship is then shown followed by an interpretation in words using the correct scientific terminology.

Figure 7

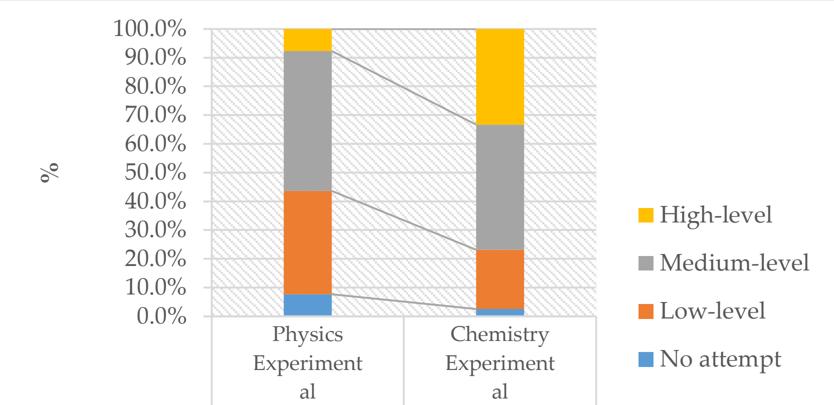
Translation from experimental data to graphical representation



In Figure 8 the differences in the experimental representational mode for Chemistry and Physics are shown. The largest differences are in the low-level and high-level categories. In Chemistry about 33% of the PSTs show a high level of representational competence and fluency, whereas in Physics 36% show a low level in the experimental representational mode.

Figure 8

Graph comparing experimental representation for Physics and Chemistry



	Physics Experimental	Chemistry Experimental
High-level	7.7%	33.3%
Medium-level	48.7%	43.6%
Low-level	35.9%	20.5%
No attempt	7.7%	2.6%

A typical Chemistry example that illustrates a high-level of competence and fluency (code 3) is shown in Figure 9. The students conducted an experiment to illustrate the pH of different solutions. A diagrammatic and symbolic representation of the concept is then shown which is accompanied by a verbal explanation using the correct scientific terms.

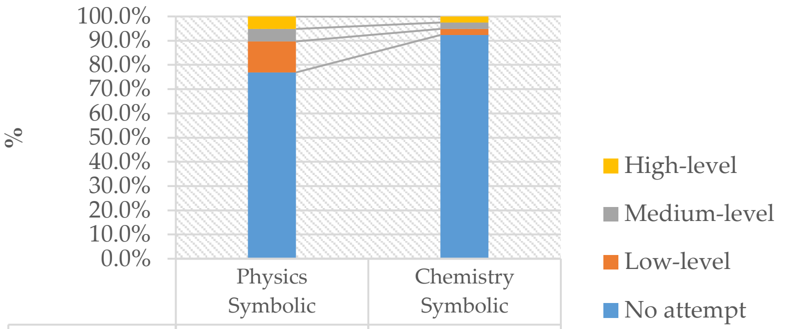
Figure 9

The experimental mode is integrated with the symbolic representational mode

Figure 10 shows that in both Chemistry and Physics there was a high percentage of PSTs who made no attempt to use the symbolic representational mode to explain concepts in these disciplines. As indicated above, the differences were not statistically significant.

Figure 10

Graph comparing symbolic representation for Physics and Chemistry

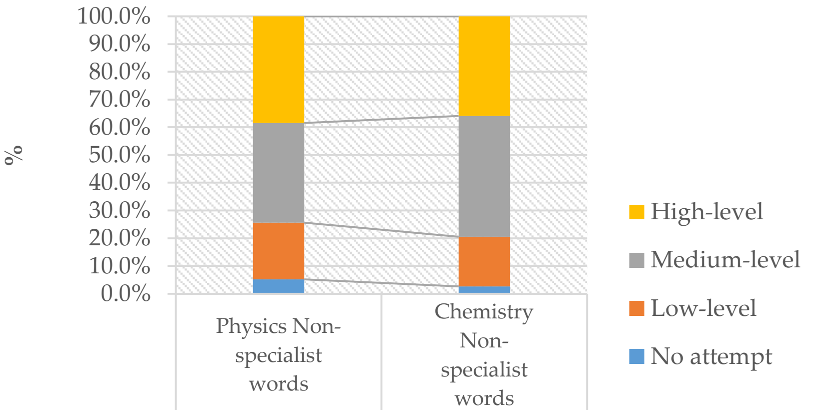


	Physics Symbolic	Chemistry Symbolic
High-level	5.1%	2.6%
Medium-level	5.1%	2.6%
Low-level	12.8%	2.6%
No attempt	76.9%	92.3%

The non-specialist words representational mode also yielded no statistically significant differences between Chemistry and Physics. The data and graph in Figure 11 clearly show that none of the categories contributed vastly different percentages.

Figure 11

Graph comparing non-specialist words representation for Physics and Chemistry



	Physics Non-specialist words	Chemistry Non-specialist words
High-level	38.5%	35.9%
Medium-level	35.9%	43.6%
Low-level	20.5%	17.9%
No attempt	5.1%	2.6%

Discussion

The chi-square analyses revealed significant differences in the modes of representation used by the same cohort of PSTs in physics and chemistry. Mathematical and graphical forms ($\chi^2 = 37.04$, $p < .001$) were favoured in Physics while phenomenological and model-based approaches ($\chi^2 = 9.00$, $p = .029$) were prevalent in Chemistry. This supports the notion that disciplinary focus influences representational preferences (Kohl & Finkelstein, 2017; Gilbert & Treagust, 2009). In both disciplines challenges were encountered with symbolic representations, which reflects broader difficulties related to task complexity and the ability to switch between representation types (Munfaridah et al., 2021;

Follmer & Sperling, 2020). This aligns with Hansen and Richland (2020), who noted that visual representations, particularly when paired with structured learning prompts, enhance understanding. The stronger competency observed among preservice teachers in Physics may stem from the discipline's reliance on graphical representations, particularly in areas like electrical circuits, although notable gaps in experimental skills indicate a need for pedagogical improvements in teacher education programs. This is in line with Yaman and Hand (2022) who encourage sustained engagements in representational practices.

No significant differences were found in the representational competence related to symbolic (χ^2 = 3.88, p = .275) and verbal representations (χ^2 = 0.73, p = .867), resonating with Chen and Gilbert (2009), who emphasized the importance of fostering mental associations across various levels of representation in Chemistry. It is particularly concerning that many participants did not attempt to engage with symbolic representations, suggesting a critical area for focus in teacher education programs. In addition, poor performance in verbal representation likely stemmed from a lack of disciplinary knowledge or misconceptions, rather than from representational challenges (Rau, 2020). Hill and Sharma (2015) suggested that students must not only choose appropriate representations but also integrate them effectively, as contextual factors such as task demands, and individual interests significantly influence understanding (Follmer & Sperling, 2020). These findings are consistent with Nichols et al. (2016), who stress that foundational competence in a single representation is crucial for successfully navigating and translating across multiple representations.

Overall, the study highlights the interconnectedness of representational competence, disciplinary preferences, and the challenges PSTs face in effectively integrating various representations, indicating a real need for targeted pedagogical strategies to enhance preservice teachers' ability to explain scientific concepts.

Conclusion

This study underscores the significant role that disciplinary focus plays in shaping the same cohort of PSTs' modes of representation in Physics and Chemistry. Their preference for graphical and mathematical forms in Physics contrasted with the phenomenological and model-based approaches favoured in Chemistry. This highlights the distinctive cognitive frameworks inherent to each discipline. Challenges were experienced in both Chemistry and Physics with symbolic representations, which can be attributed to the complexities of the tasks at hand. These findings reveal shortcomings related to representational competence and fluency in the South African context but also supports research findings internationally. It is evident that a lack of engagement with these representations points to a critical need for pedagogical interventions in teacher education programs.

Furthermore, the stronger competency in graphical representations in Physics observed among preservice teachers emphasises the necessity for enhanced training in experimental skills that complement theoretical knowledge. Notably, the lack of significant differences in symbolic and verbal representational competence raises critical questions about the underlying disciplinary knowledge of PSTs and suggests that misconceptions may hinder effective communication of scientific concepts.

Overall, our study advocates for a comprehensive approach to teaching that not only fosters foundational competence in distinct representation modes but also promotes the ability to translate and integrate these representations effectively. By addressing these challenges through targeted pedagogical strategies, we can enhance the representational competence and fluency of preservice science teachers, thereby improving their capacity to convey complex scientific ideas in their future classrooms. Future research should continue to explore the interplay between representation, discipline-specific pedagogy, and students' cognitive development, ensuring that teacher education evolves to meet the demands of modern science education.

Integrating technology into teacher education can further bridge the gap between theory and practice, utilising tools such as interactive simulations and digital visualisation software for real-time skill refinement. Future interdisciplinary research should explore the long-term effects of improved representational competence and fluency on science student achievement. This understanding is essential for refining teacher education curricula, and to ultimately prepare preservice teachers for contemporary challenges.

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Appendix

Assessment Rubric Developed By the Researchers to Measure Representational Competency and Fluency Levels

	Competency & fluency		
Representation mode	Low-level (1)	Medium-level (2)	High-level (3)
Graphical (Graphs / Diagrams/ Simulations)	Inappropriate graphical illustration that is not linked to the experimental, symbolic or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate graphical illustration that is partially linked to the experimental, symbolic or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate graphical illustration that is linked to the experimental, symbolic or word representation modes. Student demonstrates correct scientific understanding of concepts.
Experimental (Hands-on/model building)	Inappropriate experimental illustration that is not linked to the graphical, symbolic or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate experimental illustration that is partially linked to the graphical, symbolic or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate experimental illustration that is linked to the graphical, symbolic or word representation modes. Student demonstrates correct scientific understanding of concepts.
Symbolic (mathematical equations/ formulae)	Inappropriate symbolic illustration that is not linked to the experimental, graphical or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate symbolic illustration that is partially linked to the experimental, graphical or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate symbolic illustration that is linked to the experimental, graphical or word representation modes. Student demonstrates correct scientific understanding of concepts.
Words (verbal/written text)	Inappropriate use of words that is not linked to the experimental, symbolic, or graphical representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate use of words that is partially linked to the experimental, symbolic, or graphical representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate use of words that is linked to the experimental, symbolic, or graphical representation modes. Student demonstrates correct scientific understanding of concepts.