Additional Chemistry in a First-Year Chemical Engineering Class: Students' Perceptions of Teaching, Learning Support and Assessments

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ABSTRACT

This phenomenographic study explored first-year chemical engineering students' perceptions of teaching, learning support, and assessment in an additional chemistry course within an Extended Curriculum Programme at a research-intensive university in South Africa. Drawing on qualitative data obtained through semi-structured interviews, the findings from the study revealed that students appreciated opportunities offered in the course, such as peer discussions, personalized support through tutorial sessions, and consultations. Students highlighted that the formative assessments provided in the course prepared them for examinations. However, they expressed concerns over the rushed delivery of organic chemistry content, limited conceptual scaffolding, and perceived overreliance on content memorization. These results highlight the importance of aligning teaching strategies and goals with students' learning needs. Moreover, the results reveal the importance of using student feedback to inform the design and delivery of a foundational chemistry course in diverse and academically transitional contexts.

KEYWORDS

Students' perceptions, Phenomenography, Extended Curriculum Programmes, First-year chemical engineering students

Received: 10 December 2025 Revised: 7 April 2026 Accepted: 1 June 2026

INTRODUCTION

Although chemistry, serves as a gateway module for most science majors, pre-medical and engineering fields[1,2], research has highlighted that chemistry is regarded as one of the most challenging courses with high attritions rates in undergraduate studies internationally.[3-5] Research has established that students' difficulties in chemistry stem from the fact that they lack translational and visual-spatial skills hence they fail to make meaningful connections between the macroscopic, submicroscopic and symbolic levels of chemical understanding.[6-10] Factors such as inadequate high school preparation have been reported as a reason for challenges faced by students in higher education.[11,12] Efforts have been made both in South Africa and globally to support students in overcoming these challenges. Curriculum reform resulting in the Chemical Thinking and the Chemistry, Life, the Universe and Everything (CLUE) curricula,[13-15] have introduced a transformative teaching approach to teaching general chemistry. Furthermore, the use of innovative teaching methodologies, such as Process Oriented Guided Inquiry Learning (POGIL) has also yielded positive results in improving students' understanding of chemistry in Western countries,[16-19] and in African countries, such as South Africa[20].

South African universities introduced extended curriculum programmes (ECPs) from the late 1980s for, among other reasons, assisting underprepared students in their access and success in higher education Science, Technology, Engineering, and Mathematics (STEM) fields.[21] ECPs are designed to address students' academic, linguistic, and socio-cultural challenges while transitioning into university spaces by providing additional time, structural support, and developmental/additional courses alongside mainstream courses.[21-23] While numerous studies have reported students' perceptions on the general impact of ECPs on their studies, to date[24-27], to the authors' knowledge, no studies have been published on how students perceive courses offered in ECPs, specifically, the teaching, learning support, and assessment practices offered in ECP developmental support courses. Therefore, this phenomenographic study[28] focused on investigating first-year chemical engineering students' perceptions of the teaching, learning support and assessments offered in a developmental chemistry course offered within the ECP at a large research-intensive university in South Africa. By providing an audience to the students' voices, the current study sought to generate insights that can inform more equitable teaching practices in academic developmental support courses within the ECPs.

THEORETICAL FRAMEWORK

The study is informed by the principles of phenomenography, a research framework developed to explore the qualitatively different ways individuals experience a phenomenon.[29-32] Phenomenography does not focus on the phenomenon studied but on how individuals understand, perceive, and experience the phenomenon.[33] Similarly, in our study, we did not focus on the additional chemistry course as the phenomenon under study; instead, we focused on first-year chemical engineering students' perceptions and experiences of the teaching, the learning support, and the assessments employed in the additional chemistry course. Therefore, phenomenography as a guiding theoretical framework was found suitable for our study because it allowed us to focus on the various ways first-year chemical engineering students experienced the teaching, learning support, and the assessments employed in their additional chemistry course. According to Marton,[29] a phenomenon is understood not in isolation but through people's collective range of experiences. In our study, the collective range of students' experiences of teaching, learning support, and assessments employed in the additional chemistry course provided insights regarding what the students liked and disliked about how the course was taught, how their learning was supported, and how they were assessed. Furthermore, the collective range of students' experiences shed light on what they found to be helpful and not helpful for teaching and learning in the additional chemistry course. Theoretical frameworks are crucial because they assist researchers in selecting relevant questions and appropriate data collection procedures for a given study.[33] Therefore, in the current study phenomenography facilitated the capture of rich data, in the form of interviews, from the students about their perceptions of the additional chemistry course.

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ISSN 1996-840X Online / South African Chemical Institute / http://saci.co.za/journal
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https://doi.org/10.17159/0379-4350/2026/v80se1a19

CONTEXT

The need for ECPs is high in South Africa due to the country's complex educational landscape and historical inequalities. The Department of Higher Education and Training (DHET) has endorsed ECPs to redress injustices of the past and enhance equality in higher education and training.[34,35] ECPs are meant to help students by giving them extra support and breaking down difficult topics into smaller, more understandable chunks of knowledge. The university where the study was conducted is among South African universities that offer ECPs across multiple faculties, including science and engineering, thus aligning with national imperatives to improve access and throughput rates in STEM disciplines.[36,37] The Faculty of Engineering at this university offers four-year and five-year Engineering degree programmes.[38] The five-year programme is an extended degree program intended to facilitate a smooth transition from high school to university and to help students cope with the academic demands of an Engineering degree. The extended program is designed for students whose high school grades do not meet the minimum requirements for entry into the four-year program. The five-year program provides additional developmental modules intended to assist students in gaining the foundational knowledge and skills they may not have acquired in high school. The additional modules offer an extra support layer and emphasize tutorial sessions over lecture time, providing a valuable resource for enhanced practice and guidance. Students in the five-year program are required to take additional developmental modules alongside the mainstream modules offered by the respective departments. For example, chemical engineering students in the five-year program enroll for additional chemistry offered by the ECP and the mainstream chemistry provided by the Chemistry Department. Although the content covered in the additional and mainstream chemistry courses is the same, the additional chemistry is taught in simplified chunks to ensure students build a strong foundation of chemistry concepts and make it easier to understand the fast-paced teaching in mainstream chemistry courses. The current study focused on the additional chemistry course offered to first-year chemical engineering students in the five-year program.

Although students were exposed to various learning supports to help them better understand the additional chemistry course, the pass rates remained lower than the target pass rate for the university (80%). Lecturers attributed the low pass rates to poor class attendance, disinterest in completing continuous assessments, and limited prior exposure to organic chemistry, in a course demanding high student dedication, as a higher level of integration and application is required. Although the lecturers had their perceptions regarding why the pass rates were low despite the added developmental and supportive teaching methodology, it became necessary to conduct research to evaluate the course and learn more about students' experiences of the course. Therefore, this study aimed to investigate first-year chemical engineering students' perceptions of the teaching, the learning support, and the assessments provided in the additional chemistry course. The following research question was addressed: What are students' perceptions of the teaching, learning support, and assessments provided in the additional chemistry course?

METHODS

Study Setting, Participants, and Recruitment

The study was conducted at a large public research-intensive university in South Africa. Chemical engineering students who had previously enrolled in the additional chemistry course in 2022, and 2023 participated in the study. The recruitment of students was done via email: the email outlined the purpose and potential benefits of the study. A total of 28 students were enrolled in the additional chemistry course in 2022 and 2023: of the 28 purposively selected students, 11 agreed to participate in the study, and signed the consent form. While participation was based on voluntary responses, the sample included students from two cohorts with shared experiences, allowing for a range of diverse perspectives to be captured in the study. The sample size was considered sufficient as recurring patterns and shared experiences were observed across interviews with all the students.[39] In line with qualitative research principles,[40-41] the aim was not to achieve statistical generalization but to obtain rich, in-depth variations of student's experiences of how the course was taught, how their learning was supported, and how they were assessed. Pseudonyms were used to protect participants' identities, and ethical clearance was obtained (EBIT/237/2022).

Course Description

The additional chemistry course consists of physical, analytical, and organic chemistry sections, and is offered in the second semester for fourteen weeks. The first seven weeks were devoted to teaching the physical and analytical chemistry sections, and the last seven weeks to the organic chemistry section. Topics covered in the physical and analytical chemistry sections included; *physical behaviour of gases, intermolecular forces, solutions, liquids and solids, chemical equilibrium, acids and bases, buffers, titrations, and solubility;* whereas topics covered in the organic chemistry section included *structure and bonding, functional groups, drawing structures of organic compounds, nomenclature, isomerism, introductory stereochemistry, an introduction to chemical reactions, and the chemical properties of organic compounds.* Weekly contact time consisted of one double-lecture session (50 minutes) and three 50-minute tutorial sessions. Besides tutorial sessions, other learning supports made available to the students included two one-hour weekly consultation sessions and the Chirality-2 app. The prescribed textbook for the physical and analytical chemistry sections was Chemical Reactivity by Kotz, Treichel, Townsend, and Treichel, 9th and 10th editions. Organic Chemistry by JG Smith, fifth and sixth editions, was the prescribed textbook for the organic chemistry section.

Lecture, Tutorial and Consultation Sessions

Prior to the lecture sessions, the lecturer uploaded the notes and relevant page numbers from the textbook to the University's Learning Management System (LMS). Students had to prepare for the lecture session by reading the notes provided and the prescribed textbook pages. During the lecture sessions, the lecturer discussed theoretical principles and allowed students to work on simple problems to assess their understanding of the content discussed. With regards to the tutorial sessions, the lecturer uploaded tutorial questions on the LMS a week in advance and expected students to start working on them before the sessions. During the tutorials, active student engagement was encouraged by allowing students to continue working on the assigned tutorial questions individually, in pairs, or in groups of no more than four students. The lecturer provided guidance and feedback to students and worked on complex problems to demonstrate how the theory could be applied to solve them.

In addition to the tutorial sessions, students could schedule a face-to-face consultation session with the lecturer. Before attending a consultation session, students had to book a consultation session with the lecturer via email and email the questions they needed help with to the lecturer beforehand. Students were, however, not limited to asking only the questions they emailed to the lecturer. In addition to the consultation sessions, students could use the Chirality-2 app, an organic chemistry application designed to impart fundamental concepts in an engaging way. The app is available on Google and Apple stores free of charge and works even without the internet. Furthermore, the app helped students grasp concepts like *functional groups, isomers, chiral centers, structures, classification, intermolecular forces, and nomenclature.* After each session, the app shares an interesting fact about the compounds in the question, thus contributing to a more dynamic and enjoyable learning experience for the students.[42]

Data Collection and Analysis

The main source of data in phenomenographic studies is open-ended interviews;[28] therefore, semi-structured face-to-face interviews were used to collect data. The interview questions (Supplemental Information) were open-ended and probed for students' perceptions about the teaching, learning support, and assessments used in the additional chemistry course. Before beginning the interview sessions, students were reminded about the aim of the research and were also encouraged to be open and speak freely. During the interviews, in cases where the participants mentioned an interesting idea about their perceptions of the teaching, learning support, and assessments, the students were asked more questions to allow them to provide in-depth information. Furthermore, we refrained from asking leading questions and steering the conversations our way based on our perceptions and biases.[38] In the present study, we intentionally abstained from correcting what might be perceived as 'errors' by some interviewers: our rationale was that there was no single 'correct' or 'incorrect' answer, and the aim was to allow students to express their viewpoints freely. To indicate our comprehension of what the students were saying, and to encourage ongoing dialogue, we often responded with non-verbal cues like a nod or simple utterances like "mhh," and "ahh." Each interview was audio-recorded and lasted about 50 minutes.

The main aim of phenomenographic data analysis is to uncover various ways people experience a phenomenon.[33] Therefore, as we analyzed data, our aim was to learn how students experienced the teaching, learning support, and assessments used in the additional chemistry course. The initial step in the analysis involved repeated reading of the transcripts to gain familiarity with the data.[43,44] Preliminary codes were developed inductively from the students' own words (in vivo coding), ensuring that the analysis remained grounded in the students' language and voices.[45] These initial codes were then reviewed and refined through several rounds of analysis, during which related codes were grouped into broader categories that represented shared meanings and variations in students experiences.[46] The categorization of codes was further refined to form themes that captured how students viewed the course in terms of the teaching, learning support, and assessment.[32,46] Each theme was refined and adjusted to ensure clarity and reflect the holistic views of students. During the refining stage, where necessary, data excerpts were reassigned to themes that better aligned with their meaning.[46] Throughout the analysis, the researchers were guided by the question: "What does this tell us about how students perceive teaching, learning support and assessments in the additional chemistry course?"[47] Credibility was enhanced through peer debriefing and by maintaining a transparent audit trial of coding decisions.[48]

While phenomenographic studies may present findings in the form of an outcome space consisting of hierarchically related categories of description,[30,41] the focus of this study was on identifying broad themes that reflect variation in students experiences of the additional chemistry course.[32,47,48] Furthermore, since the purpose of the study was to capture the range of students' experiences about the additional chemistry course rather than to establish hierarchical relationships, the analysis of the study emphasized variation over structural ordering of categories.[32]

FINDINGS

Students' perceptions of the teaching: what students liked about the teaching

Table 1a shows a summary of students' perceptions regarding what they liked about how the additional chemistry course was taught. Overall, students liked how the course was taught because it promoted peer discussions in and out of the classroom which helped improve their understanding of the content. For example, Bella liked how the course was taught because it promoted group work which helped her grasp some of the formulas. Ella, on the other hand, liked how the course was taught because it promoted a lot of discussions, arguments, and debating among the students which helped them learn. Additionally, Hazel preferred how the course was taught because it provided opportunities to engage with other students. Besides promoting peer discussions, other students liked how the course was taught because it prepared them for the mainstream chemistry course. Zara, for example, pointed out that the coursework significantly boosted her understanding and readiness for mainstream chemistry. Diana indicated that she liked how tutorials were taught because they were given more attention and opportunities to teach one another and learn from each other.

Table 1a: Aspects of teaching liked by the students: themes and students' quotes

Themes	Examples of students' quotes
Peer discussions	**Bella:** "[…] And also, working in groups, I feel like the reason I was able to grasp some of the formulas [physical/analytical chemistry] was because I was working in a group. I feel like group work is important when it comes to learning".
	Ella: "[..] in terms of teaching, I feel like, personally, I liked all of that because we had a lot of discussions, we had a lot of debating, arguments here and there, and that was all, you know, it helped us learn and helped us, hmm [pause], I guess, talk about it, just as a whole classroom and not just sitting and listening to the teacher teach. A lot of us, you know, there were people who asked questions. There was a lot of debate in the classroom, especially with organic chemistry. So, that's what helped the most and that's what I liked the most about the teaching part of it. Because it's like we also taught each other. And, we had a group chat, so we also spoke about it in the group chat, and we helped each other like that. Besides sir teaching us, we also taught each other".
	Hazel: "And also, engaging with other students, like let's say I'm sitting next to Nancy, and I say, Nancy I don't understand, and she will explain to me. Or sometimes we call the teacher to come help us. So, engagements with the students and the teacher were very effective."
Preparation for mainstream chemistry	**Zara:** "The additional [additional chemistry course] was a booster, things made more sense in the additional because it was more interactive, and I would say it was a smaller group. So, it's where we were like more comfortable in like asking questions and Sir [additional chemistry Lecturer], what he would do is he would break things down until you understand it properly as he would repeatedly like do questions different types of questions as possible. […] so that's why I feel like most of the students that did fail 181(mainstream chemistry) are students that don't have additional chemistry [..]"
	Diana: "The tutorials help, so I only use additional chemistry tutorials to study for mainstream chemistry [...] because for tutorials he [additional chemistry lecturer] used to make us like, come up to the board and answer the questions and I think that helped a lot because we were teaching each other, you don't want to teach someone the wrong thing, so you have to like, know your stuff, So yeah."

Students' perceptions of the teaching: what students disliked about the teaching

Although the students liked how the additional chemistry course was taught, the only discontent they reported was the fact that the organic chemistry section, specifically in the mainstream chemistry, was taught towards the end of the semester hence they did not have enough time to learn and understand the organic chemistry section, specifically, the organic reactions. As shown in Table 1b students such as Bella, Hazel and Ann highlighted that the organic chemistry sections felt rushed, leaving them with inadequate time for thorough comprehension.

Students' perceptions of the teaching: suggestions for improvement

As illustrated in Table 1c, students provided one suggestion regarding how the teaching of the additional chemistry and mainstream chemistry courses could be improved: rearranging the course so the organic chemistry section is taught first, followed by the physical and analytical chemistry sections. This sentiment was reflected in student responses, such as Bella, Zara, Chloe, and Diana. The students believed that this teaching rearrangement would give them more time to focus on learning organic chemistry throughout the semester.

Students' perceptions of the learning support: what students liked

As shown in Table 2a, students' preferred learning support included consultations, the Chirality-2 app, and tutorials sessions. Students highlighted the value of consultations with lecturers and expressed how one-on-one sessions with the lecturer aided their understanding of concepts such as titrations and ICE tables. Additionally, students emphasized the lecturer's willingness to ensure that students grasped the material during consultations. Besides consultations, some students pointed out that they liked the Chirality-2 app because it was beneficial for practicing organic chemistry. Fiona, for instance, utilized the Chirality-2 app as supplementary material for extra practice. Furthermore, Hazel appreciated the fact that the app was available free of charge, and how it facilitated practice with functional groups. Chloe also liked the app because it displayed the errors made in cases where she got the answers incorrect. Fiona and Indigo liked the app because they found it helpful, had a lot of practice exercises and covered many topics. Other students liked the tutorial sessions because they felt they learned the most during the sessions as they were given more attention and clarity on what they did not understand, and they were allowed to work on different questions.

Although students were asked to share their perceptions regarding what they disliked about the learning support provided in the additional chemistry course, they did not report any aspects of the learning support they disliked.

Students' perceptions of the learning support: suggestions for improvement

Students were asked to provide their suggestions regarding how the learning support could be improved. As evidenced by students' quotes below, the only improvement that students suggested was that the Chirality-2 app should be introduced early in the semester so they could have enough time to get used to how it works prior to starting the organic chemistry section.

> ***Indigo***: *"The app should be introduced earlier in the semester so we can get used to it before starting the organic section."*
> ***Fiona***: *"I love the app [Chirality-2 app] … it helped a lot for practice, but I wish we had it earlier in the semester."*

Students' perceptions of assessments used in the course: what students liked

The majority of the students indicated that they liked formative assessments such as class tests and assignments as they helped them prepare for semester tests and exams (Table 3a). Additionally, students such as Bella acknowledged the challenging nature of certain assignments, expressing that while initially strenuous, these tasks ultimately offered a beneficial challenge. By revisiting these assignments, they found a deeper comprehension of the content.

Table 1b: Aspects of teaching disliked by students: themes and students' quotes

Theme	Examples of students' quotes
Insufficient time to teach and learn organic reactions	**Bella:** "Everything is pretty much rushed through. Because like I'm saying, the lecturer [mainstream lecturer] would say, OK, he reads over a slide and then goes to the next one and then be like oh, this is pretty easy, [..]. Everything is pretty much rushed through".
	Hazel: "The reactions […] started introducing them very late, when you were like ending the semester. So, we didn't have time to actually cover everything thoroughly. Yeah, because we didn't have time to learn all of that, […] I wish we had more time to cover the content in detail, but it was done at the very last end, and it was too much to learn."
	Ann: "We got taught the reactions at the last part of the semester […]. There was too little time to be taught. […] If it's done earlier […] you can come to the lecture and ask questions over and over again. There was no time for that—it was either cram, pass, and forget."

Table 1c: Students' perceptions of the teaching: suggestions for improvement

Theme	Examples of students' quotes
Course rearrangement	**Bella:** "I feel like it was better to start with organic chemistry, then finish with analytical [...] most of the students during the semester start, they grab the information during the first month or yeah, the first few lectures, that's when they grasp the information.
	Zara: "I would start with organic, then analytical, then yes, cause [..]also I feel like with the organic it will like, while they continue with the analytical, since we did say that it's relatable, you can still reflect on this [..] I feel like if it was organic, start with organic and then analytical afterward so then the students, while they are busy with analytical, they're still reflecting back on the organic and building those things that they don't understand".
	Chloe: "I will start with organic chemistry. We will have a lot of the rest of the semester to practice, if you have a question, you can always ask your teacher, questions and stuff, [..].

Table 2a: Aspects of learning support liked by the students: themes and students' quotes

Theme	Examples of students' quotes
Consultations improve understanding	**Diana:** "[..] while the other thing that helped was consultations. They really helped because also we're supposed to be adults, so we're still supposed to know when there's a problem and when we need help. So, I came to sir [additional chemistry lecturer] a lot. I know for titrations, and it helps to have one-on-one, but also there is nothing much you guys can do. It's up to the students to identify what they need". **Hazel:** "Yes, actually with Mr. T [additional chemistry lecturer], he did not have any problem in like meeting up [consultations] with students, so I like that, and he also made sure that we leave understanding the work."
Chirality-2 App is beneficial for learning organic chemistry	**Fiona:** "Extra material, I love the app (Chirality-2) that you introduced, and I didn't use it too much, but when I did use it, I actually enjoyed it. I liked the idea of the app for just practice". **Hazel:** "[..] Definitely, it helps so much. And the App was useful to practice functional groups, and the fact that it's free makes it even more helpful". **Chloe**: "Chirality-2 app actually really did help me study organic chemistry […] when you got it wrong, they were like, 'You're wrong; this is why you're wrong […]' That helped me understand." **Indigo:** "Yeah, it [Chirality-2] had a lot of exercises. It covers many topics."
Effectiveness of Tutorial Sessions	**Ella**: "I also like the tutorials […] I learned a lot […] that's where we learned the most rather than lectures. In tutorials we actually did work." **Ann:** "They were so interactive. [..] Yeah, and the tutorial sessions, it was good the fact that it was structured at the end of the week after all the work. Then we can go through everything." **Diana:** "The tutorials really help. So, I only used additional chemistry course tutorials to study for mainstream chemistry course physical and analytical section because for tutorials he [additional chemistry lecturer] used to make us come up to the board and answer the questions. And I think that helped a lot because we were teaching each other. You don't want to teach someone the wrong thing, so you have to know your stuff. So yeah." **Hazel:** "Tutorials, I was happy with how everything was set. They had a lot of questions asking from different angles, so I was happy with how everything was set under tutorials."

Table 3a: Aspects of assessment liked by students: themes and students' quotes

Theme	Examples of students' quotes
Formative assessments prepare students for exams.	**Diana:** "Class tests were really nice. I liked the class tests. [..] Class tests were good for practice because then most of us redid the class tests to prepare for the semester test. They really helped. Yeah, they really did help with the class tests". **Chloe:** "You know, the class tests really did help for the exam. **Indigo:** Yeah, I think they (class tests) all covered the content that we did. And if something was being introduced, I think it was more like a challenge that makes you go further with studying. So yeah, all that they covered, it was OK". **Kyle:** "And I did realize it was from the textbooks sometimes. So, it was like although you're doing the assessment, you're practicing since the assignments are preparing you for the final examination". **Bella:** "Oh, some of the assignments were hectic, but they were challenging in a good way. Yes, there is a challenge whereby [pause] let's say you find it difficult on the first try, but when you're doing it the second time, you get a better understanding. Redoing the assignments is good practice for the exam".

Students' perceptions of assessments used in the course: what students disliked

Although most of the students liked the class tests and assignments used in the course, there were a few students who did not like the assignments used in the course because they were challenging. As shown in Table 3b students such as Ella, Fiona and Ann did not like the assignments used because they felt they were difficult, were not based on what they had been taught in class, thus they struggled to find solutions.

Students' perceptions of the assessments: suggestions for improvement

Students were asked to provide their suggestions regarding how the assessments used in the course could be improved. As illustrated in Table 3c, students suggested that time management and the inclusion of more assignments in the course should be implemented. Regarding time management, students such as Bella and Diana pointed out that the only improvement, they would implement is to advise students to work on assignments immediately upon receipt as this could aid

Table 3b: Aspects of assessments disliked by students: themes and students' quotes

Theme	Example of students' quotes
Challenging Assignments	**Ella**: "[..] the only problem I had was with the assignments [..]. We had a big problem. We had a big problem with assignments because it was not the stuff we were taught in class. [..]". **Fiona**: "But [..], it's kind of difficult to link what you're learning to something completely, like, you have never been taught this thing. [..] So, I feel like assignments should be a bit of a stretch from what you know so, you can say maybe I can use what I learned here and there. The question seemed like I had no idea how to respond. Assignments dropped my marks". **Ann**: "[..] the assignments, we would be fighting with each other in the groups because we don't know where this question is coming from. [..] Assignment one was fine because it was just work, we had done, but assignment two and three, it was hard. I don't know what I would change, but it was hard".

Table 3c: Students' suggestions regarding how assessments can be improved

Theme	**Examples of students' quotes**
Time Management	**Bella:** "[..] if you get an exercise or an assignment, do it immediately because chances are, if we are given an assignment, we're going to ask our friend at the 11th hour, "How did you write this? How did you do this?" So, what I would advise them [future students] is that if you're given an assignment, start it now. The best time is to start it immediately. Then you could understand, even if, let's say, you get all the assignments correct or you don't get them all correct. That way, you're building understanding. [..]" **Diana:** "[..] for assignments, I also think that goes back to time management. I think a lot of people complain when they leave it for the day before [pause]. And then they start panicking, [..]. Also, with the assignments, if you start ahead of time, I know it's not always possible, but if it's like 2 days before, then if you have a question, you can come to sir [lecturer] and ask [..]"
Add more assignments_	**Jade**: "More assignments for practice and making sense of the work before the exam". **Hazel**: "[..] maybe like introduce more assignments on reactions for practice".

in building a deeper understanding of the subject matter and offers students the opportunity to seek clarification from the lecturer if any questions arise. Furthermore, Jade and Hazel proposed that more assignments should be included so students could use them to practice and make sense of what is taught in the course.

DISCUSSION

The study aimed to foreground student voices in understanding how the teaching, learning support, and assessment practices were experienced in the additional chemistry course at a research-intensive institution in South Africa. The findings revealed that students appreciated certain aspects of the course, such as collaborative learning opportunities, personalized academic support, the introduction of Chirality-2 app in the course, and formative assessment, while also voicing concerns about the organic chemistry section of the course. Students highlighted the value of peer discussion, describing these moments as essential to their understanding. This finding aligns with Vygotsky's sociocultural theory, which emphasizes that learning occurs through social interaction and dialogue within the learner's zone of proximal development (ZPD).[50] Vygotsky argued that peer discussions and collaborations enable pupils to co-construct knowledge through shared meaning-making during discussions and collaborations.[51-53] Studies in organic chemistry education have consistently shown that students value peer discussions for clarifying difficult concepts amongst each other, deepening conceptual understanding, and building confidence in applying problem-solving strategies.[54,55] Such interactions help students articulate reasoning processes, correct misconceptions, and internalize abstract ideas through collaborative engagement.[56,57]

Additionally, the introduction of the Chirality-2 app was well received by the students, which aligns with the reported literature on the application, as it supports conceptual learning and visual engagement in organic chemistry. Jones et al.[57] reported that interactive digital platforms such as Chirality-2 app improved students' visualization of molecular structures and increased their motivation to engage with organic chemistry content. Additionally, Ward et al.[58] found that augmented-reality tools foster students' confidence in learning organic chemistry and visualizing complex organic chemistry structures. Similarly, Mosala et al.[59] highlighted that the Chirality-2 app encouraged active student participation and provided immediate feedback for the students.

Moreover, students perceived the additional chemistry course as helpful preparation for mainstream chemistry, particularly due to early exposure to the content they covered in the physical and analytical chemistry sections. This aligns with the literature emphasizing the value of prior knowledge in supporting new learning from the students. Bransford et al.[42] explained that connecting new content to existing knowledge promotes deeper conceptual understanding for the students and long-term retention of the newly learned information. Gulacar et al.[60] found that students with stronger prior knowledge demonstrated improved problem-solving and confidence when approaching complex chemical concepts. Similarly, Sedumedi[61] highlighted that acknowledging and building upon students' prior learning enhances engagement and performance of students.

Despite the positive views expressed in Tables 1a, 2a, and 3a, students described the organic chemistry sections as overwhelming and fast-paced. The students reported that it was covered in a short period, leaving little time for them to fully grasp the material taught in class. Similar findings were reported by Salame et al.[62], who found that students struggled with the extensive amount of content taught in organic chemistry and fast pacing in the course, which often led them to rely on rote memorization rather than developing understanding. Additionally, Gyang et al.[63] identified the pace of teaching as a key barrier to organic chemistry learning, where students reported that instructors rushed through the topics and left little room for them to understand organic chemistry concepts. In response to these challenges, students made constructive recommendations. These recommendations from the students included reordering the curriculum to begin with the organic chemistry section, followed by the physical/analytical

chemistry section, and incorporating more in-class problem solving. Research by King et al.[64] shows that introducing the organic chemistry section earlier in the semester improves student retention and reduces cognitive overload, particularly for students who need more time to process the foundational concepts. On the other hand, a study by Freeman et al.[65] shows the benefits of integrating in-class engagements with the content to enhance students' understanding.

Students also emphasized the positive impact of formative assessments in the additional chemistry course, such as class tests and assignments, in supporting their learning and understanding. These tools allowed the students to gauge their understanding of the concepts and better prepare them for the summative assessments. Similar findings were reported in the literature. Hattie and Timperley[66] emphasized that effective formative feedback to students provides them with clear information on their progress and helps bridge the gap between current and desired performance. Likewise, Leenknecht et al.[67] found that formative assessment practices enhance students' motivation by making them active participants in monitoring their understanding. However, students pointed out that some assessments, such as assignments, did not align with what had been taught in class, causing confusion and discouragement. These concerns from the students highlight the importance of constructively aligning assessments with the curriculum for effective learning and understanding by the students.[68-71]

Beyond describing students' experiences of the additional chemistry course, the findings reveal underlying differences in how students interpret the purpose and effectiveness of teaching, learning support and assessments within the course. The findings demonstrate that students' experiences of the additional chemistry course ranged from surface-level, structurally constrained engagement to deep, agentic, and socially mediated learning. While the course provided opportunities for collaborative and self-directed engagement, the analysis of student self-reports revealed that factors such as pacing and sequencing influenced the extent to which they could access more complex forms of learning.

Importantly, the variation in students' experiences reveals different conceptions of how the course supports learning. While some students enrolled in the additional chemistry course perceived assessments as constructive tools that enhanced their understanding of the course and prepared them for examinations, others found them misaligned with the teaching and therefore discouraging. This divergence in students' views suggests that students do not experience assessment uniformly but rather interpret its value differently. From a phenomenographic perspective, these differences represent qualitatively distinct ways of understanding the value and role of teaching, assessments, and learning support within the ECP context. The findings from the current study further suggest that the course design may support some students more effectively than others, particularly in how assessments and learning support align with the teaching. Overall, students' views of the additional chemistry course offer both a critique of current practices and a feasible roadmap for improving the course. Students' voices highlight the potential to make the course's teaching and learning more inclusive, responsive, and effective.

CONCLUSION AND LIMITATIONS

The study explored the perceptions of first-year chemical engineering students regarding teaching, learning, and assessments in an additional chemistry course. By grounding the research on students' voices, the study revealed both affirming and challenging aspects of the additional chemistry course as experienced by the students it aims to support. Students expressed their appreciation for collaborative peer learning, accessible lecturers through consultations, and the use of formative assessments to guide their understanding. At the same time, students expressed frustration with the rushed, fragmented delivery of organic chemistry content, which led to students resorting to rote memorization of concepts rather than deep learning. Crucially, students not only criticized the course but also offered thoughtful, experience-based recommendations. These included suggestions for restructuring the course sequence by beginning with organic chemistry, followed by physical/analytical chemistry, as well as increasing in-class practice. Students' suggestions reflect a strong desire for structured, meaningful engagement and provide valuable suggestions for teaching and learning in an additional chemistry course.

While the study findings offer important insights, the study is not without limitations. The data were drawn from a single Engineering ECP programme in an institution in South Africa, thus limiting the generalizability of the data. Furthermore, the study focused purely on qualitative feedback from the students without pairing it with performance metrics; future research could benefit from a mixed-methods approach to more comprehensively examine how perceptions intersect with learning outcomes. Nonetheless, by centering the study on students' perceptions, this research contributes to a growing body of work advocating for student-informed curriculum and instruction. While to some extent the study showed the value of additional support offered through tutorials, consultations and learning support tools, the study underscored the value of student feedback as an important element of curriculum review. ECPs were designed to foster access and success, and a return on investment can be guaranteed through teaching that is responsive to the student needs. Modules such as chemistry are gateway modules and if not taught well, they may hamper progression through a degree thus defeating the very purpose for which ECPs were introduced. Future studies could include a larger sample, providing insights into the student experiences of the teaching support provided in ECPs across South African institutions of higher learning. This is necessary as ECPs have the potential to broaden access to STEM fields for students from previously marginalized communities.

SUPPLEMENTARY INFORMATION

Supplementary information for this article is provided in a separate document.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Pretoria for funding this project through the RDP grant. The authors would also like to thank the NRF for funding the first author's PhD studies.

AUTHOR CONTRIBUTIONS

Tisetso Mosala conducted the research, collected and analyzed data, validated results via peer debriefing, and was involved in the writing, reviewing and editing of the original draft of the manuscript. Kgadi Mathabathe was the co-supervisor and was involved in the conceptualization of the project. She was also involved in project administration, supervision, writing, reviewing and editing of the original draft of the manuscript. Rethabile Tekane was the supervisor and was involved in the conceptualization of the project. She was also involved in the supervision, project administration, provided any resources that were required for the project, and was involved in the peer debriefing process to validate the findings. She was also involved in writing, reviewing and editing of the original draft of the manuscript.

DECLARATION OF COMPETING OR FINANCIAL INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

AI and AI-assisted technologies were not used in this study.

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REFERENCES

1. National Research Council. Health and medicine: challenges for the chemical sciences in the 21st century. Washington DC. US: National Academies Press; 2004. https://doi.org/10.17226/10889.
2. Grove NP, Bretz SL. Perry's scheme of intellectual and epistemological development as a framework for describing student difficulties in learning organic chemistry. Chem Educ Res Pract. 2010;11(3):207–211. https://doi.org/10.1039/C005469K.
3. Garg NK. How organic chemistry became one of UCLA's most popular classes. J Biol Chem. 2019;294(46):17678–17683. https://doi.org/10.1074/jbc.AW119.008141.
4. Jacimovic N, Pulukuri SV, Abrams B. The hidden timeline for marginalized student groups: drop and withdrawal outcomes in general chemistry. J Chem Educ. 2025;102(11):4944–4949. https://doi.org/10.1021/acs.jchemed.5c00309.
5. James NM, LaDue ND. Pedagogical reform in an introductory chemistry course and the importance of curricular alignment. J Chem Educ. 2021;98(11):3421–3430. https://doi.org/10.1021/acs.jchemed.1c00688.
6. Sanchez JMP. Translational skills of students in chemistry. Sci Educ Int. 2018;29(4):213–219. https://doi.org/10.33828/sei.v29.i4.3.
7. Talanquer V. Macro, submicro, and symbolic: the many faces of the chemistry "triplet". Int J Sci Educ. 2011;33(2):179–195. https://doi.org/10.1080/09500690903386435.
8. Torres D, Xu A, Abrams B. Disentangling the dissolution of ionic and molecular compounds: alternative conceptions and teaching considerations in chemistry. J Chem Educ. 2025;102(7):2661–2672. https://doi.org/10.1021/acs.jchemed.5c00307.
9. Seethaler S, Czworkowski J, Wynn L. Analyzing general chemistry texts' treatment of rates of change concepts in reaction kinetics reveals missing conceptual links. J Chem Educ. 2018;95(1):28–36. https://doi.org/10.1021/acs.jchemed.7b00238.
10. Marais A. Overcoming conceptual difficulties in first-year chemistry students by applying concrete teaching tools. S Afr J Chem. 2011;64:151–157.
11. Potgieter M, Davidowitz B. Grade 12 achievement rating scales in the new National Senior Certificate as indication of preparedness for tertiary chemistry. S Afr J Chem. 2010;63(1):75–82.
12. Potgieter M, Davidowitz B. Preparedness for tertiary chemistry: multiple applications of the Chemistry Competence Test for diagnostic and prediction purposes. Chem Educ Res Pract. 2011;12(2):193–204. https://doi.org/10.1039/C1RP90024B.
13. Cooper M, Klymkowsky M. CLUE: Chemistry, life, the universe and everything. Michigan State University Libraries. 2020. www.chemistry.msu.edu/_assets/_files/clue/CLUEFall2019.pdf (Accessed 22 October 2025)
14. Cooper MM, Klymkowsky MW. Chemistry, life, the universe and everything: A new approach to general chemistry, and a model for curriculum reform. J Chem Educ. 2013;90(9):1116–1122. https://doi.org/10.1021/ed300456y.
15. Talanquer V, Pollard J. Reforming a large foundational course: successes and challenges. J Chem Educ. 2017;94(12):1844–1851. https://doi.org/10.1021/acs.jchemed.7b00397.
16. Hein SM. Positive impacts using POGIL in organic chemistry. J Chem Educ. 2012;89(7):860–864. https://doi.org/10.1021/ed100217v.
17. Schroeder JD, Greenbowe TJ. Implementing POGIL in the lecture and the Science Writing Heuristic in the laboratory—student perceptions and performance in undergraduate organic chemistry. Chem Educ Res Pract. 2008;9(2):149–156. https://doi.org/10.1039/B806231P.
18. Canelas DA, Hill JL, Carden RG. Cooperative learning in large sections of organic chemistry: transitioning to POGIL. In: Houseknecht JB, Leontev A, Maloney VM, Welder CO (editors), Active learning in organic chemistry: implementation and analysis. ACS Symposium Series. Washington, DC: American Chemical Society Publications; 2019. p. 199–215. https://doi.org/10.1021/bk-2019-1336.ch012.
19. Vincent-Ruz P, Meyer T, Roe SG, Schunn CD. Short-term and long-term effects of POGIL in a large-enrollment general chemistry course. J Chem Educ. 2020;97(5):1228–1238. https://doi.org/10.1021/acs.jchemed.9b01052.
20. Mamombe C, Mathabathe KC, Gaigher E. Teachers' and learners' perceptions of stoichiometry using POGIL: a case study in South Africa. Eurasia J Math Sci Technol Educ. 2021;17(9):em2003. https://doi.org/10.29333/ejmste/11140.
21. Council on Higher Education. Extended programmes with an integrated foundation phase: theoretical considerations for curriculum design. Pretoria, South Africa: Council on Higher Education; 2020.
22. Mouton M, Rewitzky I. Opportunity and outcome: a quantitative evaluation of the STEM extended curriculum programme at a research-intensive university. S Afr J High Educ. 2025;39(2):151–171. https://doi.org/10.20853/39-2-5927.
23. Megbowon FK, Palesa MK, Bongiwe K, Sipokazi M. Challenges of first-year extended curriculum programme students at a university in South Africa. Int J Learn Teach Educ Res. 2023;22(4):178–194. https://doi.org/10.26803/ijlter.22.4.11.
24. de Klerk E, Van Deventer I, Van Schalkwyk S. Small victories over time: the impact of an academic development intervention at Stellenbosch University. Educ Change. 2006;10(2):149–169. https://doi.org/10.1080/16823200609487145.
25. Wood L, Lithauer P. The 'added value' of a foundation programme. S Afr J High Educ. 2006;19(5):1002–1019. https://doi.org/10.4314/sajhe.v19i5.25541.
26. Potgieter M, Harding A, Kritzinger Q, Somo C, Engelbrecht J. Reflections of science students on their experiences of an academic development programme in South Africa. S Afr J High Educ. 2016;29(1):108–131. https://doi.org/10.20853/29-1-446.
27. Ogude NA, Meyer I, Mwambakana J, Mthethwa N. Can extended curriculum programmes be improved through engagement with students using appreciative inquiry? S Afr J High Educ. 2019;33(4):219–236. https://doi.org/10.20853/33-4-2835.
28. Bodner GM, Orgill M. Theoretical frameworks for research in chemistry/science education. Upper Saddle River: Pearson Prentice Hall; 2007.
29. Marton F. Phenomenography—describing conceptions of the world around us. Instr Sci. 1981;10(2):177–200. https://doi.org/10.1007/BF00132516.
30. Booth S. On phenomenography, learning and teaching. High Educ Res Dev. 1997;16(2):135–158. https://doi.org/10.1080/0729436970160203.
31. Han F, Ellis RA. Using phenomenography to tackle key challenges in science education. Front Psychol. 2019;10:1414. https://doi.org/10.3389/fpsyg.2019.01414.
32. Ashworth P, Lucas U. Achieving empathy and engagement: a practical approach to the design, conduct and reporting of phenomenographic research. Stud High Educ. 2000;25(3):295–308. https://doi.org/10.1080/713696153.
33. Orgill M. Phenomenography. In: Bodner G, Orgill M (editors), Theoretical frameworks for research in chemistry science education; 2007. Upper Saddle River: Pearson Prentice Hall.
34. Department of Higher Education and Training. Strategic Plan 2020–2025. Pretoria, South Africa. 2020. www.dhet.gov.za/SiteAssets/StrategicPlans/DHETAmendedSP2020-2025.pdf (Accessed 22 October 2025)
35. Shay S, Wolff K, Clarence-Fincham J. New generation extended curriculum programmes: report to the DHET. Cape Town: University of Cape Town; 2016. https://doi.org/10.13140/RG.2.1.3135.5767.
36. Council on Higher Education. National policy endorsement of Extended Curriculum Programmes (ECPs) to promote access, equity, and retention. Pretoria, South Africa. 2020.
37. Council on Higher Education. Extended Curriculum Programmes offered across South African universities and alignment with national STEM goals. Pretoria, South Africa; 2020.
38. Seidman I. Interviewing as qualitative research: a guide for researchers in education and the social sciences. New York: Teachers College Press; 2006. Bekele WB, Ago FY. Sample size for interview in qualitative research in social sciences: a guide to novice researchers. Res Educ Policy Manag. 2022;4(1):42–50. https://doi.org/10.46303/repam.2022.3.
39. Creswell JW. Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research; 2002. Upper Saddle River: Pearson Prentice Hall.
40. Corbin J, Strauss A. Basics of qualitative research: techniques and procedures for developing grounded theory. Thousand Oaks: Sage Publications; 2014.
41. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77–101. https://doi.org/10.1191/1478088706qp063oa.
42. Bransford JD, Brown AL, Cocking RR. How people learn: brain, mind, experience, and school. Washington, DC: National Academies Press; 2000.

43. Saldaña J. The coding manual for qualitative researchers. Thousand Oaks: Sage; 2021.
44. Tight M. Phenomenography: the development and application of an innovative research design in higher education research. Int J Soc Res Methodol. 2016;19(3):319–338. https://doi.org/10.1080/13645579.2015.1010284.
45. Orgill M, Bussey TJ, Bodner GM. Biochemistry instructors' perceptions of analogies and their classroom use. Chem Educ Res Pract. 2015;16(4):731–746. https://doi.org/10.1039/C4RP00256C.
46. Lincoln YS, Guba EG. Naturalistic inquiry. Thousand Oaks: Sage Publications; 1985. https://doi.org/10.1016/0147-1767(85)90062-8.
47. Rands M, Gansemer-Topf A. Phenomenography: a methodological approach for assessing student learning in student affairs. J Stud Aff Inq Improv Impact. 2016;2(1):25254. https://doi.org/10.18060/27834.
48. Akerlind G. Learning about phenomenography: Interviewing, data analysis and the qualitative research paradigm. In: Bowden JA, Green P (editors), Doing developmental phenomenography. Melbourne: RMIT University Press; 2005. pp. 63–74.
49. Vygotsky LS, Cole M. Mind in society: development of higher psychological processes. London: Harvard University Press; 1978.
50. Tudge J, Rogoff B. Peer influences on cognitive development: Piagetian and Vygotskian perspectives. In: Bornstein MH. Bruner JS (editors), Interaction in human development. New York: Psychology Press; 1989. pp. 17–40.
51. Fung DCL, To H, Leung K. The influence of collaborative group work on students' development of critical thinking: the teacher's role in facilitating group discussions. Pedagogies. 2016;11(2):146–166. https://doi.org/10.1080/1554480X.2016.1159965.
52. Tullis JG, Goldstone RL. Why does peer instruction benefit student learning? Cogn Res Princ Implic. 2020;5(1):15. https://doi.org/10.1186/s41235-020-00218-5.
53. Paulson DR. Active learning and cooperative learning in the organic chemistry lecture class. J Chem Educ. 1999;76(8):1136–1140. https://doi.org/10.1021/ed076p1136.
54. O'Dwyer A, Childs P. Organic chemistry in action! What is the reaction? J Chem Educ. 2015;92(7):1159–1170. https://doi.org/10.1021/ed5006163.
55. Carpenter S, McMillan T. Incorporation of a cooperative learning technique in organic chemistry. J Chem Educ. 2003;80(3):330–332. https://doi.org/10.1021/ed080p330.
56. Cooper MM, Stowe RL, Crandell OM, Klymkowsky MW. Organic chemistry, life, the universe and everything (OCLUE): a transformed organic chemistry curriculum. J Chem Educ. 2019;96(9):1858–1872. https://doi.org/10.1021/acs.jchemed.9b00401.
57. Jones OA, Spichkova M, Spencer MJ. Chirality-2: development of a multilevel mobile gaming app to support the teaching of introductory undergraduate-level organic chemistry. J Chem Educ. 2018;95(7):1216–1220. https://doi.org/10.1021/acs.jchemed.7b00856.
58. Ward LW, Spencer D, Chauhan D, Oliver-Hoyo M. Lessons learned: the use of an augmented reality application in organic chemistry laboratories. Front Educ (Lausanne). 2024;9:1384129. https://doi.org/10.3389/feduc.2024.1384129.
59. Mosala T, Mathabathe K, Tekane R. Learning organic chemistry on the go: chemical engineering students' perceptions of Chirality-2 App as a learning support. J Chem Educ. 2025;102(4):1410–1417. https://doi.org/10.1021/acs.jchemed.4c01470.
60. Gulacar O, Milkey A, McLane S. Exploring the effect of prior knowledge and gender on undergraduate students' knowledge structures in chemistry. Eurasia J Math Sci Technol Educ. 2019;15(8). https://doi.org/10.29333/ejmste/106231.
61. Sedumedi TD. Prior knowledge in chemistry instruction: some insights from students' learning of acids/bases. Psycho-Educ Res Rev. 2013;2(1):34–53.
62. Salame II, Casino P, Hodges N. Examining challenges that students face in learning organic chemistry synthesis. Int J Chem Educ Res; 2020;4(1):1–9. https://doi.org/10.20885/ijcer.vol4.iss1.art1.
63. Gyang NO, Adu-Gyamfi K. Teaching organic chemistry to upper-secondary students hasn't been easy. Gamtamokslinis Ugdymas. 2024;21(1):18–34. https://doi.org/10.48127/gu-nse/24.21.18.
64. King SM, Zhou N, Fischer C, Rodriguez F, Warschauer M. Enhancing student learning and retention in organic chemistry: benefits of an online organic chemistry preparatory course. In: Hartwell SK, Gupta T (editors), From general to organic chemistry. Washington, DC: ACS Publications; 2019. pp. 119–128. https://doi.org/10.1021/bk-2019-1341.ch009.
65. Freeman M. The hermeneutical aesthetics of thick description. Qual Inq. 2014;20(6):827–833. https://doi.org/10.1177/1077800414530267.
66. Hattie J, Timperley H. The power of feedback. Rev Educ Res. 2007;77(1):81–112. https://doi.org/10.3102/003465430298487.
67. Leenknecht M, Wijnia L, Köhlen M, Fryer L, Rikers R, Loyens S. Formative assessment as practice: the role of students' motivation. Assess Eval High Educ. 2021;46(2):236–255. https://doi.org/10.1080/02602938.2020.1765228.
68. Biggs JB. Assessing student approaches to learning. Aust Psychol. 1988;23(2):197–206. https://doi.org/10.1080/00050068808255604.
69. Harlen W. Teachers' summative practices and assessment for learning–tensions and synergies. Curric J. 2005;16(2):207–223. https://doi.org/10.1080/09585170500136093.
70. Gibbs G, Simpson C. Conditions under which assessment supports students' learning. Learn Teach High Educ. 2005;(1):3–31.
71. Urdan MS, Luoma P. Designing effective sustainability assignments: how and why definitions of sustainability impact assignments and learning outcomes. J Manage Educ. 2020;44(6):794–821. https://doi.org/10.1177/1052562920946798.