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Communication

Online Experimentation during COVID-19 Secondary School Closures: Teaching Methods and Student Perceptions

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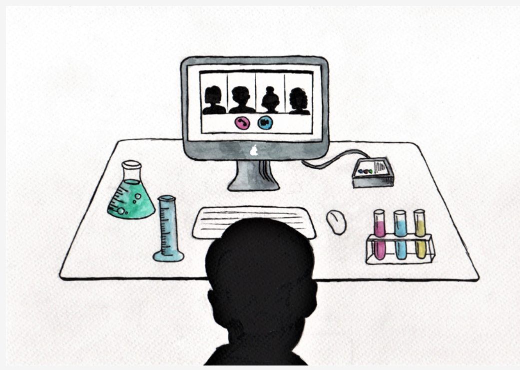

ABSTRACT: The COVID-19 lockout situation affected people all over the world. Despite all of the disadvantages, this situation offered new experiences and perspectives and pushed education advances forward as never before. Something that seemed to be unreal became a worldwide reality within a few days. Instructors of all subjects at all educational levels moved to a virtual environment instantly. Higher education institutions, universities, and colleges seemed to be fairly prepared for this situation. Unfortunately, primary and secondary schools, especially in eastern and central Europe, never considered distance education as a valuable alternative before, so they did not have software, hardware, and staff prepared for such a situation. Moreover, students' expectations and dilemmas concerning e-learning were not investigated earlier in the context of obligatory subject education. Moving to the virtual environment was particularly challenging for teachers, who wanted to transfer real class experiences into online lessons since chemistry is based on problems, observations, evidence, and experiments. Often, teachers claimed that they could be more efficient if they had knowledge, skills, and proper equipment to run classes online. This paper presents experiences of secondary chemistry teachers from Slovakia, participants in the IT Academy Project, who earlier, within the framework of the project, were equipped with the necessary skills and tools to run virtual classes, supported with data logging experiments. In this communication, the teachers' efforts using online experimental practices are described, as well as reflections by their students about the experiences.

KEYWORDS: *High School/Introductory Chemistry, Continuing Education, Internet/Web-Based Learning, Distance Learning/Self Instruction*

■ INTRODUCTION

Experiments play a tremendous role in chemistry education,[1] but the impact of hands-on chemistry laboratories on students' knowledge still requires research and better understanding.[2] During the COVID-19 pandemic outbreak and public lockout, all educators on all levels all over the world were challenged to conduct classes online. Chemistry/science school teachers were in a particularly tough situation because they had to organize teaching of not only theoretical knowledge but also practical aspects, and therefore, they needed to transfer experiments and laboratory activities to an online environment. Technical progress and the development of modern information and communication technologies (ICTs) created a wealth of opportunities to introduce students to practical aspects of chemistry during distance learning lessons. Experiments can be introduced in the following forms:

- Written descriptions assisted with photos
- Video-recorded demonstrations
- Live interactive demonstrations
- Live demonstrations of experiments with data logging systems
- Simple "linear" simulations
- Virtual laboratories in the form of advanced multithread simulations
- Remote laboratories in the form of remote-controlled real laboratory equipment[3−6]

As an alternative students can carry out experimental work at their homes using household substances or reagents sent to them.[7] There have been studies comparing students' performance in hands-on and virtual laboratory courses. Students' understanding was similar whether participation was in person or online, which implies that virtual laboratories are beneficial. They also save time and money and reduce chemical waste. However, all authors recommend a careful approach to changes and further research.[8−11] As Hensen and Barbera mentioned, not only is students' knowledge important in observing the impact of chemistry lessons, but students'

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anxiety and emotional satisfaction, the usefulness of the lab and equipment, the instructor, etc. may also influence students' affective outcomes more than the learning environment.[12]

It should be remembered that the available results were obtained from studies that were carefully planned, prepared, and run in a controlled environment. Both instructors and students were familiar with the situation that they were going to face and had alternatives available. It should be also mentioned that there was no research about distance teaching of chemistry at the secondary school level yet.

The situation that occurred because of the COVID-19 pandemic outbreak at the beginning of the year 2020 was surprising and challenging for all of us. UNESCO showed us another view of this crisis: almost 363.1 million children and youth have been affected by the closing of schools all around the world.[13] Every teacher at every level of education had to deal with this situation. Most of the teachers were unprepared. Some of them switched to online classes, but many teachers did not know how to do it. In order to help educators during this uneasy time, many journals, associations, and platforms opened their resources.[14] National organizations provided remote teaching support and webinars.[15−19]

The first case of COVID-19 in Slovakia appeared on March 6, 2020.[20] In response to that, most of the universities canceled or interrupted their classes. On March 12, 2020, the Minister of Education, Science, Research and Sport of the Slovak Republic interrupted the educational process at schools and educational facilities from March 16, and as it was later announced, schools had to remain closed until the end of the semester. Therefore, all teachers had to move to virtual classes. The situation was similar in most European countries.

As already mentioned, many schools and teachers were not prepared to run virtual classes, especially at the primary and secondary school levels. On the other hand, there were exceptions. Participants of the IT Academy project run in Slovakia[21] were ready to teach online since their goal was to enhance STEM education by introducing modern ICT tools and using them while teaching in a consistent and meaningful way.[22−28] In the area of chemical education, the main innovation consisted of the introduction of data logging devices (Vernier and CMA equipment[29,30]) integrated with the inquiry-based approach.[31−34] Project participants (60 secondary schools, 24 gymnasiums, and six secondary technical schools) were equipped with proper systems, and teachers were trained in using those in Summer 2019. During the training, data logging devices were introduced, and chemistry teachers practiced their use in the school chemistry curriculum context. They worked with various sensors (temperature, pH, gas pressure, etc.) and corresponding analysis software. Therefore, at the beginning of the pandemic, those secondary teachers were in a privileged position. They had a large range of ICT tools at their disposal and fresh knowledge on how to use them. Organizing the educational process online, they could freely choose the form of inclusion of the experiments into their lessons. They had all of the necessary equipment available, and they were trained how to use it. Moreover, thanks to the project, they were trained on how to organize classes online and how to use videoconference software (Teams, Zoom, Webex, Google classroom, etc.) at the beginning of the lockout. They could also ask their project tutors for further assistance at any time. Therefore, those teachers' practices were limited mostly by their will and beliefs. In this communication, we present data gathered after 12 weeks of the lockout, and we try to answer two questions: "How do chemistry teachers incorporate experiments in online lessons?" and "How do students perceive learning chemistry online at the secondary school level?"

■ METHODOLOGY OF THE RESEARCH

The described study was based on monitoring of teachers participating in the IT Academy project during the pandemic situation. Two short questionnaires were used, the first one aimed at teachers and the second at their students. Questions for teachers considered their approach to the application of experiments during online lessons, their frequency of using of data logging devices, their reasons for choosing the reported approach, and the pros and cons of carrying out the experiments in this way. Questions for students focused on their satisfaction with learning chemistry remotely. Participation in the study was voluntary for both teachers and students. They were aware of the data to be collected, the goal of the collection, and the mode of processing, according to the Pavol Jozef Šafárik University ethical standards. The participants might renounce their participation in the study at any stage. The questionnaires were fulfilled in the Slovak language and translated into English for publication; back translation was done to control the text quality. Teachers were asked to sign the questionnaire with a full name. Students' answers were anonymous (quotations in the Results and Discussion are presented with random nicknames), but they were asked to write their chemistry teacher's name so that their answers could be related to the teaching approach used. The questionnaires were administered online 12 weeks after the COVID-19 school closures, during the last week of May 2020. Twenty teachers, from grades 7 to 12, were asked to complete a form and provide a link to the student version of the questionnaire for their classes. Data were collected from 17 female teachers with experience ranging from 5 to 30 years (mean 18.8, median 17). The student data were collected from 78 students. Each teacher had up to 13 students participating in the survey (average 4.5, median 3). Three teachers' students did not complete the form.

The study had a mixed character: the data were encoded and analyzed with basic statistics, but the teachers' and students' answers were also analyzed as separate cases.

■ RESULTS AND DISCUSSION

Teachers were asked whether they carried out experiments during online classes. Teachers indicated the type of approach used by answering multiple-choice questions. The results showed that all of the teachers used experiments during online classes, with some using more than one approach, as summarized in Table 1. There were no additional approaches utilized by teachers. As it was a multiple-choice question, various combinations of approaches were possible, as presented in Figure 1.

Table 1. Online Experimental Methods

Letter	Experimental Method	Number of Teachers
A	Showed pictures with captions	10
B	Showed videos	11
C	Demonstrated live during online class	10
D	Students conducted experiments at home	11

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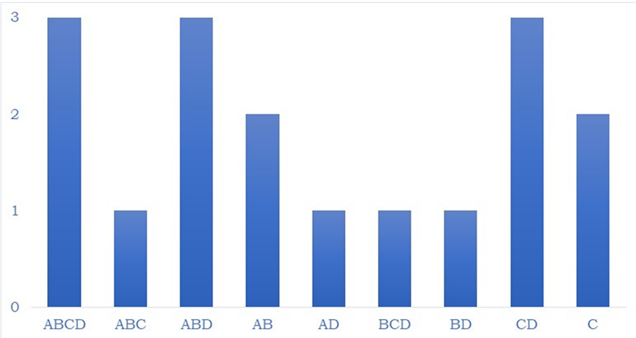

Figure 1. Distribution of the sets of approaches to experiments during online chemistry lessons (A, B, C, D as defined in Table 1).

Teachers provided also examples of experiments run in a chosen way (Figure 2). In approach A, teachers mentioned experiments such as flame tests, Fehling's test, and Tollens' test. Approach B was used by teachers to present experiments that they performed before class, such as measurements of the rate of a chemical reaction and investigation of the factors affecting the reaction rate. However, they also used videos available online, usually with demonstrations of characteristic chemical reactions. Live demonstrations (approach C) were performed with activities such as separation processes, extractions of essential oils, and caffeine sublimation. Students conducted experiments at home (approach D) using household goods, such as investigating the role of food additives while baking sweets, factors influencing kitchen salt crystallization, and properties of carbonates using vinegar and baking soda.

Most of the teachers (seven of 17) claimed to use data logging devices occasionally, while four claimed to use them often, three used them rarely, and three did not use them at all. There were no teachers who used data loggers at every lesson. Working with data loggers, teachers used two strategies: (1) measurements were prepared, performed, and recorded earlier and then presented as a video clip during the lesson, or (2) live measurement demonstrations were performed during an online lesson. In both cases, teachers shared and discussed the collected data with students. Contemplating pros and cons of using experiments and data loggers during online lessons, teachers were convinced that this approach made lessons more interesting/attractive to students, made problems easier to understand, and gave more time for discussion of results compared with carrying out similar experiments during regular classes. On the other hand, they regret that students did not develop manual laboratory skills, that multiple data sets were not explored, and that they missed the direct contact with their students, which caused, i.a., a less effective discussion.

The student survey was meant to diagnose the level of students' satisfaction with online chemistry learning. Starting with a simple yes/no question about whether they enjoyed such chemistry lessons, 20 of 78 students answered "no" when

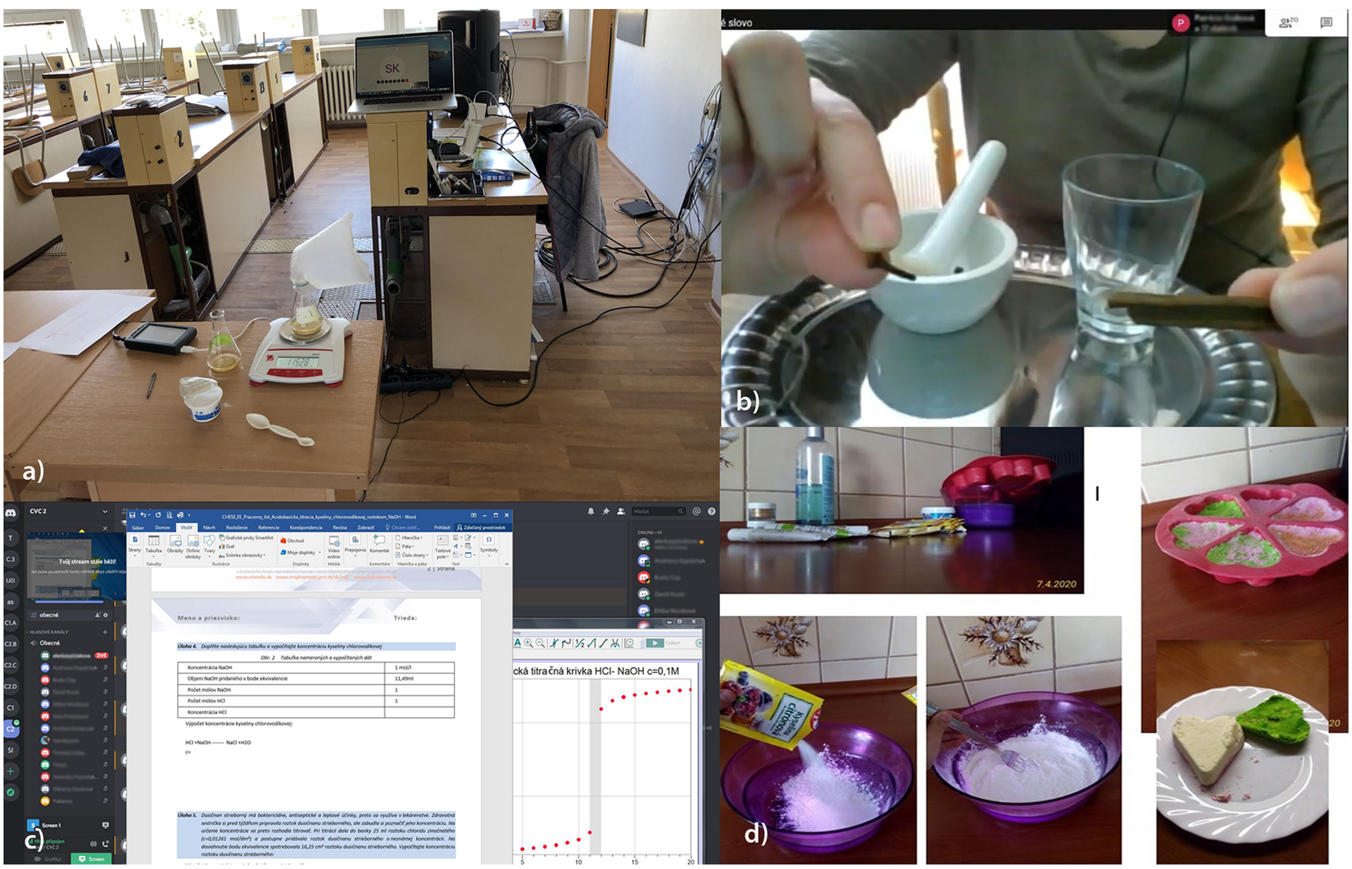

Figure 2. Examples of different approaches to experiments used by teachers. (a) Live demonstration in an empty classroom of an experiment on mass conservation involving a data logger (setup overview). (b) Live demonstration of an essential oils extraction experiment (screenshot). (c) Presentation of data recorded earlier in an acid–base titration experiment with a pH sensor and data logger. (d) Investigation done by students at home on the influence of food additives on the properties of baked sweets (pictures from students' report).

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asked if they liked the online lessons, with every teacher having at least one student with this response. Students were asked to write what they liked most about online learning. The replies by students who did not enjoy the lessons were very brief. Among those who claimed to enjoy online chemistry, extensive answers were more common, for instance: "I like that it is not very different compared to our traditional lessons. I mean that we don't have to skip some topics. Also, I like that we don't have to have an assessment based on oral answers" (Alan, 17 years old (y.o.), taught with approaches A and B); "That our teacher shows us many interesting videos and interactive homework" (Beth, 16 y.o., taught with approaches A and B); "I like that I can use household stuff during my experiments" (Cecilia, 16 y.o., taught with approaches A, B, and D); "That we can do experiments at home" (Deidre, 18 y.o., taught with approaches B and D).

Online lessons offer a more relaxed environment compared with traditional lessons.[35] They also provide an opportunity to manage time and work more efficiently. More than 70% of students preferred working in their home environment, as it allowed for sleeping later and working in a more comfortable and less stressful environment. Earlier studies revealed that school transport mode and commuting also have the potential to influence cognition and educational achievement.[36,37] However, secondary school students are less skilled and less competent in controlling their learning activities, and moving to a virtual environment could be a difficult change for them.[35,38] Students also appreciated experiments using household chemicals, interesting videos and interactive homework, independence, thoughtful choices of topics by the teacher, the silent learning environment, and the possibility to participate in the innovative educational process.

When students were asked what was most difficult for them during the online chemistry lessons, 33% complained that they had problems with understanding the lesson content, and as the reason, they pointed to the inability to ask questions, the fast course pace, difficulty in taking notes, and too much homework. Here are some example student comments and the teaching methods experienced (A,B,C,D): "To understand the topic. It would be better if our teacher could do it in our class in front of our blackboard" (Eliz, 15 y.o., taught with approaches B, C, and D); "Teaching of my teacher—it's not that good as in traditional lessons" (Deidre, 18 y.o., taught with approaches B and D).

Twenty percent of the students also reported time management and the inability to stay focused as concerns. Problems with attention during online lectures was also described by Korving et al., who indicated that the sight of the lecturer during online classes increased students' interest and attention.[39] Exemplary student answers include the following: "At our school, we learn from 8 am to 1 pm. It's not that bad, but we also have a lot of homework so I have to learn non-stop. I think it's too much and tiring and stressful" (Alan, 17 y.o., taught with approaches A and B); "Time management. It's difficult to make myself to do my homework when it's that free" (Fiona, 13 y.o., taught with approach C).

Ten percent of students pointed out a slow internet connection as the main problem. In fact, the internet connection and access to computers are true limiting factors in e-learning during the pandemic. A report prepared in Poland (a country nearby to Slovakia) indicates that close to 330,000 students do not have home access to a computer connected to the internet, and in the case of another 1,320,000 students, the number of computers in the household is lower than the number of students living in the household (based on a 2018 data set).[40] Therefore, students often have to use small-screen mobile devices while learning or cannot participate in distance classes at all.

Finally, approximately 5% of students consider unfair assessment the main drawback, e.g., "I think that assessment is not very fair because students can cheat. Many teachers have used it for the first time" (Gary, 16 y.o., taught with approaches A and B).

One student answered that the most difficult thing was "To do experiments at home with my home equipment" (Henry, 17 y.o., taught with approaches A, B, and D).

When students were asked, "What do you miss most in chemistry distance learning?", 46% of the students missed experiments. Such an answer was given by every second student in the group taught with experiments done at home (approach D in various combinations) and by 34% in the group without experiments done at home (approaches A, B, and C in various combinations). Apparently, doing experiments at home does not work as a satisfactory substitute for experimentation in the school lab, and students who carry out such experiments miss regular laboratory exercises more often. Ten percent of the students did not enjoy online experimentation because it was not as "cool" as doing experiments in the classroom, and 28% of the students reported missing the live interaction with their teacher and classmates. Only 5% of students answered that they did not miss anything.

■ CONCLUSIONS AND IMPLICATIONS

Transitioning to distance learning in chemical education is more challenging than for nonscience courses because of the experimental nature of the subject. Students are required to base their answers on observations and evidence. For that reason, this study delivered information on chemistry teachers' practices and student satisfaction mostly on questions considering various approaches to the use of experiments during online classes. The data presented in this communication were originally meant to monitor teachers' practices within the IT Academy project and enhance the use of data loggers during online teaching. Analyzing the results, we have realized that those teachers faced many serious general problems, and a broader approach and assistance are necessary. As mentioned above, teachers participating in the study were well-equipped and trained in using various ICT tools, including hardware and software to run live online measurements. From analysis of the data, it is obvious that many teachers are using this approach, but not as the only solution. They use also more basic techniques, such as photos/pictures of experiments with a description or recorded videoclips. Teachers pick one of the various techniques that they consider the most appropriate for each experiment (that was confirmed in postquestionnaire talks with the teachers). However, looking at students' answers, they should consider using multiple approaches to each experiment. Many students complained about a slow internet connection, and therefore, they may have trouble using high-quality videos or videocalls/video meetings. Written descriptions with pictures could be very useful for them. On the other hand, students look forward to chemistry experiments, and therefore, instructors should not omit them. Teachers point to a positive fact that during an online lesson they can run measurements quicker, or just show a video clip of a

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measurement taken earlier, and then focus on data analysis and conclusions. At the same time, 33% of the students complained that they have problems with understanding material during online classes and that teachers run classes too quickly, without enough time for asking questions, discussion, and taking notes. Therefore, teachers should keep in mind that as during ordinary lessons, students need time to think and ask questions and that diagnostic questions to students are crucial to find a balance between interesting and dynamic presentation and efficient teaching. Moreover, the online lessons and experiments should be recorded and shared with students after classes. That would allow students with a slower internet connection or those who are forced to use small-screen devices (e.g., mobile phones) to watch the video clip later when a faster internet connection or another device is available.

Students miss direct contact with the teacher and classmates during online learning. Moreover, they miss the blackboard. Many students pointed out that their teacher "can explain problems better" in front of the blackboard. Therefore, teachers should use the available technology better to make notes on the screen, handwriting and commenting as they do at school. Many low-cost devices have touchscreens or allow for pen computing with a stylus. In-person instruction can be simulated using the computer's webcam and the screen as a blackboard with free and easy to use apps such as whiteboard.fi. Moreover, screenshots can be combined with written notes and shared afterward as handouts, which can help students who have trouble taking notes instantly during the lesson.

We are aware that the presented study raises more questions than it provides answers. As mentioned earlier, it evolved from a monitoring project, and therefore, many of the questions concerned using data loggers during online teaching rather than focusing on more general practices. However, the collected data seem to be quite universal and can be used as an entry point to further, more systematic studies. The teachers participating in this research can be treated as a model group, as they were trained in using ICTs before the pandemic outbreak and in using videoconferencing software for online teaching just at the beginning of the lockdown of schools. This study shows that although they may not have been ready for the situation but maybe were a little bit better prepared than ordinary teachers, they still faced many problems, and their practices did not always meet the students' needs and expectations. Unfortunately, a second outbreak of the pandemic in the autumn is a real threat, and further lockdown of schools is a possible scenario. Therefore, educators must do their best and use all of their possible resources to guide teachers and prepare them for decent further online teaching. Even if the dark scenario does not happen, those skills are valuable, and teachers and their students will benefit from more effective blending of virtual and face-to-face environments.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00748.

Questionnaire (PDF, DOCX)

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Notes

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