Special Issue Paper

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How green is green chemistry? Exploring the experiences and views of Turkish chemistry teachers on practical activities including green and sustainable chemistry

https://doi.org/10.1515/cti-2025-0037
Received May 4, 2025; accepted November 18, 2025; published online December 8, 2025

Abstract: Learning chemistry involves comprehension of chemical phenomena through practical activities. Chemistry teachers generally take various factors, including conditions and context, into consideration when integrating practical activities. In recent years, with the aim of having a more sustainable world, there has been a notable shift towards the adoption of green and sustainable chemistry (GSC) in practical activities. Therefore, this study aimed to investigate the experiences and views of chemistry teachers in Türkiye, regarding the practical activities, in general, and the ones focusing on GSC. In this mixed-method study, 206 chemistry teachers working at various types of high schools completed the International Teacher Survey on GSC Practical Activities. Subsequently, focus group interviews were conducted with teachers employed at the same school type. The survey responses were analyzed descriptively, and the focus group interviews were subjected to content analysis for further comparison. The findings indicated that chemistry teachers at science and private high schools implement practical activities more frequently than teachers at other schools. The challenges teachers face when conducting practical activities were categorized as *infrastructural, systemic, teacher-based*, and *student-based*. Finally, most teachers lacked knowledge and skills regarding GSC, and adopted *environment-centered, economy-centered* and *belief-centered perception* views in choosing GSC activities.

Keywords: green chemistry; sustainable chemistry; practical activities; chemistry teachers; ECRICE 2024

1 Introduction

Practical activities, in which the students are engaged in scientific practices are an essential part of science education across all levels of education as they help students in terms of cognitive[1] psychomotor,[2,3] and affective[4] gains. In the context of chemistry education, practical activities conducted in the laboratory facilitate students' comprehension of chemical phenomena through direct observation involving sensory perception and measurement.[5] Despite the numerous advantages of conducting practical activities, teachers encounter obstacles that limit their integration in chemistry classes. As the world is adopting more sustainable approaches, it is essential for chemistry teachers to adapt their practical activities to incorporate green and sustainable chemistry (GSC).

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Consequently, there is a continued need to investigate in-service chemistry teachers' experiences and perspectives on implementing practical activities in general, and those involving GSC.

1.1 Practical activities in chemistry education

Practical work in science education broadly refers to teaching and learning activities in which students, working individually or in small groups, engage directly with the material world or its representations, typically through experiments, investigations, or demonstrations.[2,6] Within this broad category, **practical activities** can be described as the specific tasks or exercises that learners undertake in the classroom or laboratory setting, such as conducting a titration, testing water quality, or designing a green chemistry experiment. While the term *practical work* is often used to emphasize the overarching pedagogical approach, *practical activities* highlight the concrete tasks through which this approach is realized. In this section, first the significance of practical work in science education, and then the role of practical activities in chemistry education will be discussed.[2,7]

The primary rationale for incorporating practical works in science teaching is rooted in the belief that it can serve as a catalyst for student motivation in the study of science.[8,9] In addition to 'affective arguments', other compelling reasons for incorporating practical works in school science teaching include skill development, fostering a deeper understanding of fundamental scientific concepts, and nurturing procedural knowledge for the scientific method and the nature of science[10] (p. 110).[2,7,11]

Since the 1960s, practical activities have gained prominence in science education, in general, and in chemistry education, in particular, as an essential technique for students to study natural phenomena and transfer their experiences to the real world.[9] Implementing laboratory practices to investigate chemical phenomena at the macroscopic level is important in chemistry education since students can connect to the submicroscopic and symbolic levels.[12] Practical activities in laboratory settings play a key role in the science curriculum by providing students with meaningful learning experiences,[1] developing interest and motivation towards science,[4,13] increasing their positive attitudes, and achievement[14] toward chemistry, developing their problem-solving skills,[15] and improving their understanding of the nature of science.[16]

From another perspective, it is claimed that laboratory practices develop multiple skills in cognitive, affective, and psychomotor domains, For instance, in a review study, Wellington[17] classified the rationale for practical activities into three domains: the cognitive domain, the affective domain, and the skills and processes domain. In the cognitive domain, practical activities develop students' understanding of the scientific process and allow them to explain and visualize theoretical knowledge. In the affective domain, practical activities motivate and interest students in science and help them retain their knowledge through meaningful learning. In the skills and processes domain, practical activities develop skills such as manual dexterity, which is a motor skill, as well as science process skills such as observation, measurement, prediction, and reasoning.[17]

Despite the significant role of practical activities on improving student learning and inquiry outcomes, Hofstein et al.[18] reported that teachers struggle to integrate laboratory (practical) activities efficiently and appropriately. Recent studies have reported the reasons behind insufficient integration of practical activities in chemistry classes; for instance, in a review study, Batı[19] examined 42 publications and summarized these problems under three headings: teachers feeling inadequate, deficiencies in the curriculum and textbooks, and finally, physical setting and material shortages. Although these problems have been identified in recent years, similar problems have been seen in previous years. For instance, teachers' poor attitudes toward laboratory applications and their negative beliefs and perceptions,[20,21] the intensity of the subjects in the curriculum,[22] and physical conditions and materials deficiencies[23,24] the insufficient length of lessons,[25] the failure to take adequate safety precautions in the laboratory environment,[26] overcrowded classrooms,[27] issues in classroom management,[28] lack of support from school administration,[22] and lack of in-service training[22] have also been listed among the reasons for the inability to conduct laboratory work.

Although there are limitations and problems perceived by the chemistry teachers, practical activities, which are said to be an effective method for understanding observable phenomena and improving science process skills as well as attitudes, are indispensable in chemistry lessons. Therefore, this study first aimed to reveal the current

situation regarding the implementation of practical activities in high school chemistry education in Türkiye, and then, to propose solutions for possible problems.

1.2 Green and sustainable chemistry in high school chemistry education

Dynamic and complex issues such as population growth and food consumption are damaging the environment and leading to unexpected unsustainable behaviors.[29] Therefore, there is an increasing emphasis on GSC practices to meet the needs of present and future generations and to preserve the ecosystem.[30] Green chemistry first emerged in 1996 as a solution to improve laboratory safety by decreasing hazards of chemical substances and modernizing the chemistry curriculum.[31,32] The initial efforts were concentrated on the integration of green chemistry principles into undergraduate chemistry laboratories,[33,34,35] and developing materials for the instructors, including textbooks[36,37] and lab manuals.[38]

There are recent attempts to integrate education for sustainable development based on the concept of green chemistry into high school programs. Occasionally, green chemistry is taught to high school students in a 2-week summer camp,[39] or in terms of a specific one-semester course on waste management.[40] In addition, green chemistry have been integrated to high school and general chemistry curricula via relevant and greener laboratory experiments,[41,42,43,44,45,46] mobile apps,[47] games,[48,49,50] digital tools,[51] concept map visualizations,[52] student generated presentation videos,[53] and case studies.[54,55]

The integration of GSC activities into the curriculum can pose significant challenges for chemistry educators, necessitating support and guidance from faculty mentors. In certain instances, chemistry instructors receive support in the form of a professional development program focused on integration of green chemistry[52,56,57] or through teacher-centered action research that incorporates authentic classroom practices.[58]

Whilst chemistry teachers may value and appreciate the need for a green and sustainable world, they may have divergent views on the implementation of GSC laboratories. For instance, following a series of workshops on green chemistry experiments, Malaysian chemistry teachers reported that green chemistry experiments are in accordance with the curriculum, are feasible to implement, possess the characteristics of encouraging inquiry, and are safe and relevant.[57] In Türkiye, there is a limited number of studies on the views of teachers on green and sustainability education, as seen in the bibliometric study conducted by Doğan et al.[59] However, there were some researchers who investigated the place of environmental education in the chemistry curriculum. Icoz[60] explored three chemistry teachers' views about to what extent the subjects related with environmental education should be integrated into high school chemistry curriculum. It was reported that there was a consensus among teachers on the inadequacy of the chemistry curriculum for providing students an effective environmental education.

For a sustainable future, it is important for chemistry teachers to incorporate GSC into their practical activities. Despite all the efforts of researchers to integrate GSC into high school chemistry, it was reported that there is a limited amount of work conveying the experiences and perspectives of in-service chemistry teachers, and that more work with in-service teachers is needed.[54] There is also limited research on whether teachers actually implement GSC in the school environment and what practical activities they implement if they do.[61]

This study focused on investigating chemistry in-service teachers' views and experiences on practical activities including GSC, working at different types of schools, that will shed light on the needs of teachers for educating the next generation in a more sustainable world.

1.3 Theoretical framework

The theoretical framework of this study is based on variation theory. Variation theory is "a theory of learning and experience that explains how a learner might come to see, understand, or experience a given phenomenon in a certain way"[62] (p. 3391). According to variation theory, people's experience of a phenomenon depends on the particular features we focus our attention on, and different people's individual experiences of that phenomenon

explain it differently. Therefore, this study aims to explore the extent to which the principles of GSC are adopted by teachers and the perceptions of chemistry teachers towards GSC.

1.4 Significance of the study

Although many studies have examined the concepts, typologies, and objectives of practical activities, only a small number have focused on practicing science teachers.[63] Therefore, to address this gap, IUPAC funded a project called "International Teacher Survey on Green and Sustainable Chemistry (GSC) Practical Activities",[64] which collected data from different countries to explore the current status of chemistry teachers. This project specifically aims to investigate the extent to which chemistry practical activities are carried out in schools, and the experiences and opinions of teachers regarding the adoption of GSC principles in laboratory practice. Therefore, the present study is supported as part of this international project by presenting the practical activities, experiences, and views of chemistry teachers working in different cities and school types in Türkiye regarding GSC.

There are several reasons for investigating practical activities related to GSC in Türkiye. First, the importance of GSC has grown in the face of rapidly diminishing natural resources and increase in environmental pollution, all over the world. Therefore, the views of teachers on laboratory practices involving GSC need to be investigated in depth for the effective implementation of practical activities.[18] Second, the inclusion of GSC in the 9th grade chemistry curriculum in 2024,[65] which has not been specifically emphasized in the chemistry curriculum in the Türkiye context before, is an important innovation in terms of its alignment with global sustainable development goals. This study makes a unique contribution to the Turkish chemistry curriculum by presenting the current situation and identifying the needs before its implementation.

In addition, in Türkiye, there exists different types of high schools; namely *regular* (named as Anatolian, in Turkish context), *science, private, vocational*, and *religious* high schools. Despite the variations in the backgrounds and needs of the students, there is only one national chemistry curriculum that is implemented in all school types. On the other hand, the needs of the students in each school type which are usually chosen by the students and/or parents would vary. For instance, the students in science high schools usually plan to study in STEM (Science, Technology, Engineering, Mathematics) fields so the enacted chemistry curriculum might change accordingly. Although the teachers don't have different preparation depending on school type, they attend in-service programs or participate in different projects to enhance their pedagogical content knowledge.

Investigating chemistry teachers' experiences, barriers, challenges, and views in implementing practical activities in general, as well as the integration of GSC topics is important to ensure effective implementation of the curriculum in different school types. The results of this study will shed light on efforts to support teachers' knowledge and competencies related to practical activities. In addition, according to the views of Turkish high school chemistry teachers, efforts will be made to improve educational policies by developing strategies by identifying infrastructure and resource problems in education. This study aims to identify the experiences and views of Turkish high school chemistry teachers who are working in different types of high schools on practical activities including GSC. This study is guided by the following three research questions:

1. What are the experiences of Turkish chemistry teachers who are working in different types of high schools, in implementing practical activities?
2. What are the views of Turkish chemistry teachers who are working in different types of high schools, on practical activities of chemistry?
3. What are the views of Turkish chemistry teachers who are working in different types of high schools, on the practical activities focusing on GSC?

2 Methods

2.1 Research design

This study adopted an explanatory sequential mixed methods research design in which quantitative data are collected followed by qualitative data, allowing for a deeper understanding of the phenomenon under investigation, broadening and deepening the overall picture of the problem.[66] The rationale for using this design in this study was to examine high school chemistry teachers' experiences and views on practical activities as well as GSC, first from a general perspective, and then to explore those more in depth.

2.2 Participants

The 206 participants, who took the GSC Survey in this study, were teaching in 31 different provinces from seven geographical regions of Türkiye, and almost half of them (n = 100) were teaching in Istanbul, a metropolitan city in Türkiye. As shown in Figure 1, a large number of the chemistry teachers were working in regular high schools (n = 70) and another higher number of teachers indicated that they work in private high schools (n = 47), these ratios seemed very similar to the distribution of chemistry teachers in Türkiye since the number of regular high schools is more than the number of other types of schools.[67]

The participating chemistry teachers had varying teaching experiences, with the majority of them, (n = 87) had 16–30 years of teaching experience, followed by those with 6–15 years of teaching experience (n = 68) and very few (n = 3) were in their first year of teaching, as shown in Figure 1.

It was also observed that the chemistry teachers were teaching different grade levels. 186 of the participants were currently teaching 9th–10th grade chemistry, 157 were teaching 12th grade chemistry, 156 were teaching 11th grade chemistry, and 8 were teaching 7th–8th grade science.

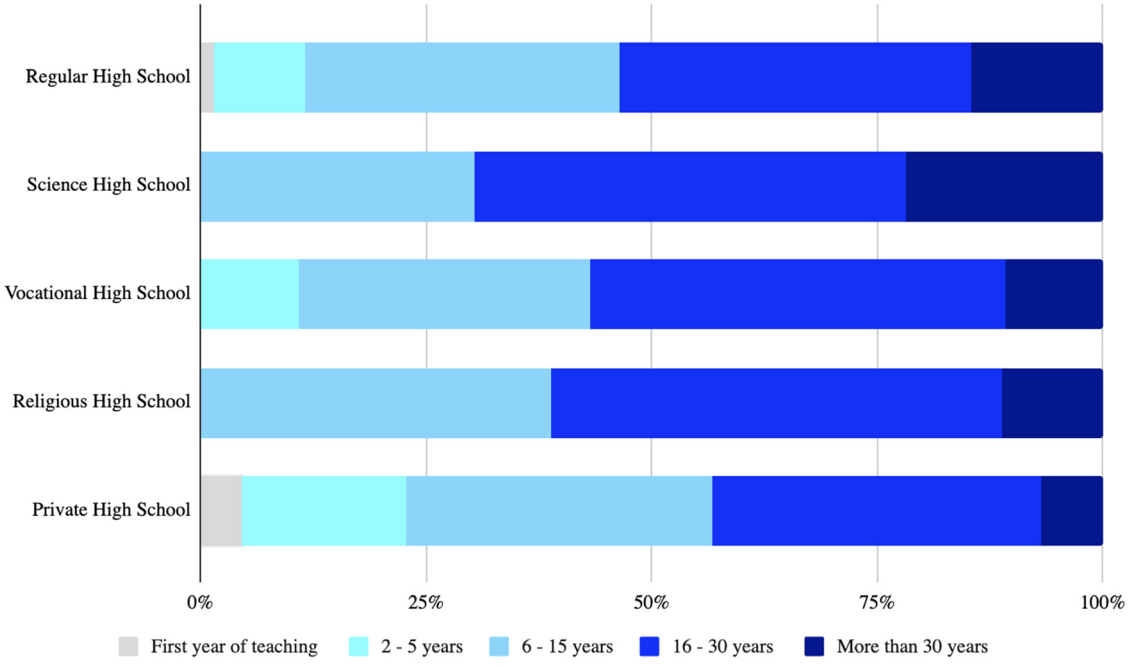

Figure 1: Participant demographics by year and school type.

2.3 Procedure

The Turkish project coordinators, who are the first and the fourth authors of this paper, adopted the GSC survey into Turkish to contribute to this international effort by collecting data from Türkiye. It was administered to 206 high school chemistry teachers working in different school types in Türkiye between November 2023 and August 2024. In addition, eight focus group interviews were conducted between August 2024 and March 2025 to better understand their experiences and views on practical activities. Two focus group interviews were conducted with regular high schools and private high schools, while one focus group interview was conducted with each of the remaining high school types, considering their distribution in Türkiye. Chemistry teachers who taught in the same type of schools were interviewed in focus groups of three, with the idea of grouping them according to similar teaching conditions. A total of 24 chemistry teachers were interviewed on an online platform while video recording.

2.4 Data collection tools

2.4.1 Green and sustainable chemistry survey (GSC)

The GSC survey, which was the first data source in this study, consists of three sections: 1) Demographic data, 2) Chemistry practical activities, and 3) GSC practical activities.[61]

In the demographic data section, there are multiple-choice questions about graduate degrees, years of experience as a chemistry teacher, and subjects currently taught. In the Chemistry Practical Activities section, there are two survey questions and two open-ended questions. It is asked about the typical chemistry class and the importance of each of the factors in the choice of chemistry practical activities in class. Open-ended questions ask what factors are important in choosing practical activities and what factors prevent practical chemistry activities from being used more often in the classroom. In the last section of the GSC survey, which focuses on Practical Activities, it is asked about the importance of factors and resources of chemistry practical activities related to green chemistry and/or sustainable chemistry explanation of their specific example, additional resources, and challenges about chemistry practical activities or sustainability in their teaching. The full Turkish adaptation of the GSC survey is included in the SF-Table 1 (see Supplementary File).

2.4.2 Focus group interview protocol

The IUPAC GSC Questionnaire Focus Group Interview Protocol was developed in parallel with the GSC Survey. The focus group interviews aimed to obtain more detailed information about the chemistry laboratory practices that chemistry teachers use in their classrooms. The focus group interview protocol consisted of three sections: 1) Introduction, 2) Chemistry Laboratory Practices, 3) GSC Laboratory Practices.

It was designed to elicit the participants' experiences and views about the laboratory practices they implement, why they choose these practices, and what principles of green chemistry and sustainability they consider in their practical activities. The English and Turkish versions of the questions used in the focus group interviews can be found in SF-Table 2 and SF-Table 3 (see Supplementary File).

2.5 Data analysis

GSC Survey responses were obtained from the IUPAC project's use of the online survey software *Qualtrics*.[64] Frequencies of survey responses were calculated and descriptive results were visualized. Video-recorded focus group interviews were transcribed verbatim. The codes emerged from the focus group interview were refined by two chemistry education researchers and reviewed by another researcher. The agreed codes are extracted,

categorized, and tabulated. The categories and codes for the Views on Practical Activities are shown in SF-Figure 1, and those for GSC are shown in SF-Figure 2 (see Supplementary File).

3 Results and discussion

In this section, the findings are presented with respect to the research questions in the light of two main data sources: GSC Survey and Focus Group Interviews.

3.1 RQ1 What are the experiences of Turkish chemistry teachers who are working in different types of high schools, in implementing practical activities?

The experiences of high school teachers were investigated in terms of the frequency of having different types of practical activities, including performing a chemistry experiment, making a demonstration in front of the class, having students interact with a simulation, showing a video or an animation, as well as providing students experimental data to analyze.

3.1.1 Performing chemistry experiments

It was observed that having students conduct an experiment in the laboratory "once per month" was the most common condition for the private (54 %) and science high schools (HS) (50 %), whereas "few times a year" was the

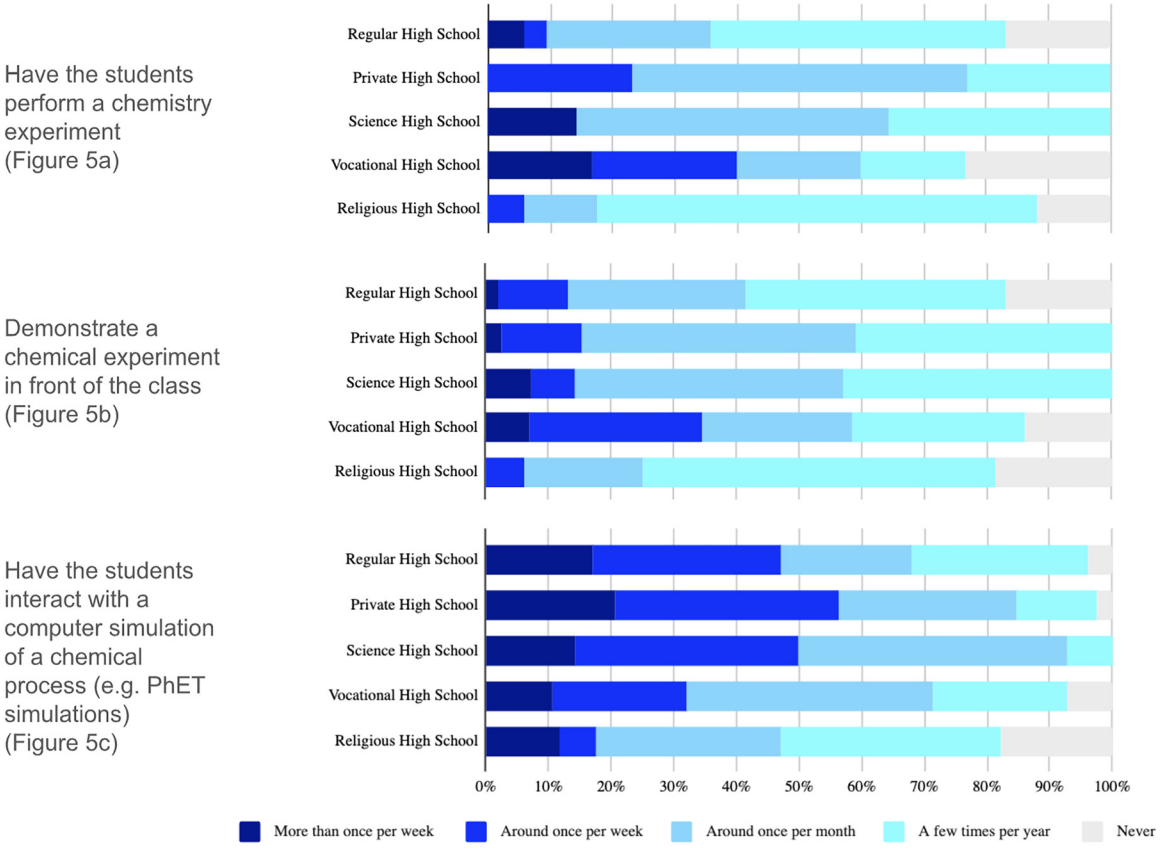

Figure 2a–c: Proportion of teachers indicating how often they typically undertake a particular activity in their chemistry, for each school type. a: Have the students perform a chemistry experiment, b: Demonstrate a chemical experiment in front of a class, c: Have the students interact with a computer simulation of a chemical process.

most typical condition for the regular (47 %) and religious HS (71 %). Vocational high school teachers responded with a range of answers from more than once per week (17 %) to never (23 %) as seen in Figure 2a.

Therefore, it was observed that the chemistry teachers working at private and science high schools were more inclined to have the students conduct experiments more frequently than the ones at other types of schools. This situation was also observed during the focus group interviews. The chemistry teachers working at private schools explained their frequency of having students conduct experiments in the laboratory, as follows:

> *In 9th and 10th grades, much more laboratory and activity-based work can be integrated into the lesson, it works very well with these students.* (Selecting the type of the practical activity, Teacher from private HS)

> *If a precise work is not required, I generally try to use daily life materials. For example, while discussing gas laws, the pressure-volume relationship, in the 9th graders, we were able to use the marshmallow experiment and we saw that the students were able to achieve the outcomes.* (Strategy of using chemistry experiments, Teacher from a private HS)

3.1.2 Performing chemistry demonstrations

Due to some of these challenges that the teachers face, they prefer to demonstrate the experiment in front of the class instead of having students perform practical activities. It was observed this was a more typical activity for science and private high school teachers answered that they demonstrate a chemical experiment in front of the class either around "once per month" (43 %, each) or even more frequently, "once per week" (43 % and 41 %, respectively). Most of the teachers working at religious (56 %) and regular HS (42 %) responded that they demonstrate a chemical experiment in front of the class mostly "a few times per year". In addition, vocational high school teachers responded with a wide range of answers from "once per week" (28 %) to "never" (7 %) (see Figure 2b). In the focus group interviews, the reasons for performing such a demonstration were closely related with the reasons for not being able to have students perform an experiment. The following quotations taken from the focus group interviews convey the experiences and reasons of chemistry teachers regarding performing the in-class demonstrations.

> *There was only 70 centimeters of space for each student. I had to do the titration as a demonstration to show them.* (Lack of infrastructure, Teacher from regular high school HS)

> *We do this more depending on the content of the topics and the context of the class. For instance, in the 10th grade, I usually ask one student to prepare a mixture and show it to the [class].* (Classroom management, Teacher from regular HS)

3.1.3 Utilizing computer simulations

Despite the underpinning role of practical activities in learning chemistry, some teachers might prefer utilizing computer simulations depicting a chemical process at the submicroscopic level. Therefore, in the GSC survey chemistry teachers were also asked to rate their frequency of using simulations while teaching chemical phenomena. Another common practical activity is to have students interact with a computer simulation. This activity seemed to be commonly implemented by the science high school teachers and private high school teachers who responded that they had students work with a computer simulation of a chemical process mostly either about "once a week" (36 % for each) or about "once a month" (43 % and 28 %, respectively). In contrast to the aforementioned groups, the majority of regular high school chemistry teachers reported that their students engage with a computer simulation of a chemical process on a weekly basis (30 %) or monthly basis (21 %). While vocational high school teachers responded that they provided students with a computer simulation of a chemical process mostly around "once per month" (39 %), religious high school teachers mostly performed it "a few times a year" (35 %) (see Figure 2c). In focus group interviews, the experiences of teachers in implementing simulations seemed to include their reasons for selecting simulations or their strategies of using them, as seen in SF-Figure 1

(see Supplementary File). The following quotations, extracted from the focus group interviews, articulate the experiences of chemistry teachers considering the utilization of computer simulations for student engagement.

> *I use the PhET simulations, but since our laboratory facilities are quite convenient, we give priority to the laboratory.* (Prioritizing laboratory over simulations, Teacher from private HS)

> *We also have shortcomings. I saw that on my own behalf. If we improve ourselves a little bit more, it definitely attracts more interest and attention from the students.* (Conditions limiting the use of practical activity, Teacher from religious HS)

> *Like flipped learning, we share related tasks, which can be animations, simulations or videos of experiments that students can work on. Before the class, they gain awareness about the subject and then we make an introduction to the subject.* (Strategy of using simulations – flipped learning, Teacher implementing IB curriculum)

3.1.4 Playing experimental videos

The macroscopic level of chemistry can also be presented by playing an experimental video and some teachers prefer to do so by having students watch it instead of working on it. When the chemistry teachers were asked to rate their frequency of having students watch an experimental video of a chemical reaction or experiment being conducted by someone else, various ratings were observed as seen in Figure 2d. This activity was more common among science high school teachers as the majority of them responded to this activity by stating that they were showing an experimental video about "once a week" (54 %). The chemistry teachers working at vocational, religious, and private high schools typically said they show the videos "once a month" (45 %, 41 % and 40 %, respectively). It was a less commonly preferred activity for the chemistry teachers working at regular high schools as the majority of them show an experimental video "a couple times a year" (33 %) or "once a month" (29 %). When this situation was asked during the focus group interviews, they mostly agreed showing experimental videos as an alternative for conducting experiments in case of limited use of experimental activities. The following quotations of chemistry teachers convey this situation.

> *In 9th grade, we actually follow the new curriculum. At the beginning of the year, for example, there was the aluminum foil experiment, and of course, the laboratory was not very suitable at that time. We turned on the video of it, and we showed it [in class].* (Selecting the type of the practical activity, Teacher from private HS)

> *Water and life, the diminishing water in dams, the importance of water, but how can we use a non-toxic tablet in the dishwasher? There are comparative videos of these. I can't do [these as experiments], but at least I can send a video of it.* (Strategy of using videos, Teacher from vocational HS)

3.1.5 Playing particulate-level animations

The observation of a task on a board screen was not confined to the experimental videos; as chemistry teachers also incorporated particulate-level animations of the chemical phenomena in their teaching. In this type of activity, chemistry teachers working at private and science high schools reported that they show animations around "once a week" (33 % and 31 %, respectively). For the teachers working at regular, vocational and religious high schools, the most typical condition of playing a particulate level animation was "a few times a year" (32 %, 39 %, and 53 %, respectively) (see Figure 2e). During the focus group interviews, it was observed that there were various instances that served to underscore the experiences of chemistry teachers in regard to the showing of animations. The following quotations taken from chemistry teachers illustrate these instances.

> *The new generation of students are doing things very fast. The animation that I occasionally show in the 9th and 10th grades almost completely replaces the laboratory in the 11th grade."* (Selecting the type of the practical activity, Teacher from regular HS)

> *In our school, we couldn't use the laboratory because we didn't have that opportunity, but instead I was continuing with animations, using YouTube and things like that.* (Prioritizing animations over laboratory, Teacher from regular HS)

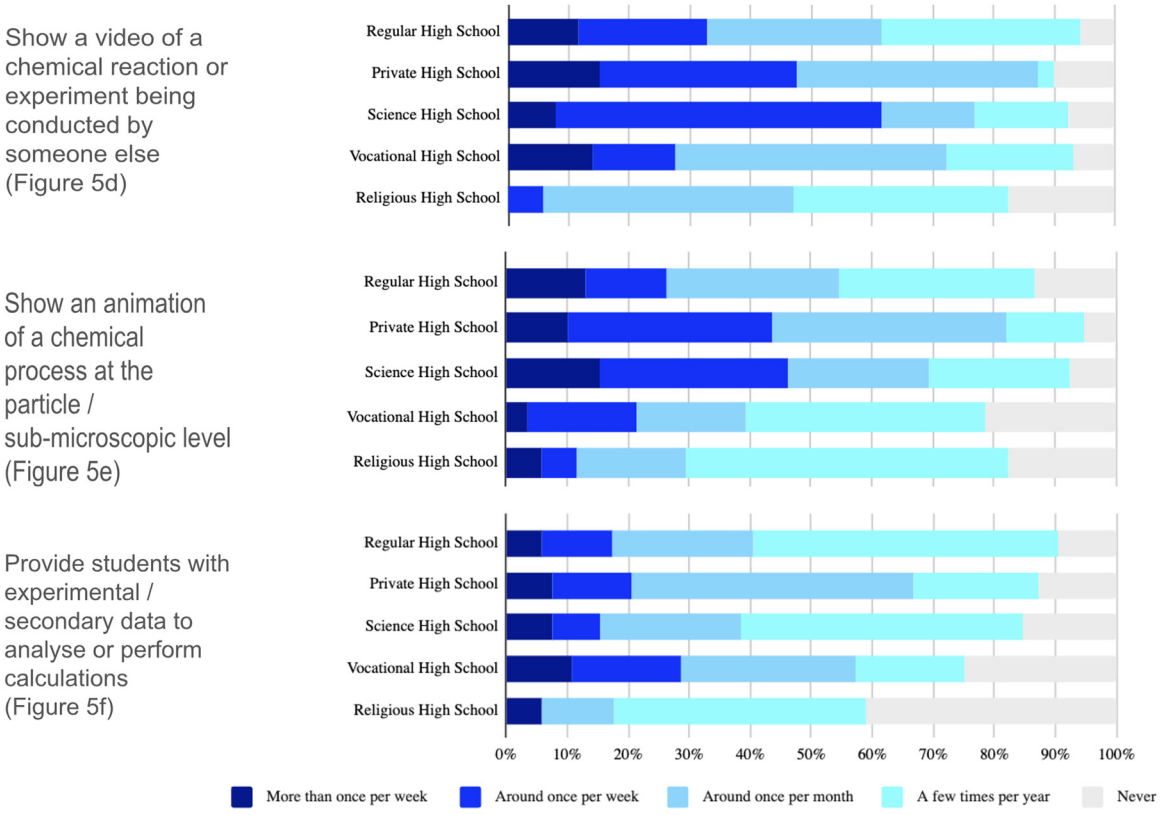

Figure 2d–f: Proportion of teachers indicating how often they typically undertake a particular activity in their chemistry, for each school type. d: Show a video of a chemical reaction or experiment conducted by someone else, e: show an animation of a chemical process at the particle/sub-microscopic level, f: provide students with experimental/secondary data to analyse or perform calculations.

3.1.6 Utilizing experimental data

Another way of engaging students with the experimental work is providing them with the experimental data while letting them examine, analyze and drive conclusions. When the chemistry teachers were asked to rate the frequency of conducting such an activity, it was observed that was not very common, as seen in Figure 2f. The chemistry teachers working at regular, science, and religious high schools (50 %, 46 % and 41 %, respectively) responded that they typically provide students with experimental/secondary data to analyze or perform calculations “a few times a year”. It seemed to be a little bit more common for the teachers working at private and vocational high school teachers (46 % and 28 %, respectively) as they generally responded about “once a month” (46 %). During the focus group interviews, it was observed that this was a more common activity for the teachers implementing IB curriculum.

> *In fact, this is what we did during the pandemic period: we conducted the experiment in the laboratory, filmed it and presented it to the students in class. We asked them to analyze it at work and write a laboratory report. It does not necessarily have to be an experiment.* (Strategy of using experimental data, Teacher implementing IB curriculum)

> *We are trying to make it a little more permanent or to make concepts that seem very abstract a little more concrete. Experiments are conducted, skills are developed, but on the other hand, how to interpret data, how to record data, how to read a table or how to create a graph, how to draw it, how to interpret the graphs there? These are also expected by IB.* (Strategy of using experimental data, Teacher implementing IB curriculum)

All in all, it was observed that chemistry teachers working at different school types were using various activities ranging from engaging students actively involved in conducting experiments to letting them watch the

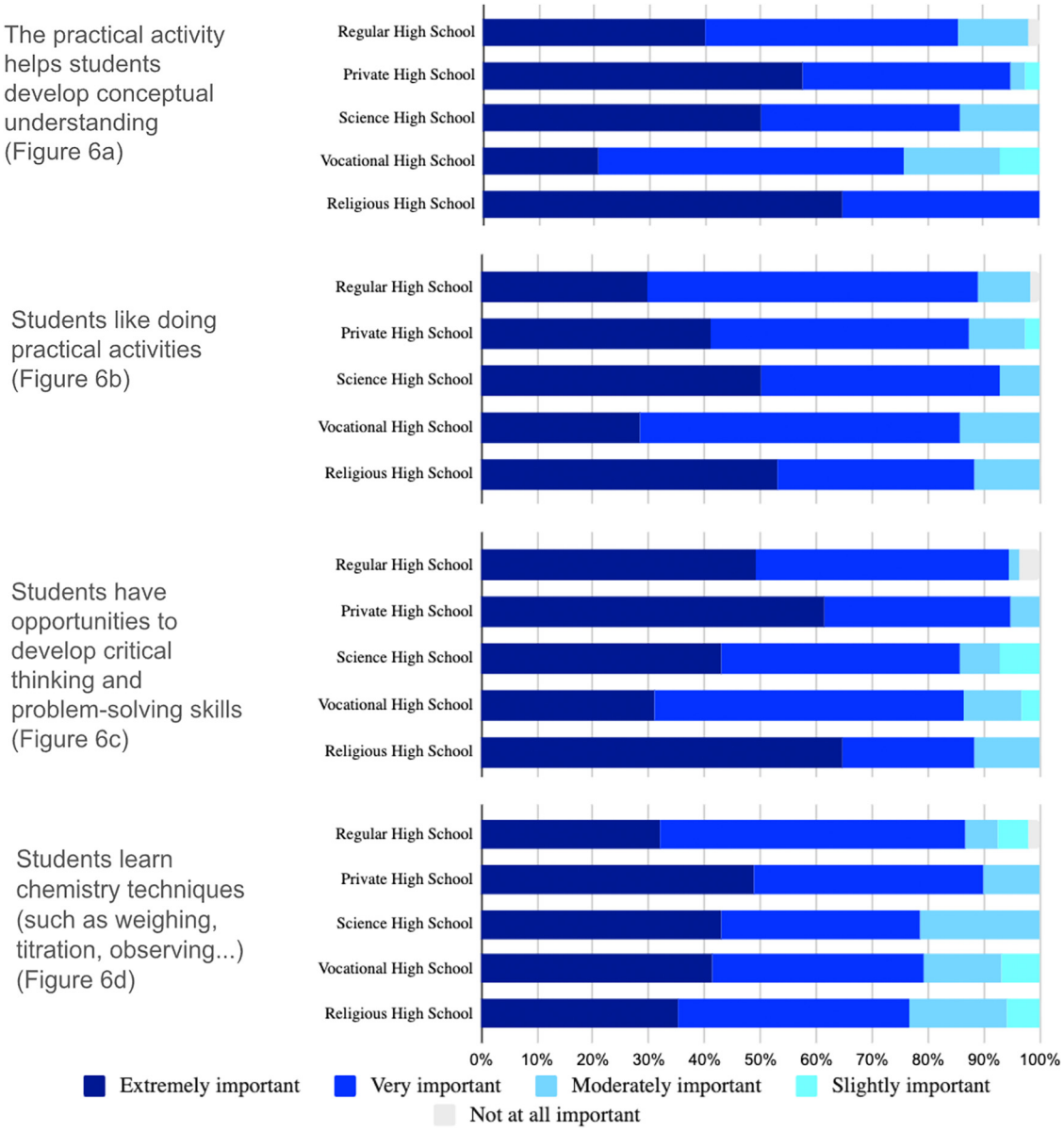

Figure 3: Proportion of teachers indicating how often they typically undertake a particular activity in their chemistry, for each school type. a: The practical activity helps students develop conceptual understanding, b: Students like doing practical activities, c: Students have opportunities to develop critical thinking and problem-solving skills, d: Students learn chemistry techniques (such as weighing, titration, observing).

experiments or particulate-level animations on the screen, at different frequencies, depending on the conditions at their schools.

3.2 RQ2 What are the views of Turkish chemistry teachers who are working in different types of high schools, on practical activities of chemistry?

This research question was first considered based on the views of chemistry teachers who are working at different types of schools, regarding the manner in which practical activities contribute to students' development

across diverse academic domains. Secondly, their views regarding the factors preventing them conducting laboratory experiments were also examined.

As depicted in Figure 3a–d, chemistry teachers' perspectives on the extent to which the practical activities contribute to student development are summarized. Although the teachers were queried on a broader array of dimensions in the GSC Survey, the present study has chosen to focus exclusively on those dimensions that received the highest ratings, with the objective of maintaining a concise and focused analysis.

3.2.1 Helping students develop conceptual understanding

In the GSC Survey, the majority of chemistry teachers, regardless of their institution type, expressed a high value of practical activities in fostering conceptual understanding, as seen in Figure 3a. In this sense, while the chemistry teachers in the religious, private and science high schools (65 %, 58 %, and 50 %, respectively) consider conceptual understanding as an "extremely important" factor when selecting chemistry practical activities for their class, the teachers in vocational high school (55 %) and regular high school (45 %) consider it as a "very important" factor. The following quotations from chemistry teachers, obtained during the focus group interviews, convey their views on the importance of practical activities, specifically experiments and simulations, for conceptual understanding.

> *Chemistry requires manual skills and observation, which is more permanent through experiments. When s/he does it herself/himself and combines it with visuals, s/he actually understands chemical reactions. That's why it is very important.* (Conceptual understanding – Experiments, Teacher from regular HS)

> *Even if we do an experiment, we need to support it in a simulation to make sense of the interactions. I think augmented reality or web-based simulations increase the student's learning very much.* (Conceptual understanding – Simulations, Teacher from private HS)

3.2.2 Helping students develop critical thinking and problem-solving skills

As determined by most of the chemistry teachers, practical activities were also valued for helping students develop higher order thinking skills, such as critical thinking and problem solving. Figure 3b shows the importance of these transferable skills in the selection of chemistry practical activities. In the GSC survey, it was observed that the majority of the chemistry teachers in religious, private, regular, and science high schools (65 %, 61.5 %, 49 %, and 43 %, respectively) were most likely to consider it "extremely important" while the majority of the chemistry teachers (55 %) working at the vocational high school consider it "very important". The following quotes from chemistry teachers interviewed in the focus groups illustrate how they view the importance of practical activities, specifically of experiments and simulations, for developing transferable skills.

> *We prefer experiments where they can actually make observations, collect qualitative or quantitative data, draw conclusions from the data and interpret the results critically.* (Critical thinking – Experiments, Teacher from private HS)

> *Simulations can facilitate the student's ability to better analyze, interpret, discover or connect with something else at the particle level* (Critical thinking – Simulations, Teacher from private HS)

3.2.3 Helping students learn experimental techniques of chemistry

Chemistry teachers also rated the factor of learning experimental techniques as another important factor in selecting practical activities. While the teachers working at private, science, and vocational high schools (49 %, 43 %, and 41 %, respectively) considered chemistry-centered student learning factor "extremely important" for students to learn chemistry techniques (such as weighing, titrating, observing, etc.), teachers in regular and religious high schools (55 % and 41 %, respectively) considered it "very important" (see Figure 3c). The following quotations show how the teachers emphasized the importance of learning the experimental techniques of chemistry for students.

The student should at least know how to make a titration, how to keep it running (Laboratory technique, Teacher from regular HS)

Students confuse the burette and the pipette a lot, both are long and thin, one with a stopcock, one without a stopcock. They confuse the round bottom flask with the volumetric flask. I found it very useful in this regard. (Laboratory equipment use, Teacher from regular HS)

3.2.4 Enhancing students' motivation

One final factor that was found to be also quite important by the chemistry teachers who answered the GSC survey was the motivational aspect. Specifically, the teachers were asked to rate the following factor: "Students like doing practical activities". Teachers in religious and science high schools (53 %, and 50 %, respectively) consider student enjoyment of doing practical activities as an "extremely important factor" when selecting chemistry practical activities to do with their class. Similarly, teachers in regular, vocational, and private high schools (59 %, 57 %, and 46 %, respectively) consider it as a "very important" factor (see Figure 3d). During the focus group interviews, they explained this factor for different practical activities.

Even very simple experiments could have a huge impact on students' motivation (Motivation – Laboratory experiments, Teacher from regular HS)

Virtual laboratory applications attract students' attention more (Motivation – Virtual laboratory, Teacher from regular HS)

3.2.5 Factors preventing teachers conducting laboratory experiments

Even though it is a very well-known fact that having students engaged with chemistry experiments in the laboratory is important in learning chemistry, there are various factors preventing teachers conducting laboratory activities. In the GSC Survey, teachers were asked what factors prevent them from using chemistry practical activities more often in their classes. The chemistry teachers in all school types overwhelmingly reported that lack of time was the factor that prevented them from using chemistry practical activities more frequently in their classrooms (56 % for private, 48 % for vocational, 46 % for science, 44 % both for religious, and regular high schools, as seen in SF-Figure 3, in the Supplementary File). Lack of materials/infrastructure is the second most important barrier for teachers in science, vocational, religious, and regular high schools (31 %, 25 %, 24 %, and 23 %, respectively). While the third most important factor is curriculum to hinder chemistry practical activities for science (23 %), regular (18 %), vocational high schools (12 %), lack of teacher knowledge and practice is the third most important factor for religious high school (19 %). Private high school teachers consider the lack of materials/infrastructure (18 %) and curriculum (18 %) to be equally important preventing factors for chemical activities.

During the focus group interviews, the reasons underlying for not having students perform chemistry experiments were also elaborated. As seen in SF-Figure 3, the categories emerged for these reasons overlapped with the results of the GSC Survey. These factors that prevent teachers from conducting experiments, or the challenges they faced were, were also observed in the interviews, and were categorized as *infrastructural, systemic, teacher-based*, and *student-based challenges*. While the category of infrastructural challenges included the subcategories of *lack of infrastructure* and *lack of materials,* the category of systemic challenges included the subcategories of *lack of time, load of curriculum,* and *lack of institutional support.* In terms of the teacher-based challenges, the subcategories of *lack of teachers' knowledge,* and *teachers' workload* were observed. Finally, the category of student-based challenges included the subcategories of *safety concerns, classroom management, and lack of students' awareness.*

With the exception of teachers implementing the IB curriculum, the chemistry teachers in all school types identified similar challenges regarding underutilized laboratory facilities and effective implementation of practical student activities. The following quotations convey the causes of an insufficiency of practical chemistry laboratory activities as stated by chemistry teachers from various types of schools during the focus group interviews.

There is already an obligation to finish a whole curriculum in one semester. Last year, we could use the laboratory, but I was barely able to cover the topics by the end of the year. (Systemic factors – load of curriculum, Teacher from private HS)

In my school, the area allocated as a laboratory is not physically adequate. If I bring 33 students into the laboratory, they can only stand side by side. (Infrastructural factors – lack of infrastructure, Teacher from regular HS)

Even the smallest experiment requires a preliminary preparation. There are problems of workload (Teacher-based factors – teachers' workload, Teacher from religious HS)

Although our laboratories are well-equipped, because the students are not interested, we do not have the opportunity to conduct experiments at a very advanced level. (Student-based factors – lack of students' awareness, Teacher from vocational HS)

3.3 RQ3 What are the views of Turkish chemistry teachers who are working in different types of high schools, on the practical activities focusing on GSC?

In the GSC survey, first the definition of GSC is given and then questions regarding the experiences and views of teachers were asked. When the chemistry teachers were asked what percentage of the chemistry practical activities that they run involve green chemistry, or relate chemistry to sustainability, in the GSC survey, it was observed that teachers from all types of schools reported that only 29 % of their chemistry practical activities included green chemistry or linked chemistry to sustainability.

3.3.1 Knowledge about GSC activities

This situation was also confirmed in the focus group interviews since most of the teachers stated that they had limited knowledge and experiences regarding the GSC. Even though some teachers said that they learnt these concepts through *professional development*, *online materials, university training*, most of them admitted that they rely on their *daily experiences* or have a *lack of knowledge*. Sample quotations from the responses given in the focus group interviews, as seen below, mostly conveyed this situation.

We did not receive any training, I mean, I have heard about these things conceptually, but for the first time when I was filling out your questionnaire. (Lack of knowledge, Teacher from science HS)

When I include [green chemistry] in my lessons, I can honestly say that I benefit from my knowledge of being a housewife. For example, I tell the students that tell your mothers at home, they should not buy chemicals for decalcification, they should use lemon powder etc. (Daily life experiences, Teacher from science HS)

3.3.2 Factors affecting choosing GSC activities

Despite the fact that a limited number of chemistry teachers claimed that the chemistry practical activities were linked to GSC, they rated the factors that they would consider when choosing GSC practical activities for their classrooms, as given in SF-Figure 4 (see Supplementary File). More than one third of the teachers at regular, religious and private high schools reported they would consider practical activity in clearly linking to local environmental issues "very important" in linking to local environmental issues, while most of the teachers working at vocational high schools said they considered the sustainability-related activities "extremely important" (SF-Figure 4a). When this issue was discussed during the focus group interviews, one of the chemistry teachers, who was working at a regular high school said she tried to link sustainability concepts to their local context. The following quotation given below is an example for this case.

We are in Büyükçekmece [a district]. We also analyzed Büyükçekmece lake water, we even bought the kits for it [the analysis]. With those kits, for example, we observed the pH of the water, the nitrogen ratio, oxygen ratio, etc. We also did such a study on where Büyükçekmece Lake was heading [environmentally]. (Linking practical activities to local environmental issues, Teacher from science HS)

Another factor for teachers to choose the GSC practical activities, asked in the GSC survey, was whether the students find green chemistry and sustainability issues and topics engaging. While most teachers in private, regular, religious and science high schools considered this factor "very important", whereas about one third of the vocational high school teachers considered this factor "extremely important" (see SF-Figure 4b). This factor can be seen as consistent with the factors affecting choosing practical activities in general, because as discussed earlier, *enhancing students' motivation* was seen as one of the factors that was found to be quite important.

Providing opportunities for students to develop critical thinking and problem-solving skills while engaging in GSC activities can also be an important factor for chemistry teachers to integrate GSC activities into their teaching. While half of the chemistry teachers at private high schools considered it an "extremely important" factor, most of the chemistry teachers in science, regular, vocational, and religious rated this factor as "very important" (see SF-Figure 4c). This factor was also found to be consistent with the factor for choosing practical activities, in general, since the majority of the teachers in all the school types had found that helping students develop transferable skills such as critical thinking and problem-solving was an important factor for them. So, this factor was clearly seen in selecting the GSC activities.

Seeing the practical activities as a way to introduce green chemistry and sustainability through a hands-on activity can be considered a factor in integrating GSC into the classroom. While most of the chemistry teachers in private, religious, and regular high schools responded that practical are a way to introduce green chemistry and sustainability through a hands-on activity as a "very important" factor, again about one third of the vocational and science high school teachers considered this factor as "extremely" important (see SF-Figure 4d). This factor was also found to be consistent with the reasons for selecting practical activities, in general, as discussed earlier. Because most of the teachers claimed that students could improve their scientific practice skills through hands-on activities. This idea was localized by a science high school teacher during the focus group interviews.

There is no point in the experiment unless each student does the experiment with his/her own hand and proves the subject. (Hands-on activities, Teacher from science HS)

3.3.3 Type of GSC practical activities

Teachers working in different types of schools were found to use different practical activities adopted to incorporate green chemistry or sustainability. When the participants in this study were asked to state what percent of their practical activities relate with GSC, in the GSC survey, it was found that there was variation in implementing GSC practical activities across school types. Specifically, few of the chemistry teachers in science, private and regular high schools stated that they implement activities integrating *chemistry and environment* (18 %, 15 %, and 10 %, respectively).

In the focus group interviews, as seen in SF-Figure 4, it was observed that chemistry teachers referred to *using house-hold materials, activities of recycling and reusing, cased-based discussions,* and *extracurricular activities* for the examples of GSC activities. Only the chemistry teachers implementing IB curriculum referred to the category of *producing safer solutions* when implementing practical activities. The following quotations convey the examples given by the chemistry teachers working at different types of schools.

The magnesium strip burning experiment is a very cool experiment. Once, after I obtained magnesium oxide, we collected them in porcelain containers. In the next stage, I did activities with phenolphthalein showing acid-base properties. (Recycling and reusing, Teacher from private HS)

I give an example. The Karasu river passes through Erzurum. It originates from Dumlu and Hasangala. I say, when you throw garbage in Karasu, the garbage you throw will go to Erzincan and Erzincan, it will become the Fırat river. Then it will leave the borders of Türkiye and merge with the Tigris. The nature we pollute here will affect people in the Gulf of Bafra. I am not a nationalist person. The world belongs to everyone. (Cased-based discussions, Teacher from regular HS)

In the IB curriculum, we expect students to indicate environmental issues, ethics and safety. Let's say, they perform the experiments in lower concentrations to cause less harm to the environment. Do they pour products diluted, do they turn it into salt and pour it in? (Producing safer solutions, Teacher implementing IB curriculum)

We use well-plates to work with less chemicals. (Producing safer solutions, Teacher implementing IB curriculum)

3.3.4 Perceptions regarding the adoption of GSC practical activities

During the focus group interviews, chemistry teachers discussed their rationale behind adopting GSC practical activities. The chemistry teachers' perceptions of green chemistry were grouped into three categories: *environment-centered, economy-centered* and *belief-centered perception.* The following quotations convey different perceptions of chemistry teachers for implementing GSC practical activities.

When we do experiments, we release the waste from the lab, it goes right into the sea. There are fish and living things in there. So, let's collect the chemicals somewhere. (Environment-centered perception, Teacher from regular HS)

You do experiments in all classes. The material is expensive. They don't give you an endless check. So, we should do experiments on a small scale. (Economy-centered perception, Teacher from regular HS)

My mother was very against waste. She raised us in this way. So, when I use a pH paper by cutting it into thirds. I never dip one pH paper into a solution. It's a little bit due to belief, I say I will give an account for it. (Belief-centered perception, Teacher from regular HS)

3.3.5 Challenges regarding the implementation of GSC practical activities

In the GSC survey, an open-ended question of what challenges chemistry teachers face when trying to use more practical activities related to GSC was asked. The responses for the challenges determined by the teachers were grouped into four categories: *Infrastructural*, *content-based*, *teacher-based*, and *student-based challenges*. Under the category of *infrastructural challenges*, there are three types of challenges noted by the teachers: *lack of laboratories, lack of equipment*, and *crowded classrooms*.

Science high school teachers reported that they did not face any infrastructural challenges, while regular high school and vocational high school teachers reported that they encountered all challenges under this category. Religious high schools reported that they faced only the challenge of *lack of laboratories*, while private high schools reported only *lack of equipment* challenges under the category of infrastructural challenges.

The results of the analysis revealed three types of challenges in the *content-based challenges* category: *intense curriculum*, *lack of resources*, and *lack of time*. Chemistry teachers working at the regular and vocational high schools reported facing all three challenges. While the teachers at private high schools reported both *intense curriculum* and *lack of resources*, the chemistry teachers at the science high schools reported only *lack of time*, and those at the religious high schools reported only *lack of resources*.

Regarding the *teacher-based challenges*, two types of subcategories of challenges emerged: *lack of motivation* and *lack of knowledge*. For this type of challenge, teachers in religious high schools reported facing both of these challenges, while teachers in private high schools reported facing only the *lack of motivation of teachers*. Teachers in the remaining school types only reported that *lack of teacher knowledge* was a significant challenge. There is only one challenge under the category of *student-based challenges*: *lack of motivation of students*. In this case, only the teachers working at the regular and vocational high schools mentioned a *lack of students'* motivation as a challenge.

During the focus group interviews, most of the chemistry teachers had said they had lack of knowledge in GSC, thus they were fully integrating GSC to the experiments conducted in the laboratories. The categories for the *challenges* emerged from the focus group interviews were *infrastructural, content-based* and *institutional* challenges, as seen in SF-Figure 4. Regarding the *infrastructural challenge,* two subcategories were observed: *lack of time* and *lack of waste management.* The subcategory of *lack of time* was already observed in the GSC survey but the subcategory of *lack of waste management* was a new issue brought by the chemistry teachers. The following quotation represents how one of the chemistry teachers explained this challenge:

> *… Then I am thinking, what can we do with the waste after the experiment? Should we pour it down the sink? What happens if we do, what is in the waste?* (Infrastructural challenge – lack of waste management, Teacher from vocational HS)

The final two categories emerged from the focus group interviews were *content-based* and *institutional challenges* which were similar to the categories observed in the GSC survey. Regarding the *content-based challenges*, the subcategories *lack of time* and *intense curriculum* were stated by the teachers who participated in the focus group interviews. For the category of *institutional challenges,* only the subcategory emerged was the *lack of support* which was also observed as a challenge for practical activities, in general.

3.3.6 Needs of chemistry teachers regarding the adoption of GSC practical activities

The final question in the GSC survey asked chemistry teachers what additional resources they need when trying to use more practical activities related to sustainability. Similar to the categorization of the responses given for the challenges determined by the teachers, the needs of the teachers were grouped into three categories: *Infrastructural*, *content-based*, and *teacher-based*. For the category of *infrastructural needs*, the only subcategory emerged was the *need for laboratory equipment.* Regarding the *content-based needs,* four subcategories; namely *printed materials, online materials, scientific research,* and *engaging activities*, were observed. Finally, for the *teacher-based needs,* two subcategories; *content knowledge* and *practical skills* to teach GSC were determined.

Teachers from all school types agreed that they needed *teacher-based* and *content-based needs.* More specifically, they argued that they needed the necessary *content knowledge* and *practical skills* to teach GSC, as well as *printed materials* to be used while teaching. In addition, teachers from all school types except the religious high school stated that they lacked equipment, therefore they would need the *laboratory equipment,* which is an *infrastructural need*. On the other hand, only vocational high school chemistry teachers reported that they would need a variety of *content-based needs,* which were *online materials, cooperation and engaging activities*, while only vocational high school and private high school teachers agreed that they need to read and discuss more on *scientific research* on GSC, its applications and impacts, as another *content-based need.*

3.3.7 Suggestions of chemistry teachers regarding the adoption of GSC practical activities

In the focus group interviews, chemistry teachers were asked whether they had any suggestions regarding the adoption of the practical activities of GSC. The categories emerged for the suggestions were *infrastructural*, and *teacher-based* suggestions. While, for the infrastructural suggestions, few of the chemistry teachers suggested that special kits of GSC can be developed and distributed to the teachers, for the teacher-based suggestions, few of them said they requested having professional development training on GSC. The following quotations convey these suggestions.

> *For certain experiments in the curriculum, it would be great if kits could be sent to every school, every region of Türkiye.* (Infrastructural suggestion, Teacher from religious HS)

> *We made a request to the Istanbul Provincial Directorate of National Education for inservice training to improve our knowledge and practices.* (Teacher-based suggestion, Teacher from science HS)

4 Conclusions

Chemistry education is based on practical applications, including laboratory experiments, in-class demonstrations, computer animations and simulations. These activities are designed to engage students physically and mentally. It has been reported that practical applications provide students with meaningful learning experiences,[1] improve their science process skills,[17] enhance interest and motivation towards science,[4] and increase their positive attitudes.[68] Nevertheless, teachers may select different practical activities depending on their own conditions and circumstances. Accordingly, the objective of this study was to determine the experiences and views of chemistry teachers in Türkiye regarding practical activities in general, as well as those focusing on GSC. This was initially achieved through the GSC survey, and subsequently via the focus group interviews with the teachers from the same school type.

Given the experimental nature of chemistry, it can be suggested that priority should have been placed on having students perform the chemistry experiments. In fact, the findings of the study showed that "once per month" was the most common condition for the chemistry teachers from private and science high schools, whereas "few times a year" was the most typical condition for the regular and religious high schools. During the focus group interviews most of the teachers claimed that depending on the topic, they usually have 9th and 10th grade students perform the experiments rather than 11th and 12th graders. This condition can be explained due to the *systemic issues*, including the overload of curriculum and limitation of the national examinations. This finding was aligned with the previous studies regarding the systemic issues in Türkiye.[18,22]

Among the other factors conveyed by the chemistry teachers on the GSC survey for not having students perform chemistry experiments, the ones on *teacher-based* factors such as lack of time, and *infrastructural* factors such as lack of laboratory space or materials were the most common ones, regardless of the school types they were working. These factors were confirmed, and *student-based factors* such as crowded classes and safety concerns were also revealed during the focus group interviews. In Türkiye, some of the schools, such as vocational and religious schools, are usually more crowded than private and science high schools, because a relatively smaller number of students are eligible to go to these schools. Therefore, in crowded classes, teachers prefer not to implement practical activities in-person. All these findings are also aligned with the previously determined situation in Türkiye[19,22,24] and in other countries.[18,25,27]

The factors that limit chemistry teachers from conducting experiments may have led them to integrate in-class demonstrations as an alternative to conducting hands-on experiments. Focus group interviews highlighted the lack of infrastructure and overcrowded classrooms, in particular, as reasons why chemistry teachers preferred demonstrations to hands-on experiments. Another alternative for hands-on experimentation was said to be playing experimental videos in class, as about half of the teachers, except those in science high schools, said they played experimental videos every month. The focus group interviews revealed that the teachers usually preferred to play the experimental videos when they were concerned about the safety of the students. Finally, although the utilization of experimental data can be another alternative to hands-on experiments, it was integrated by about half of teachers only for "a few times a year", and more often by the chemistry teachers teaching IB curriculum at the private high schools as they said they integrated it "once a month". This method may have been more in line with the structure of the IB chemistry curriculum and was therefore preferred by those teaching the IB curriculum.

Another type of practical activity, integrated in teaching chemistry is having students interact with the particulate-level chemistry simulations. In the GSC survey, it was determined that this activity was adopted by about one third of the chemistry teachers on a "monthly" basis. During the focus group interviews it was observed that teachers were generally utilizing the simulations in addition to the experimental work. They said they were showing them in class as long as the schools had suitable physical and technical conditions, if not they were integrating them as a tool for flipped learning or homework. Besides simulations, chemistry teachers said they were also playing particulate-level animations, as about 30 % of the teachers claimed that they played them "once a week". During the focus group interviews teachers claimed that they prefer utilizing computer animations instead of performing experiments. However, the particulate-level animations cannot actually substitute

performing experiments, since they represent chemical phenomena at different levels, i.e. macroscopic versus submicroscopic. Therefore, it can be argued that chemistry teachers may need to be assisted in terms of understanding the nature of chemical phenomena at three levels[12] through in-service training as well as getting support from their institutions.[22]

Regarding the experiences of chemistry teachers for implementing different practical activities, it was observed that the teachers working at science and private high schools were implementing almost all the practical activities more frequently than the teachers at regular, vocational and religious high schools. The reasons for this finding can be explained in three manners by using the categories that emerged in the study: *student-based, teacher-based* and *infrastructural*. First, students in science high schools spend more hours per week in science courses than students in other schools, therefore the teachers at science high schools probably design their lessons to include more practical activities. Secondly, the teachers in private schools may usually attend professional development programs more frequently and hence may be more competent to include a variety of practical activities to enhance students' learning. Finally, private schools may have better infrastructure in terms of physical and digital resources, as well as personnel, so teachers can easily use these resources to incorporate a variety of practical activities. This situation might be because private schools are better funded, so the teachers have access to more materials. On the contrary, chemistry teachers working at the vocational and religious high school teachers implemented all the practical activities less frequently, than the teachers working at the other school types. This finding could be explained due to *systemic* and *infrastructural* factors as the focus of these schools might be very specific, which means that teaching science may not be a priority and they may lack the necessary infrastructure.

The second research question in the study was on eliciting the chemistry teachers' views about practical activities. Specifically, first they were asked to rate their reasons for selecting practical activities in the GSC survey. The majority of the teachers in all the school types said the main reason for selecting their practical activities was helping students *improve their conceptual understanding*, followed by the reason for developing *critical thinking and problem-solving skills*. These findings are in parallel with previous studies, as these factors were found to be important for the adoption of experimental activities in particular.[1,15,69] The next important factor for many chemistry teachers was for the students to develop scientific process skills and learn experimental techniques of chemistry, as previously reported,[17,70,71] this factor was considered as an important outcome for having experimental activities. Last but not least, the majority of the chemistry teachers in all school types, indicated that they would consider the motivational factors very much when selecting the practical activities as supported by many studies.[4,68]

The last research question explored the experiences, perceptions, and needs of chemistry teachers regarding GSC through the GSC survey and focus group interviews. First of all, regardless of the school type they were working at, it was observed that chemistry teachers lacked knowledge of GSC and relied on their personal daily experiences. Even though they didn't receive any training on this issue they said they tried to incorporate GSC through *using house-hold materials, activities of recycling and reusing, cased-based discussions,* and *extracurricular activities.* During the focus group interviews, only teachers implementing the IB curriculum indicated that the practical activities they conducted included the production of safer solutions for the environment and human health. When asked about their motivations for adopting activities related to GSC, their perceptions were found to fall into three categories: *environment-centered, economy-centered* and *belief-centered perception*. This finding can be said to be a novel contribution to the literature in this field, since there has been a limited number of studies[58] that have determined the experiences, views and perceptions of chemistry teachers about GSC. The challenges that chemistry teachers said they might face in implementing the GSC were very similar to the challenges they had with the hands-on activities in general. This may have been because they didn't know much about GSC, so they couldn't anticipate the different challenges they might be facing. However, they could determine their needs in three categories, *infrastructural*, *content-based*, and *teacher-based*. Specifically, they said they needed laboratory equipment as ready-made kits, printed or online materials to improve their content knowledge and practical skills for teaching. In this regard, they brought back suggestions for professional development training and ready-made kits to easily teach GSC.

4.1 Limitations of the study

This study attempted to convey the experiences and views of the chemistry teachers working at different types of high schools in Türkiye, through GSC survey and focus group interviews. Despite the large number of chemistry teachers working all over Türkiye, the study was limited with the 206 participants who responded to the GSC survey and 24 chemistry teachers who participated in the focus group interviews. There may have been other experiences, views and perceptions than those captured in this study.

4.2 Implications and suggestions

Practical activities, especially the ones involving laboratory experiences, in chemistry education have prime importance for improving students' conceptual understanding, critical thinking, science process skills, and positive attitudes. Therefore, it is recommended that teachers integrate them into their lessons on a regular basis. However, in order to overcome the challenges, they may experience regarding the implementation of practical activities, especially the ones involving GSC, they may need to be supported by providing teacher training and infrastructural support including materials and guidance.

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Supplementary Material: This article contains supplementary material (https://doi.org/10.1515/cti-2025-0037).