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Assessing teachers' knowledge: incorporating context-based learning in chemistry

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Content knowledge (CK), pedagogical content knowledge (PCK) and, assessment knowledge (AK) are fundamental types of teachers' knowledge. Second-career, pre-service chemistry teachers leave the industry and return to the Technion to study in the *Views* program to obtain a high school teaching certificate. Their background can potentially contribute to higher quality of science teaching and learning in general and of chemistry teaching in particular. We investigated how pre-service chemistry teachers' knowledge develops as they are exposed to chemistry context-based learning, and what differences are there between pre- and in-service teachers' knowledge types and their self-efficacy. The participants were 25 second-career pre-service teachers and 29 in-service chemistry teachers who served as a comparison group. The teachers' professional growth was examined by assessing their CK, PCK, AK, and self-efficacy by using three questionnaires that included adapted scientific articles on energy, acid-base, and oxidation-reduction in the context of sustainability. Five expert chemistry teachers validated the questionnaires. We found that all three knowledge types of the pre-service teachers improved during the course and they became more aware of sustainable chemistry issues than the in-service teachers. The study contributes to chemistry education by narrowing the gap that exists in the literature between chemistry teachers' PCK and AK on the one hand and self-efficacy on the other hand. We offer an assessment tool for identifying and quantifying teachers' knowledge. We offer recommendations for science educators about the needs, strengths, and weaknesses of pre- and in-service teachers related to teaching sustainable chemistry.

Introduction

The Technion—Israel Institute of Technology in Haifa, Israel offers *Views* (*MABATIM*)—a four-semester program designed to prepare industrial scientists and engineers to make the transition to second-career positions as high school educators (Shwartz and Dori, 2020). The rich scientific backgrounds of these participants enhance the learning experience of their students and school communities. Well-prepared, capable teachers can markedly impact student performance, cultivating skills that enable them to contribute to the 21st century workforce. Despite their importance, the shortage of certified science, technology, engineering, and mathematics (STEM) teachers is a global concern (Fantilli and McDougall, 2009). In Israel, chemistry teachers are particularly in short supply. High attrition rates persist among STEM teachers within the first three years of entering the field. Additionally, a large cohort of these teachers, who had emigrated from the former USSR in the 1990s, have retired (Barnea *et al.*, 2010).

One way to alleviate the shortage of STEM teachers is to recruit and train second-career teachers. Effective teacher education programs can offer tracks that train second-career teachers. For chemistry teachers, sustainable chemistry training is specifically important as this enables them to capitalize on their ability to create sustainable societies and prepare their students to become future scientists and leaders.

Conceptual framework of pedagogical competencies

In the research described in this paper we characterized the professional growth of second-career, pre-service chemistry teachers based on three knowledge types – content knowledge (CK); pedagogical content knowledge (PCK), and assessment knowledge (AK), while exposing them to the context-based learning (CBL) approach with an emphasis on sustainable chemistry. We also compared these second-career teachers' CK, PCK, AK, and self-efficacy to those of in-service chemistry teachers. In this section, we first describe CBL and sustainable chemistry. We then discuss teachers' knowledge types, including CK, PCK, and AK.

We will then go on to discuss the term self-efficacy, along with a brief description of the terms self-esteem and self-concept. All these terms are generally used to describe how people perceive themselves. In this study, we use the term self-efficacy to evaluate

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how teachers assess their own knowledge in a particular field (Nielsen and Yezierski, 2016; Flaherty, 2020), in our case chemistry (Krause *et al.*, 2017; Avargil, 2019).

We refer to professional growth of the pre-service teachers based on two studies (Kotul'áková, 2020; Popova *et al.*, 2020) that describe teachers' professional growth as a mechanism through which a change may occur *via* learning and understanding of teaching practices. In our research, professional development (PD) included a course entitled *Advanced Topics in Teaching Chemistry* for pre-service chemistry teachers, and a summer workshop for in-service chemistry teachers.

Context-based learning – CBL

Chemistry plays a key role in sustainability, a topic that has become increasingly relevant in recent years. Chemists are working on solving today's and tomorrow's environmental problems by preserving and recycling natural resources, such as drinking water, gas, oil, and minerals. Moreover, most countries' science education standards acknowledge that students, as future citizens, require a foundational understanding of science in general and of chemistry in particular. This re-orientation of science education goals has led to discussions concerning reorientation and restructuring of the chemistry curriculum to achieve those new objectives (Hofstein *et al.*, 2011). Nevertheless, studies have shown that some students are not interested in studying chemistry and other sciences. Students' lack of interest may be partially due to the disconnection between the chemistry curriculum and students' lives (Hofstein *et al.*, 2011). To address this problem, the first decade of the 21st century was characterized by educational reforms that emphasized context-based learning, thinking skills, learning progression, and integration of technology for hands-on experiments and visualizations (Dori and Herscovitz, 1999; Sevian and Talanquer, 2014; Sevian *et al.*, 2018). When using CBL, students analyze a case study on a topic familiar to them, and utilize scientific reasoning methods. This teaching method is very effective in science, especially when it is taught along with metacognitive prompts that direct the teacher to focus on the context-based assignments (Avargil *et al.*, 2012; Pabuccu and Erduran, 2016). CBL is strongly influences scientific teaching throughout the world, as it can engage and stimulate students. Many students find context-based chemistry more interesting and motivating than traditional approaches (King, 2012; Pabuccu and Erduran, 2016).

Sustainable chemistry is a core topic in chemistry. Therefore, chemistry teachers must have solid knowledge and a deep understanding of this subject in order to teach it properly to their students.

Although sustainable education is viewed positively by most chemistry teachers, many of them have difficulty incorporating it in their classes due to their lack of knowledge, and pedagogical experience (Burmeister *et al.*, 2013; Zuin and Eilks, 2019).

In light of the above, teacher education that incorporates learning and evaluating CBL, with an emphasis on sustainable chemistry, may be very beneficial for these pre-service chemistry teachers when they start teaching in schools.

CBL focus on sustainable chemistry

Green chemistry relates to economics and environmental aspects of energy generation and sustainability. It is often used as context for CBL in chemistry, with the learning objective of presenting green chemistry as the future of the chemical industry. CBL facilitates learning on sustainable development, and it is most readily implemented in applied aspects of chemistry, where the real-life contexts are easily identified. Therefore, sustainable development is included in many modern chemistry curricula (Arnold and Williams, 2012).

Studies have shown that for students to understand the role of chemistry and other sciences in solving environmental problems, learning it in context of sustainable chemistry can be very effective (Overton and Randles, 2015; Günter *et al.*, 2017). Integration of sustainability topics into chemistry education has been researched extensively in both formal and informal education (Overton and Randles, 2015; Affeldt *et al.*, 2017; Haley *et al.*, 2018).

All the higher education students should be exposed to and familiar with the sustainability topic (Mintz and Tal, 2018), as this subject is critical for the future of each individual and to the entire planet. Sustainability is a prominent trans-disciplinary domain of human research and activity that can promote active learning using real-life problems. In addition, increasing awareness of sustainability issues might serve as a good platform for developing important skills such as system thinking, modeling, and scientific understanding (Akiri *et al.*, 2020). However, even in higher education, the topic of sustainable chemistry is usually not part of the undergraduate or graduate curriculums.

Professional knowledge base for teaching science in the 21st century

In recent years, the question of how teacher preparation should take place as part of teacher education has received much attention (*e.g.* Boyd *et al.*, 2009; Day, 2016). One reason for this is that policy makers and educational researchers around the world have embraced the idea that teachers are among the most important contributors to students' achievements (OECD, 2005). Therefore, policy makers and teacher educators must consider many questions regarding the qualifications teachers need in order to teach a specific subject, and which types of knowledge, skills, and support they need in order to become experts (Sleeter, 2014).

Table 1 presents the three teachers' knowledge types – CK, PCK, and, AK. Many teachers' education programs around the world recognize that these knowledge types play a crucial role in the development of expert, domain-specific teachers (Abell *et al.*, 2000; Sickel *et al.*, 2015).

Teachers' knowledge types

Currently, many teachers' education programs around the world recognize the important role of CK, PCK, and AK in the development of expert teachers (Abell *et al.*, 2000; Mertler, 2009; Sickel *et al.*, 2015).

PCK. Introducing the term in an address in 1985 at the American Educational Research Association Annual Meeting,

Table 1 Teachers' knowledge types

Knowledge type	Definition	Citations
Content Knowledge (CK)	The body of knowledge and information that teachers teach and that students are expected to learn in a given subject or content area.	Shulman, 1987; Loewenberg *et al.*, 2008.
Pedagogical Content Knowledge (PCK)	Teachers' knowledge with respect to how to teach specific content and extend their level of pedagogical expertise beyond familiarity with the content or the pedagogy alone.	Shulman, 1986; Demirdöğen *et al.*, 2016; Krepf *et al.*, 2018; Ekiz-Kiran *et al.*, 2021.
Assessment Knowledge (AK)	The knowledge and understanding teachers have about assessment, its value, types, and applications for evaluating students' learning outcomes. AK refers to the ability of teachers to design and implement appropriate tasks to accurately assess students' knowledge and skills.	Magnusson *et al.*, 1999; Shepard, 2000; Avargil *et al.*, 2012; Tacoshi and Fernandez, 2014; Martinovic and Manizade, 2018; Schafer and Yezierski, 2021

Shulman (1986) included a large array of skills related to CK, PCK, and AK that teachers should know and be aware of.

The idea underlying PCK is based on research that focused on teachers' use of knowledge during the practice of teaching. Shulman (1987) further defined PCK as "...the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction" (p. 8).

Since Shulman described the concept of PCK, many attempts have been made to expand its construct across different domains. Magnusson *et al.* (1999) defined PCK in science as a unique domain of teacher's knowledge (Magnusson *et al.*, 1999) for helping students to appreciate and comprehend specific subject matter.

Later on, Van Driel *et al.* (2002) investigated the development of PCK among a group of pre-service chemistry teachers. The results showed growing awareness among the pre-service teachers of the importance of explicitly relating the macroscopic and microscopic levels to one another.

In another study, the authors discussed the fact that teachers' education can never address all the components of specific PCK that a teacher needs. Their conclusion was that pre-service teachers can use their PCK effectively to develop their plans for teaching other topics (De Jong and Van Driel, 2004).

Over the years since Shulman's work, the research on PCK has grown. Almost 30 years later, Shulman (2015) acknowledged that insufficient attention had been paid to the social and cultural contexts in his original PCK construct. He continued to emphasize that culture and context are a large portion of the components of teaching and learning. "PCK must be pedagogical content knowledge, but also ... that the big idea within PCK was that all teaching must be mindfully situated in the disciplinary, cultural, personal, and social settings in which it occurs." (p. 10).

Considering this important observation, a study cannot be separated from the culture in which it was conducted. For example, in Israel, methods of teaching and learning that includes posing questions are very popular since questioning used to be a part of the traditional Jewish education (Kent, 2006 and Segal, 2011). Furthermore, it is impossible to detach the PCK idea neither from the current era in which we live nor the skills required for science professionals and students (NGSS Lead States, 2013). Therefore, PCK must be suited for the interests and capabilities of today's learners and the skills they must develop in order to become science professionals. Question posing is a key skill that ought to be included in any teaching process (NGSS Lead States, 2013), especially in teaching science (Dori and Herscovitz, 1999; Kaberman and Dori, 2009) and considering that question posing is the first of eight key practices used by scientists and engineers. For teachers, asking questions is a key tool they can and should use during the teaching process to engage students and help them become active learners. Therefore, in this study, we assessed teachers' PCK level using three-dimensional analysis of the questions the pre- and in-service teachers posed: (a) chemistry understanding level domain-specific, (b) thinking level, and (c) context-based sustainable chemistry – subject matter knowledge. Hence, posing questions – a skill related to the context-based article, which integrates domain-specific subject matter knowledge and can therefore represents teacher's PCK level.

AK. Magnusson and colleagues (1999) also introduced the concept of teachers' AK and defined it as the knowledge and understanding teachers have about assessment. Teachers should be familiar with methods of assessment, including specific instruments, approaches or activities that can be used for a particular unit of study to assess science learning. The teachers should also be aware of the advantages and disadvantages associated with employing a particular assessment method or task (Magnusson *et al.*, 1999; Abell *et al.*, 2000)

Based on these two constructs – PCK and AK – Avargil and colleagues (2012) discussed the correlation between different types of teacher knowledge and assessment knowledge. The researchers linked teachers' knowledge with their stage of professional growth. These authors discussed the teachers' knowledge as comprises of CK and PK, which are the building blocks of PCK. As teachers develop professionally, their AK develops as well. Accordingly, the researchers determined that AK is a separate and valuable body of knowledge that requires more than PCK alone. As such, AK requires not only a completely new teaching approach, but also the ability to design and implement assessment tools that accurately assess students' knowledge and skills. Consequently, assignments designed by teachers can be used as a method for determining their AK or assessment practices (Avargil *et al.*, 2012; Dori and Avargil, 2015;

Schafer *et al.*, 2021). Other researchers discussed assessment literacy (Abell and Siegel, 2011; Gottheiner and Siegel, 2012; Xu and Brown, 2016), and more broadly, assessment expertise (Gearhart *et al.*, 2006; Lyon 2013).

Teacher education is receiving increased consideration, as the current era is marked by an increasing need for a new set of practices, often referred to as 21st-century skills (NGSS Lead States 2013; NRC 2013; ABET 2018).

According to NGSS, engineers and scientists need the following six (out of eight) important skills, which are fundamental for the construction of scientific theories, models, and developments:

- Asking questions (science) and defining problems (engineering),
- Developing and using models,
- Planning and carrying out investigations,
- Analyzing and interpreting data,
- Constructing explanations (science) and designing solutions (engineering),
- Engaging in arguments based on evidence.

''*These practices are not isolated from core ideas; they are the means by which scientists investigate and build models and theories*'' (NGSS Lead States 2013, P 6). Science teachers must master these practices to impart them to students and to be able to prepare appropriate assignments that give their students the opportunity to use these practices. Teacher educators need to combine teachers' knowledge types with 21st century skills in order to provide pre- and in-service teachers with extensive training (NGSS Lead States 2013).

Teachers are often required to teach new topics that were previously not in the curriculum, since curricula might change and new real-life issues (like the pandemic) can be added to the syllabus of the domain they teach. Consequently, it is important for teachers to know how to apply the PCK and AK they gain in other areas of chemistry (De Jong and Van Driel, 2004). In this paper, we evaluated teachers' CK, PCK and AK by using criteria based on general chemistry, education, and thinking skills.

Chemistry self-efficacy

Three common terms used in the literature to describe how people view themselves, what they know, and what they perceive they can do are self-efficacy, self-esteem, and self-concept. The term self-esteem is generally viewed as a global construct and less topic-specific than the other terms, and therefore, it is not often used in the context of chemistry (Nielsen and Yezierski, 2016; Flaherty, 2020).

The two terms self-efficacy and self-concept are similar and therefore interchangeable. Nielsen and Yezierski (2015, 2016) defined these terms and discuss the differences between them at length.

Self-concept is used to describe how people perceive themselves (Marsh *et al.*, 1981; Bong and Skaalvik, 2003). This concept is domain-specific and can be used to define how people assess their abilities in a specific domain, such as chemistry. Studies of self-concept in the context of chemistry have found that it correlates with student achievements in chemistry, and it can be used as an effective predictor of performance (Lewis *et al.*, 2009).

Self-efficacy is a psychological construct related to a person's confidence in her ability to complete a task or achieve a goal (Bandura, 1977; Bong and Skaalvik, 2003). It is future-focused by definition, as it requires people to assess their capabilities.

A person's attitudes and self-efficacy beliefs might greatly influence their perception of how they view the solution of a specific issue in science teaching (Krause *et al.*, 2017). One's self-efficacy is the conviction they have about their abilities to solve a given task. Bandura (1994) defined self-efficacy is as ''people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives'' (p. 71). He added that self-efficacy beliefs determine how one feels, thinks, and behaves, and how she is motivated.

In chemistry self-efficacy studies, students are often asked to evaluate their ability to understand chemical concepts and processes, and solve chemistry problems (Nielsen and Yezierski, 2015).

Nielsen and Yezierski (2015) consider self-efficacy to be a task-specific concept related one's confidence in his ability to successfully complete a specific task, such as balancing a chemical equation or solving a stoichiometry problem.

Self-concept is situated between self-efficacy, which is task specific, and self-esteem, which has a more global meaning. Self-concept is the belief held by an individual about domain-specific capabilities, and can be applied to students who judge their capabilities in a specific subject, such as chemistry, based on prior performance in that subject. A student's frame of reference also contributes to the self-concept that develops (Nielsen and Yezierski, 2015).

In this study, we use the term self-efficacy based on the review of Flaherty (2020), who showed that the term self-efficacy is the one most frequently used in the context of chemistry. The review includes a summary of key concepts in chemistry education, where a higher number of studies utilize mixed methods or qualitative data analysis related to the self-efficacy. Also, a study by Nielsen and Yezierski (2015) used a questionnaire similar to the one we use, in order to assess teachers' perceptions of their own knowledge. These researchers used the term self-efficacy to describe the perceived knowledge of the participants.

Additionally, the term self-efficacy has been well researched and discussed, and there are many studies in the field of chemistry education that relate to the way one perceives one's own knowledge (Avargil *et al.*, 2020; Ogunde *et al.*, 2017; Vishnumolakala *et al.*, 2017; Willson-Conrad and Kowalske, 2018). Finally, our decision to choose to use the term self-efficacy for our study is founded on a paper by Gibbons and Raker, 2019, in which they stated:

''*... self-efficacy is described as future-oriented while self-concept is based on past experience...self-concept does not refer to a specific outcome as self-efficacy does.*'' (pp. 600–601).

For more detail, see Appendix 1 that illustrates the differences between self-concept and self-efficacy.

The primary objective of this study is assessing teachers' knowledge types. Referring to their self-efficacy is a secondary objective. The comparison between the assessed knowledge and self-efficacy enables determining whether there is a gap between teachers' perceived knowledge and their actual knowledge.

Research plan

Our objective was to investigate the PD of second-career pre-service teachers and compare their knowledge types to those of in-service chemistry teachers (first career). In the course, the teachers studied, CBL was an integral part in the teaching and learning methods in order to emphasize the relevance of chemistry to their students' experiences in everyday life (Dori *et al.*, 2018a and b; Sevian *et al.*, 2018). We focused on three topics, with an emphasis on sustainable chemistry—chemical energy, acid–base, and oxidation–reduction reactions—and raised the following research questions with respect to teachers' CK, PCK, and AK:

RQ1. How do second-career pre-service chemistry teachers' three knowledge types develop as they are exposed to chemistry context-based learning?

RQ2. What are the differences, if any, between the pre- and in-service chemistry teachers' knowledge types and self-efficacy?

In RQ1, we investigated the processes that the second-career pre-service teachers underwent during the course and as they became teachers, and analyzed their retention levels after about two months. In RQ2, we compare the teachers' knowledge and self-efficacy of second-career pre-service chemistry teachers with those of in-service chemistry teachers.

Research settings

The research was conducted at the Faculty of Education in Science and Technology at the Technion, Israel Institute of Technology. The research participants included the pre-service teachers in the *Views* program, who attended an *Advanced Topics in Teaching Chemistry* course, and in-service chemistry teachers, who attended a summer workshop at the Technion. This 3 credit, 13 week course, includes four 1-hour sessions per week. The course focuses on advanced topics in chemistry education such as biochemistry (Barak and Hussein-Farraj, 2013), nanochemistry (Dori *et al.*, 2014), and thermodynamics. Methods taught include utilizing computerized laboratories, molecular modeling, and reading and analyzing adapted scientific literature (Kaberman and Dori, 2009; Dori *et al.*, 2018a and b).

The views program. Like many other countries, Israel has been experiencing a shortage of STEM teachers. Second-career teachers are people from outside the field of education who leave other jobs to become teachers (Shwartz and Dori, 2020). One way to reduce the shortage of STEM teachers is to recruit qualified professionals with chemistry degrees and help them become qualified, second-career chemistry teachers.

Recent studies indicate that second-career teachers have specific strengths and weaknesses that must be acknowledged (Tigchelaar *et al.*, 2010) in order to offer to them a tailored, unique teacher education program (Koballa *et al.*, 2005; Baeten and Meeus, 2016).

The *Views* program is designed for Technion graduates with degrees in mathematics, science, or engineering, and endows those completing the program with an additional BSc degree and a Teaching Certificate in Science and Engineering Education in biology, chemistry, computer science, electrical engineering, environmental sciences, mathematics, mechanical engineering, or physics.

The program, which requires studying 36 credit points over two years, two days per week, comprises three levels. The basic level, shared by all education tracks, focuses on educational psychology and general teaching methods (PK). The intermediate level addresses teaching methods specific to the relevant discipline, including high-school practicum (PCK). Finally, the highest level comprises advanced elective courses in education or educational research (Gero and Hazzan, 2016; Dori *et al.*, 2018b; Shwartz and Dori, 2020). The challenge in preparing these pre-service second-career teachers is that while they are expected to have an extensive background in the science subject matter (CK), they lack PCK and AK. Even so, some of these second-career pre-service teachers were studying this program long since they completed their degrees, and many of them have even worked in other fields. Therefore, they sometimes forget certain chemistry topics and have difficulty explaining and expressing their knowledge. This may create a significant discrepancy between their SE and their actual knowledge.

In the chemistry education track, the program focuses on strengthening teachers' mastery of key concepts and phenomena, as well as their PCK in chemistry. The program includes general pedagogy coursework, chemistry and pedagogy-related courses, chemistry teaching methods courses (*e.g.* inquiry and lab work), action research, and an internship.

Participants

The participants were divided into three research groups: (a) expert chemistry teachers—the pilot group, (b) pre-service chemistry teachers, and (c) in-service chemistry teachers. The role and characteristics of each research group are described below.

Expert chemistry teachers – Phase I. Phase I was the pilot study, which included five expert teachers who participated in this pilot phase to establish the validity and the reliability of the questionnaires developed for this study.

These experts were chemistry teachers who specialized in several areas of chemistry. In addition to teaching chemistry in schools and preparing students for the matriculation examinations, these teachers were involved in professional activities related to chemistry education, including (1) development of teaching materials within the chemistry curriculum framework, (2) teaching

Table 2 An overview of the Phase II research participants

	Research group	
Characteristics	Experimental group	Comparison group
Chemistry teachers	Pre-service – *Views* students	In-service
No. of participants	25	29
Degrees	76% BSc 17% MSc 7% PhD	83% MSc 17% BSc
Teaching experience	None	41%: over 15 years 38%: less than 5 years

chemistry teachers' in-service training courses or academic courses for pre-service teachers on methods for teaching chemistry, and (3) chemistry education research and publication of papers in scientific journals.

Pre- and in-service chemistry teachers – Phase II. Phase II, the main stage of the study, included 54 participants, 83% of whom were female. The participants were divided into two groups: (a) an experimental group that included 25 second-career pre-service chemistry teachers with at least a bachelor's degree in chemistry or a related field, who had completed the *Advanced Topics in Teaching Chemistry* course; and (b) a comparison group of 29 in-service chemistry teachers, who participated in a 30-hour a summer workshop for teachers at the Technion. This group was diverse in terms of age and teaching experience. Table 2 presents an overview of the participants in this phase of the study.

Research methodology

The questionnaires were analyzed in three rounds. In the first, the qualitative round, we applied content analysis of the participants' responses. In the second, the quantitative round, we scored each participant's response using rubrics (see more details in the sequel).

The constructs were verified by consulting with chemistry education professionals who did not participate in the study, as recommended by Creswell and Creswell (2017). The objectivity of the coding and the scoring process according to the three rubrics was validated through inter-rater reliability checking process. The inter-rater reliability, which was applied to about 20% of the answer excerpts, ranged from 84% to 93%, as detailed next to each rubric. The five expert teachers who responded to the questionnaires (see details in pilot study section) also validated the rubrics and the scoring of teachers' knowledge types.

In the third round, we statistically analyzed the results (Creswell *et al.*, 2006; Erickson, 2012). We performed a *t*-test and ANOVA tests to compare the knowledge types of the different research groups.

The research tool we designed included three case-based questionnaires related to sustainable chemistry, focusing on chemical energy, acid–base, and oxidation–reduction reactions. We choose these topics as they are the main topics studied in the chemistry curriculum and include core concepts of high school chemistry. We focused on sustainable chemistry as it represents important, context-based topics that teachers should be aware of and emphasize while teaching chemistry (Dori *et al.*, 2018a and b; Mintz and Tal, 2018).

Ethics. This research was reviewed and approved by the Behavioral Sciences Research Ethics Committee of the Technion - Israel Institute of Technology (approval number 2017-60).

All teachers in the study gave their consent to be part of the research and filled in the questionnaires. To protect confidentiality and ensure that all data remained confidential, the participants were given codes and any identifying details were removed from the data.

Phase I – the pilot study phase. For the pilot phase, we created an initial version of the three questionnaires and administered them to the five expert chemistry teachers. The expert teachers served as a validation group. We investigated their professional knowledge by determining their CK, PCK and AK levels. The experts' professional knowledge was analyzed using the data obtained from all three questionnaires. Their average scores for all types of knowledge in all three questionnaires were homogenous and close to the maximum value of 5. The experts' responses helped us design the rubrics.

The experts' CK and PCK average scores were similar (4.2 with a range of 4.1–4.5), and their AK average score were very high (4.9 with a range of 4.8–5.0). Their responses collected in the pilot phase helped us confirm that all three questionnaires were very similar in terms of questions and tasks. In-depth analysis of the expert responses helped us define which response was the best answer and build the rubric for the three types of skills in the questionnaires. Based on these teachers' feedback, we developed the final version of the three questionnaires.

Phase II – the main study. In Phase II, we administered the three questionnaires, pre, post, and retention, to the pre-service teachers. The pre-questionnaire was administered before they started learning the topic addressed by the questionnaire in the course. The pre-service chemistry teachers answered the questionnaires at three time points: at the beginning (pre) and end (post) of the course, and two months after they finished the course (retention).

The question posing and student classroom assignment composing skills were not directly taught in the *Advanced Topics in Teaching Chemistry* course. Instead, these skills were embedded in various teaching methodology courses, so our assumption was that these skills were acquired in the teaching certificate program. The in-service chemistry teachers answered the three questionnaires once during the summer workshop. Each participant responded randomly to one of the three questionnaires during the workshop.

All the questionnaires were answered anonymously, with identification codes assigned to each participant to enable matching the different questionnaires to the same responding participant.

The questionnaires included two parts: (a) self-efficacy and concept explanation, and (b) a context-based, adapted scientific article (hereinafter "the context-based article") related to sustainable chemistry, with question posing skill (represents PCK) and assignment composing (represents AK).

To evaluate self-efficacy, the participants were asked to rate their knowledge on seven concepts related to the three chemistry topics (see Table 3). In each of the three questionnaires, they rated their level of knowledge on seven different concepts (see Table 3) on a Likert scale ranging from very low (1) to very high (5). We received Alpha Cronbach of at least 0.92 for all three questionnaires.

In an open-ended task that followed, the participants were asked to choose two of these concepts and explain them.

We determined the teachers' CK, PCK, and AK by applying the rubric for analyzing their responses from a variety of perspectives as shown in Fig. 1.

CK assessment. We determined participants' CK by analyzing three aspects of their explanations of the concepts: (a) subject

Table 3 Context-based articles: topics, titles, and concepts

Topic	Title	Chemistry concepts
Energy	*Hybrid bio-photo-electro-chemical cells for solar water splitting*[a]	Kinetic energy, fusion, burning, boiling temperature, speed of reaction, catalyst, spontaneous process
Acid–base	*Wastewater treatment of wine*[b]	Acid, base, indicator, pH, naturalization, neutral solution, hydroxyl ion
Oxidation–reduction	*Hydrogen fuel—hydrogen cars*[c]	Oxidation-reaction, electrochemical series, reduced, oxidizer, corrosion, electrolysis oxidation state

[a] (Pinhassi *et al.*, 2016; Kornienko *et al.*, 2018). [b] (Rupasinghe *et al.*, 2017; Raposo *et al.*, 2018). [c] (Newcomb *et al.*, 2017; Procházka *et al.*, 2018).

matter knowledge, (b) number of chemistry-related understanding levels used, and (c) visual presentation or other unique aspects incorporated. The highest possible score for CK is 5.

The CK scores received an inter-rater reliability of 85%.

For the second part of this phase, we used a context-based article related to sustainable chemistry (see Table 3).

Following is an example of a context-based article that was included in the Energy questionnaire.

Hybrid bio-photo-electro-chemical cells for solar water splittin

Researchers at the Technion have developed a bio-photo-electro-chemical (BPEC) cell based on spinach membranes. This BPEC cell preforms a simple process of water to produce H_2 fuel. It is a promising approach to provide clean and renewable energy, which still remains a big challenge. Natural photosynthesis conducting efficient solar-to-chemical energy conversion inspired the researchers, who come from three different faculties, to design and construct an artificial photosynthetic water splitting systems. This system splits water molecules into oxygen and protons, which are used to produce ATP molecules—the main energy carriers in the animal and plant world (the "fuel" of the cell). The process of photosynthesis occurs naturally in plant membranes.

In order to harness the cell for the production of photo-flow (solar current), the researchers added an iron ion solution. Iron ions mediate the passage of electrons from the membranes to the electric circuit and allow the generation of electric current in the cell. Alternatively, the current may be directed to create hydrogen gas by applying additional voltage from the rear of the photovoltaic cell. This approach demonstrates the idea of combining natural photosynthetic membranes and human-made photovoltaic cells to convert solar power into hydrogen fuel. This innovative hybrid system developed to solve one of the greatest challenges in renewable energy development: solar energy conversion and storage in hydrogen fuel. This energy can be converted to heat and electricity by burning hydrogen, like burning a hydrocarbon fuel. While in the combustion of hydrocarbon fuel, carbon dioxide (a greenhouse gas) is emitted into the atmosphere, the product of the combustion of hydrogen is clean water.

In conclusion, the system is a closed cycle that begins with water and ends with water, allowing conversion and storage of solar energy with hydrogen gas, which can be a clean and sustainable replacement for fossil, hydrocarbon-based fuel.

After reading the article, the pre- and in-service teachers were asked to pose questions and compose student classroom assignments, which enabled us to determine their PCK and AK, respectively.

For example, the participants received the following instructions after reading the context-based article above:

1. Formulate three questions you would like to ask the research team regarding this article.

2. Design assignments that incorporate chemistry and thinking skills for students who read this article.

The questions were revised slightly for each article based on its context.

None of the questionnaires explicitly stated that the context-based article was related specifically to sustainable chemistry, and the teachers were not asked to address this topic in their assignments.

Question posing is a key skill that ought to be included in any teaching process (NGSS Lead States, 2013), and can be associated with a teacher's pedagogical knowledge (PK). Moreover, considering that question posing is the first of eight key practices used by scientists and engineers, the ability to ask professional questions is an important skill that can reflect teachers' professional knowledge (CK). Hence, question posing on a context-based article integrates CK with PK, and can therefore represent the teacher's PCK level.

PCK assessment. We analyzed the questions posed by the participants using the three-criteria rubric presented in Fig. 1.

Each category had three levels with a maximum score of 9. In order to keep the scale of 1 to 5, we normalized the PCK scores, following which, the highest possible PCK score is 5.

The PCK scores rated by the three experts based on Dori and Herscovitz (2005) and Kaberman and Dori (2009) received 84% inter-rater reliability (Kottner *et al.*, 2011; Belur *et al.*, 2021).

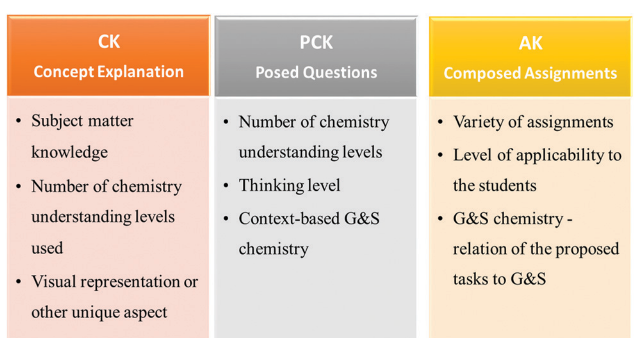

Fig. 1 Rubric for assessing participants' CK, PCK, and AK based on their questionnaires.

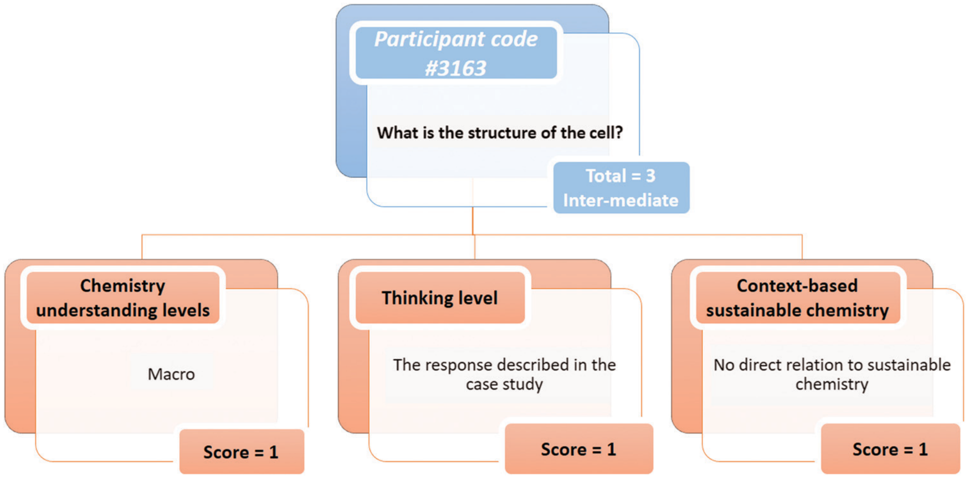

Fig. 2 A question posed by a pre-service teacher and its scores [#3163].

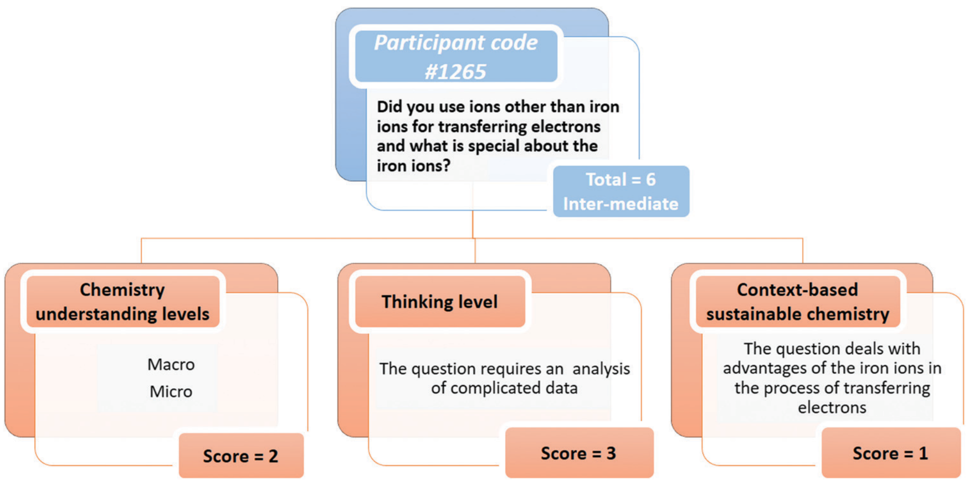

Fig. 3 A question posed by an in-service teacher and its score [#1265].

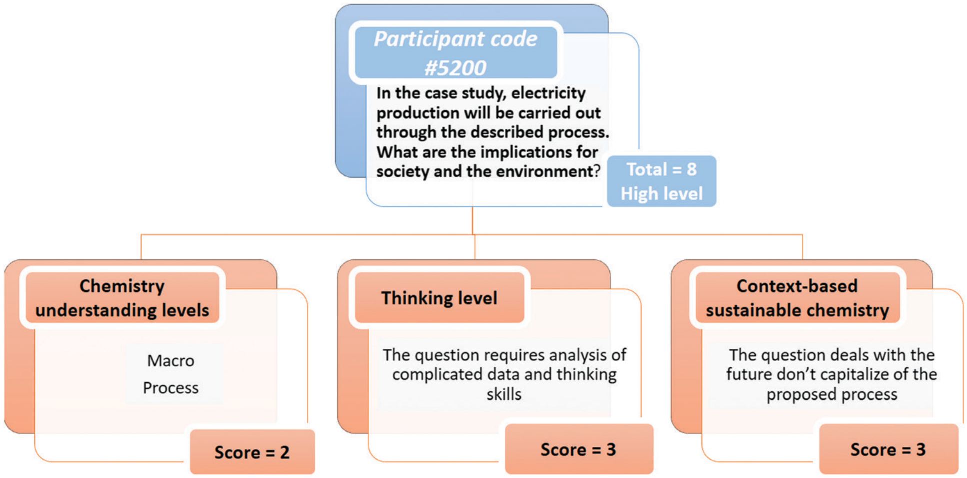

Fig. 4 A question posed by an expert teacher and its score [#5200].

Each criterion was ranked from 1 to 3, yielding a maximal score of 9, as follows:

• Number of levels of chemistry understanding: 1 – one level; 2 – two levels; 3 – three or four levels.
• Number of thinking levels:
  1 – The full answer to the question can be found in the case study.
  2 – Knowledge and understanding is required to answer the question.
  3 – A higher thinking level is necessary to answer the question, for example information analysis and application, drawing conclusions, inquiry questions, assessment, and critical thinking.
• Context-based sustainable chemistry material included in the question:
  1 – The question focuses on a technical issue unrelated to sustainable chemistry.
  2 – The question focuses on understanding the sustainable chemistry process that appears in the text, but is not directly related to sustainable chemistry.
  3 – The question focuses on advantages or disadvantages of the innovation, or other solutions related to sustainable chemistry.

Fig. 2–4 present examples of questions posed about the context-based article on energy and the scores that were given, for a pre-service teacher, an in-service teacher, and an expert teacher, respectively.

AK assessment. According to NGSS, students should have opportunities to employ the key practices. "*When students have the opportunity to 'do' science, they don't just learn facts and ideas; they learn to engage in complex scientific reasoning*" (NGSS Lead States 2013, P 7).

The NGSS authors emphasize that assessments should be used in the classroom as part of the day-to-day learning process. Consequently, it is very important for science teachers to be able to offer their students assignments related to specific chemistry subjects that require using one or more key practices. This observation was considered in the design of the rubric used to analyze the assignments composed by the participants.

The AK scores rated by the three experts based on Kaberman and Dori (2009) received 93% inter-rater reliability (Kottner *et al.*, 2011; Belur *et al.*, 2021).

This three-category rubric gives a score of 1 or 2 for each category, as follows:

• Varied activities and required thinking skills: 1 – All the proposed activities were of the same type and required only one type of thinking skill; 2 – A variety of activities were proposed that require diverse thinking skills.
• Level of adaptation and applicability to students: 1 – The activity was not adapted to the students' abilities; 2 – The activity can be applied by students.
• The relation of the proposed tasks to sustainable chemistry: 1 – There was no direct connection between the proposed activity and sustainability; 2 – The activity was based on sustainable chemistry.

Fig. 5 presents three examples of assignments that participants composed after reading the adapted article on oxidation–reduction.

Example 1 is an assignment composed by a pre-service teacher: "*Perform an electrolysis experiment with the students.*"

Example 2 is an assignment composed by an in-service teacher: "Write advantages and disadvantages of the proposed method for producing electricity. Ask the students to search the internet and

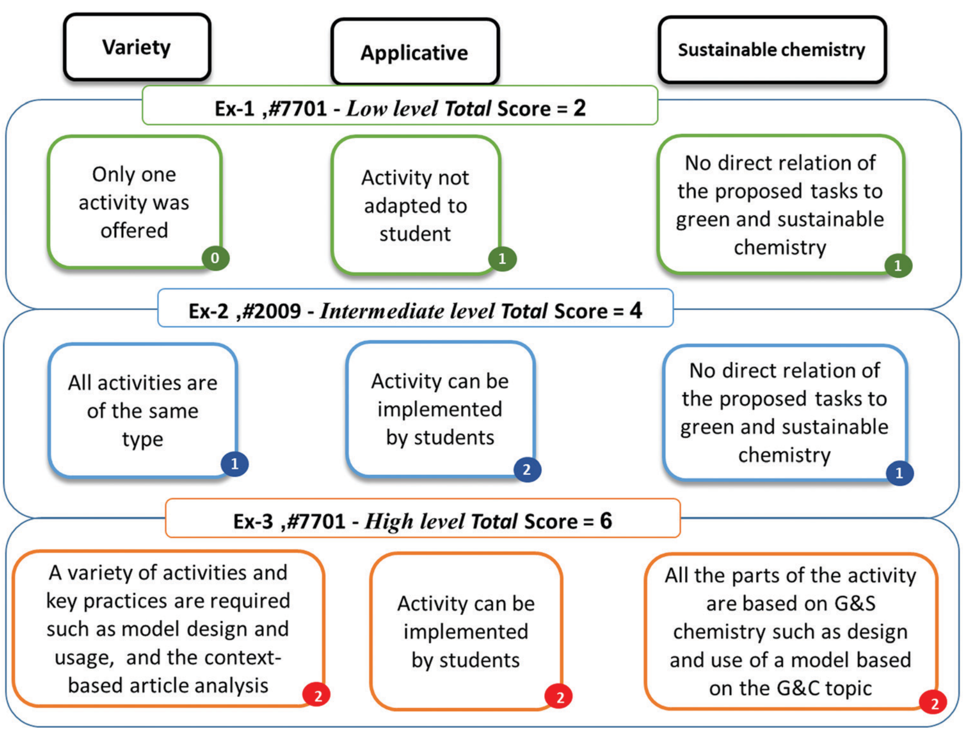

Fig. 5 Examples of assignments composed by participants on the oxidation–reduction context-based article, and the scores given for each assignment.

describe the importance of adding iron ions to the process. Is it used for oxidation or reduction, or another process?"

Example 3 is an assignment composed by a pre-service teacher: "Design a three-dimensional model to explain in a simple way how the described device works. Use the model to explain the following sentence: "All in all, it is a closed loop that starts with water and ends with water". Explain why the process is defined as a clean process? Why is it defined as a sustainable process?

Findings

The findings presented in this section address the two research questions: First, we refer to the pre-service teachers' (experimental group) knowledge types in the different questionnaires (pre, post and retention). Then, we describe the in-service teachers' (comparison group) knowledge types and compare the two groups.

Pre-service chemistry teachers' knowledge types

As noted, in RQ1 we asked: How do pre-service chemistry teachers develop the three knowledge types as they are exposed to sustainable chemistry context-based learning?

The pre-service teachers' knowledge was analyzed in the pre-post-, and retention questionnaires. Fig. 6 presents the averages score for the CK (6A), PCK (6B), and AK(6C) knowledge types in all three questionnaires answered by the pre- and in-service teachers.

Fig. 6 shows that the pre-service teachers' knowledge improved after the PD course and that their knowledge was retained two months after the end of the course, as demonstrated by the third questionnaire, oxidation–reduction.

We used the mean value of the seven terms in order to evaluate participants' self-efficacy. The mean value of the pre-service teachers' self-efficacy score was very high (4.4) in all three questionnaires.

As Fig. 6A shows, the CK values, which ranged from 2.6–3.1, were much lower, indicating a very large gap between self-efficacy and actual knowledge (CK) in each questionnaire.

A one-way ANOVA was conducted to compare the effect of the questionnaire topic on the pre-service teachers' average CK, PCK, and AK scores. The pre-service teachers' knowledge type was analyzed using the three questionnaires, Q-energy, Q-acid–base, and Q-oxidation–reduction, focusing on energy, acid–base, and oxidation–reduction, respectively. We found a significant difference between the teachers' PCK scores in these three questionnaire topics ($F(2,75) = 8.69$, $p < 0.001$).

Tukey HSB post-hoc comparison indicated that the teachers' PCK mean score of Q-energy ($M = 2.78$, SD = 1.33) was significantly lower than that of Q-acid–base ($M = 3.97$ SD = 1.21) and

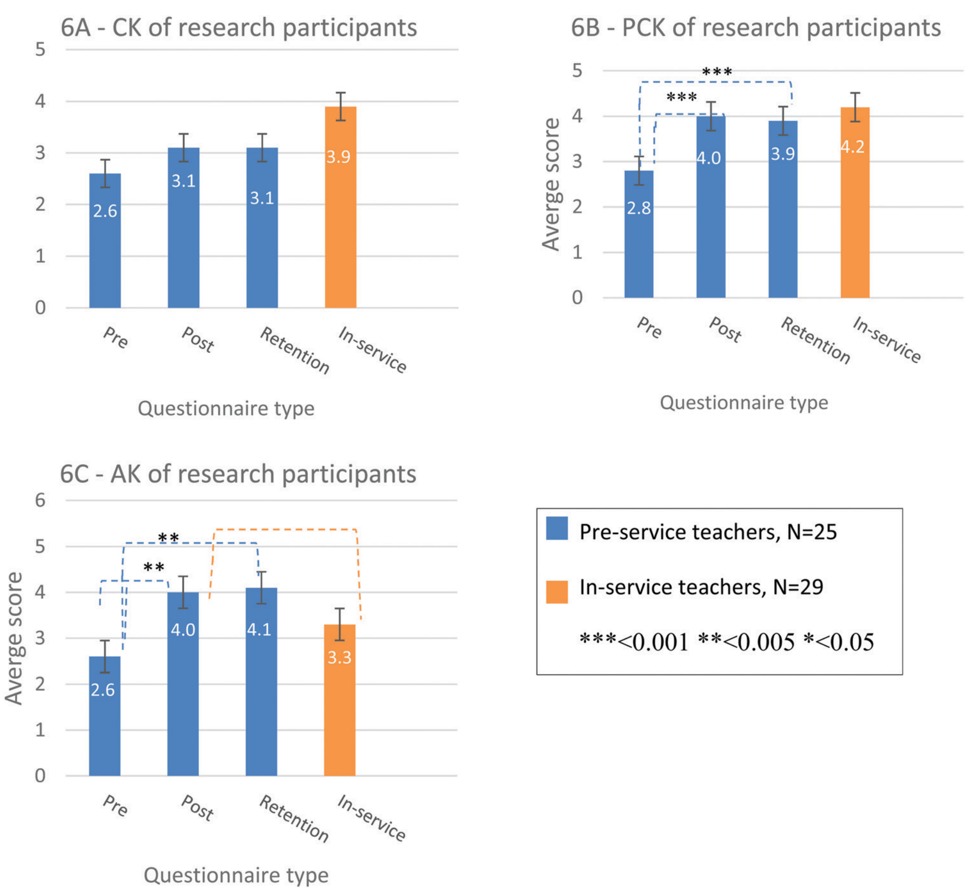

Fig. 6 The average CK, PCK, and AK of the pre-service teachers in the pre-, post-, and retention questionnaires and of the in-service teachers.

that of Q-oxidation–reduction (M = 3.93 SD = 0.83). No significant difference was found between the PCK of Q-acid–base and that of Q-oxidation–reduction. In addition, a significant difference in AK values was found for different questionnaire types ($F(2,75) = 10.91$, $p < 0.001$).

With respect to the AK mean score, Tukey HSB Post-hoc comparison indicated that the Q-energy score (M = 2.56 SD = 2.05) was significantly lower than that of Q-acid–base (M = 4.02 SD = 0.77), as well as than that of Q-oxidation–reduction (M = 4.13 SD = 0.65). No significant difference was found between the AK of Q-acid–base and the AK of Q-oxidation–reduction. The CK values were not significantly different ($F(2,75) = 1.38$, $p > 0.05$) between the three questionnaire topics.

In-service chemistry teachers' knowledge types

In order to respond to RQ2, this section focuses on the in-service chemistry teachers who participated in the research. Since these teachers served as a comparison group, we investigated their professional knowledge by determining their CK, PCK, and AK levels as well as their self-efficacy.

The in-service teachers' received very similar results on the three questionnaires, Q-energy (N_{teachers} = 10), Q-acid–base (N_{teachers} = 9), and Q-oxidation–reduction (N_{teachers} = 10), with average CK, PCK, and AK scores ranging from 3.9 to 4.0, from 4.0 to 4.4, and from 2.9 to 3.6 respectively.

Although their CK is incomplete, the in-service teachers rated their self-efficacy in the three questionnaires as very high (ranging from 4.4 to 5.0).

We conducted a one-way ANOVA to compare the effect of the questionnaire type on the in-service teachers' average CK, PCK, and AK scores. We found no significant difference between the case-based questionnaires in concept explanation (CK, $F(2,28) = 0.037$, $p > 0.05$), question posing (PCK, $F(2,28) = 0.48$, $p > 0.05$), and comparison assignments (AK, $F(2,28) = 0.59$, $p > 0.05$).

Comparison of knowledge types of pre- and in-service teachers

Fig. 6 presents compares the average scores for the various knowledge types of the pre- and in-service teachers. We calculated the average CK, PCK, and AK levels of the in-service teachers and compared them to the CK, PCK, and AK levels of the pre-service teachers in the three questionnaire types—pre, post, and retention. Since the number of participants in each questionnaire was low, statistical comparisons were conducted on the average CK, PCK, and AK of all the teachers in all the questionnaires.

The results showed that the CK of pre-service teachers was lower than that of the in-service teachers in each one of the three questionnaires (Fig. 6A). The PCK level of the pre-service teachers improved significantly, placing them virtually on par with in-service teachers (Fig. 6B). Fig. 6C shows that while in the Q-energy (pre-questionnaire), the assessment knowledge (AK) of in-service teachers was higher than that of the pre-service teachers, in the post-Q-acid–base and the retention Q-oxidation–reduction questionnaires, the AK level of the pre-service teachers was higher than that of the in-service teachers. To examine the differences between the CK, PCK, and AK values

Table 4 CK, PCK, and AK average scores and comparison between pre- and in-service chemistry teachers

		Pre $\bar{X}$ (SD)	In $\bar{X}$ (SD)	t	P
CK	En	2.58 (1.22)	3.94 (0.77)	−4.83	***
	Ac	3.07 (1.26)	3.94 (0.77)	−3.207	**
	Ox	3.14 (1.39)	3.94 (0.77)	−2.47	*
PCK	En	2.78 (1.33)	4.23 (0.93)	−4.72	***
	Ac	3.98 (1.21)	4.23 (0.93)	n.s.	
	Ox	3.93 (0.83)	4.23 (0.93)	n.s.	
AK	En	2.57 (2.05)	3.33 (1.47)	n.s	
	Ac	4.02 (0.77)	3.33 (1.47)	2.22	*
	Ox	4.13 (0.65)	3.33 (1.47)	2.35	*

*** <0.001, ** <0.005, * <0.05.

of pre- and in-service chemistry teachers, independent t-test samples were conducted. We found significant differences between the average score of the pre- and in-service teachers in CK, PCK, and AK (see Table 4).

Finally, we analyzed the percentage of respondents who addressed sustainable chemistry aspects in their questions and assignments after reading the context-based article. The percentage of pre-service teachers who designed assignments that focused on sustainable chemistry aspects was higher than that of the in-service teachers. The analysis of the pre-service teachers' responses showed that more than half of them related to aspects of sustainable chemistry in the questions they posed (58%) and in the assignments they designed (62%), while only half (50%) of the in-service teachers referred to sustainable chemistry aspects in the questions they posed, and even less (45%) in the assignments they suggested.

Summary and discussion

We investigated the development process of CK, PCK, and AK knowledge types of second-career pre-service chemistry teachers, and compared their knowledge to that of in-service teachers. This study contributes to the body of knowledge in chemistry education in several aspects. First, current literature (Shepard, 2000; Martinovic and Manizade, 2018; Ekiz-Kiran *et al.*, 2021; Schafer and Yezierski, 2021) discusses PCK and assessment either as the latter being part of the former or separately. Second, there are a few studies that measure quantitatively chemistry teachers' PCK (Park *et al.*, 2020; Chen and Chen 2021) in and one that measures AK in chemistry (Avargil *et al.*, 2012). Thirdly, this study contributes to narrowing the gap that exists in the literature between teachers' PCK and AK on the one hand and self-efficacy on the other hand.

Pre-service chemistry teachers' CK, PCK and AK development

Second-career pre-service teachers who begin their studies at the *Views* program are expected to have broad, solid chemistry knowledge and industrial experience that they gained while working in research institutes or in the industry. Nevertheless, we found that some of them graduated from their chemistry studies, a few decades ago while others indicated in the questionnaire that their specialty was water chemistry or organic chemistry. It is thus likely that the CK of many of the second-career pre-service teachers is focused on a very specific topic, but they lack deep, holistic understanding of chemistry in general. Therefore, at the beginning of the course, the average CK level of the participants was, perhaps not so surprisingly, quite low (2.6 of 5). Although they improved their CK level towards the end of the semester, their content knowledge remained incomplete.

The pre- and in-service teachers described their self-efficacy regarding their knowledge of the concepts addressed in the three questionnaires as very high. Although their CK improved during the course, the gap between their self-efficacy and CK scores was maintained in all the questionnaires. Yet, raising both pre- and in-service teachers' awareness of the gap between their CK and self-efficacy can improve teachers' metacognitive abilities.

Based on Avargil and colleagues (2012), we assumed that the improvement in CK occurred because the participants incorporated more levels of chemistry understanding, which improved their explanations of the concepts. As part of their professional growth, the pre-service teachers went through a metacognitive process of monitoring their answers as a subset of their changed beliefs regarding the overall chemistry teaching process (Kotul'áková, 2020; Popova *et al.*, 2020).

In each questionnaire, the pre- and in-service teachers were asked to pose questions and design assignments related to the context-based article that focused on one of three high school curriculum chemistry topics: energy, acid–base, and oxidation–reduction. As noted in the methods section, although all three context-based articles included topics related to sustainable chemistry, the participants did not receive explicit prompts about it.

The analysis of the findings from the Energy questionnaire, which the pre-service teachers received first, revealed that while the CK of some of these teachers reached the maximum value of 5, none of their scores reached 5 for PCK or AK.

Teachers' PCK and AK scores were initially in the medium range, around 3.1 out of 5, but they improved significantly by the end of the PD course and were retained two months later.

This finding is similar to that of Demirdöğen and colleagues (2016), who investigated a two-semester course based on PCK on the nature of science, aimed at enhancing pre-service chemistry teachers' science teaching orientations. They found that the orientation of the participants improved following the course, but they did not investigate other knowledge types or groups of second-career, pre-service teachers.

We found a significant effect of the time (pre, post, retention) at which the questionnaire was given on the average PCK and AK scores (see Fig. 6). The pre-service teachers significantly improved their question posing skills as well as the complexity level of the questions they posed. The improvements were retained two months after the PD course ended. The teachers' PCK and AK improved also due to their improvement in the awareness of sustainable chemistry, but this improvement was small. We assume that if the participants had been given explicit instructions to address sustainable chemistry, the improvement would have been greater.

CBL is very effective in science, especially when it is taught along with CBL prompts (Pabuccu and Erduran, 2016). Teachers' question posing and classroom assignment composition skills are not taught directly in the PD courses, but they are embedded in the various teaching methods. Therefore, the assumption is that these skills are acquired as part of the PD process. The same applies to the field of sustainable chemistry, which was not explicitly studied during the course, but some of the CBL discussed during the course was implicitly focused on this issue. This is in contrast with Haley and colleagues (2018), whose goals for the course were explicitly to expose both undergraduate and graduate students to the basics of sustainable chemistry.

Comparison between pre- and in-service chemistry teachers

For the in-service teachers, we observed no significant differences between the three case-based questionnaires in concept explanation (CK), question posing (PCK), or composing assignments (AK). These findings were expected, since the in-service teachers are usually familiar with all the chemistry topics we asked about due to their teaching experience. Moreover, the identical reliability level of the three questionnaires was validated in the pilot phase by expert teachers, and their scores were almost identical for all the questionnaires.

Although the in-service teachers rated their knowledge as very high, their CK was incomplete. Yet, the in-service teachers had significantly higher CK than the pre-service teachers. We assume that this is because while teaching these topics, the teachers are expected to be aware of all the aspects and subtleties of the subject matter.

Comparing the PCK levels of the pre- and in-service teachers, we found that the PCK of the pre-service teachers in the pre-questionnaire was significantly lower than that of the in-service teachers. However, the PCK level of the pre-service teachers improved significantly during the PD course and placed them on par with in-service teachers, as indicated by the post and retention questionnaires (see Fig. 6). Avargil and colleagues (2012) suggested using teachers' assignments as a diagnostic tool. The teachers' AK shows their ability to design and implement appropriate assignments for accurately assessing their students' knowledge and skills.

According to NGSS, assessments should be used in the classroom as part of the day-to-day learning process. As noted, teaching within a context that is suited to the students' world of content is very important for imparting scientific knowledge and skills. Combining these two assertions implies that assessment knowledge based on context-based learning is very important for a 21st century chemistry teacher. Moreover, chemistry teachers must master most, if not all, of the eight key practices required of scientists and engineers in order to give their students appropriate assignments that offer opportunities to apply these practices (NGSS Lead States 2013). Considering this, we used composing assignments as an AK indicator. As for the in-service teachers' AK, we found it to be lower compared to that of the pre-service teachers. We associate this finding with a higher level of understanding and novelty as represented in the variability we found in the assignments that the pre-service teachers composed. This can be related to the fact that the second-career pre-service teachers have experience with the practices of researchers and engineers, and therefore they have already mastered these skills better than the in-service teachers.

Assignments designed by in-service teachers sometimes included traditional calculations and exercises that were not related to the CBL topic and did not require higher order thinking skills. This is very unfortunate, because based on literature, students generally find context-based chemistry more interesting and motivating than traditional approaches (King, 2012; Pabuccu and Erduran, 2016).

Sustainable chemistry in context-based learning

Although the context-based article involved sustainable chemistry, most of the teachers did not include this aspect in the questions they posed or in the assignments they designed. Sustainable chemistry aspects were incorporated in the questions more by pre-service teachers than by in-service teachers. The same pattern was also in the assignments.

Despite the fact that the education system aspires to instill awareness of sustainable chemistry in the future generation, some teachers are not sufficiently aware of these topics and sometimes ignore them, since there are no explicit guidelines for focusing on them. We assume that the in-service teachers often composed very conservative assignments, based on a "fixed template" that does not require higher order thinking skills or familiarity with sustainable chemistry topics. This finding did not surprise us, because there is evidence in the literature that chemistry teachers tend not to compose assignments that evaluate students' higher order thinking skills, focusing instead on very traditional tasks entailing routine calculations and exercises (Tacoshi and Fernandez, 2014). Many teachers prioritize preparing students for matriculation or other standardized examinations. Whereas few studies have investigated all the teachers' knowledge types, we found that a low AK level does not necessarily imply a low PCK level.

Evidence suggests that studying sustainable chemistry topics increases the chances of recalling studied material, improving thinking skills, and helping to research and solve problems faced in daily life (Overton and Randles, 2015; Günter *et al.*, 2017). Yet, our findings suggest that chemistry teachers are not sufficiently familiar with aspects of sustainable chemistry and do not sufficiently incorporate them into the teaching process.

We found that the assessment knowledge of the in-service teachers was deficient. We must foster sustained innovation and variability in thinking among teachers in the education system. In light of the high AK of second-career teachers, we assume that they have great potential to contribute to the educational system, as well as to their in-service colleagues thanks to their experience in industry.

Though these conclusions are encouraging, we must emphasize that the contribution of second-career teachers needs to be evaluated over time, after they finish their education and when they begin to teach in the school system.

This will usher in a new era in science education, not only from the content point of view, but also from the perspective of variability and novelty in education. This is especially applicable in Israel, where environmental friendliness should be improved. Teachers with creative ideas for engaging students in environment and sustainability will contribute to improving the Israeli education system and society at large.

Our research has limitations, strengths, and contributions to literature on pre-service teachers' challenges and developments. The main limitation of this research is our group of pre-service teachers, which was not sufficiently diverse, as the study focused on second-career teachers. In addition, though the study's findings could indicate that second career teachers have the potential to strengthen the educational system in general and to chemistry education in particular by utilizing their industrial experience in their classroom. This effect should be researched over a longer period of time (Shwartz and Dori, 2020).

Our methodological contribution is the assessment tool we developed for identifying and quantifying various types of teachers' knowledge based on a context-based article related to sustainable chemistry. Our theoretical contribution lies in extending the PCK framework to include AK, and our methodological contribution is the assessment tool we developed for identifying various types of teachers' knowledge based on a context-based article related to sustainable chemistry. Our theoretical contribution lies in extending the PCK framework to include AK and their relationships to self-efficacy.

Conflicts of interest

There are no conflicts to declare.

Appendix

Appendix 1. a comparison of the terms self-concept and self-efficacy based on the literature

Term	Definition	Citations
Self-concept	*Self-concept is made up of the beliefs that one holds to be true about one's experience*	Pajares and Schunk, 2002, p. 2
	self-concept is informed by feedback from the environment as well as authority figures and peers	Gibbons and Raker, 2019, p. 600
	Self-concept is a person's perceptions of [them]self	Shavelson *et al.*, 1976, p. 411
	For the purpose of this study, we define chemistry self-concept as part of the motivational side of Scientific Literacy, being a student's perception of his or her abilities in chemistry	Rüschenpöhler and Markic, 2020, p. 210
	Self-concept is a construct that describes a person's perceptions of his/her self	Nielsen and Yezierski, 2016, p. 711

(continued)

Self-efficacy	*Self-efficacy defined as a person's beliefs about their ability to successfully perform a given task. Self-efficacy is associated with performance, persistence, and the willingness to try challenging tasks*	Villafañe *et al.*, 2016, p. 974
	"...self-efficacy, which is considered to be task-specific. Self-efficacy refers to a person's belief that s/he can accomplish a specific task, such as balancing a chemical equation, solving a stoichiometry problem, or following a laboratory procedure"	Nielsen and Yezierski, 2015
	Chemistry self-efficacy studies often refer to students' evaluations of their ability to do such things as solve chemistry problems and understand chemical concepts	Nielsen and Yezierski, 2016, p. 711
	"...the conviction that one can successfully execute the behavior required to produce the outcomes..."	Bandura, 1977, p. 193
Self-concept *vs.* Self-efficacy	*"Self-concept seems to indicate a more generalized perception of one's competence and self-worth and thus has limited utility in predicting specific task performance. If the goal of researchers is to predict students' performance on specific school tasks, assessing task-specific self-efficacy will provide better predictive precision"*	Bong and Clark, 1999, p. 151
	"...self-concept does not refer to a specific outcome as self-efficacy does. Self-concept is understood through an internal/external frame of reference mode" *"One key difference between is that self-efficacy is described as future-oriented while self-concept is based on past experience"*	Gibbons and Raker, 2019, pp. 600; 601

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