Emerging Online Science Teaching Practices: Insights from High School Physics Teaching Cases in South Korea during COVID-19 Pandemic

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Abstract

By analyzing cases in South Korea, this study examined high school physics teachers' online teaching practices during the first semester of school lockdown due to COVID-19. A total of eight physics teachers participated in this study. Data sources included observations of online classes, interviews with the teachers, and lesson materials. Data analysis was informed by social practice theory and literature on online learning. As a result, teachers' practices were distinguished based on teaching emphases including content explanation, participatory learning, and independent first-hand experience. Through the application of various technological tools, teaching practices varied in terms of the degree of interactions and student self-directedness. Three essential practices of physics teaching, defined as those preserved from on-site teaching, were identified. Those features reflected the nature of schooling and the subject matter. The teachers were found to have professional development opportunities through online teaching experiences. Implications for professional development and further research topics are suggested.

초록

이 연구에서는 COVID-19로 인한 학교 폐쇄 첫 학기 동안 수행된 한국의 고등학교 물리 교사의 온라인 수업 실천을 탐색하였다. 총 8명의 물리교사를 대상으로 온라인 수업의 관찰, 교사와의 인터뷰 및 수업 자료를 수집하였고, 데이터 분석은 사회 실천 이론과 온라인 학습에 대한 문헌을 기초로 하였다. 연구 결과 내용설명, 참여 학습, 독립적인 직접경험이라는 세 가지 교수 초점에 따라 여러 교사의 실천이 구분되는 것으로 드러났다. 한편, 다양한 기술적 도구의 적용을 통해 수업실천이 상호 작용의 정도와 학생의 자기 주도성 측면에서 다양하게 드러났다. 교사들이 오프라인 수업으로부터 유지하고자 노력한 수업 요소로부터 유추한 물리수업의 필수 특성으로는 학교 교육의 성격을 나타내는 학생의 수업참여 독려하기와 교과외의 성격을 반영하는 일상적인 현상을 물리 모델로 나타내기, 물리 모델 검증하기로 드러났다. 연구가 이루어진 기간동안 참여 교사들은 대체로 일관된 온라인 수업 실천을 개발하였고, 온라인 수업 경험을 통해 전문성을 개발할 기회를 가졌다고 인식한 것으로 드러났다. 이러한 결과를 바탕으로 온라인 수업 관련 전문성 개발 및 추가 연구 주제에 대한 시사점을 제시하였다.

Keywords

online teaching – science teaching practices – online science teaching practices – physics teaching practices – physics online teaching

1 Introduction

In January 2020, COVID-19 started spreading, and unexpected school lockdowns made school teachers around the world begin online teaching. In South Korea, where the academic year typically starts in the first week of March, a decision was made to delay the start of the new school year while the whole nation was not sure of the strength of the pandemic. After heated discussion on the possibility and safety of opening schools, the Ministry of Education in South Korea announced a school lockdown, and online schooling began 5 weeks later than in a normal year, which affected about 5.4 million students in Grades 1 through 12 across the country.

South Korea has an excellent digital infrastructure in terms of access to, use of, and skills in information and communication technology (ICT; International Telecommunication Union, 2017). According to a 2020 national survey of ICT use (National Information Society Agency [NIA], 2020), 99.7% of

households in Korea had internet access, which was the same as in 2019. The survey also reported that 91.8% of citizens aged more than 3 years use internet, which is 0.1% higher than in 2019. Most Koreans have internet access and use the internet. However, this excellent digital infrastructure is not reflected in the schools. According to a PISA 2018 report, the average number of computers per student in schools of South Korea was only 0.4, and daily internet use by students in schools, which is an indicator of ICT use for classroom learning, was about 26 minutes, which was far below OECD average of 71 minutes (OECD, 2021). Typically, schools in South Korea have one or two computer labs shared by all teachers, and each classroom has one internet-connected computer with a large screen to share with students. For information security reasons, wireless internet connections in school buildings have been restricted.

In South Korea, the scope of use of online classes for formal education was very limited prior to COVID-19. Digital technologies such as presentation tools, computer simulations, and physical computing were utilized locally for regular classes or science club activities. However, online classes were not a part of normal schooling before COVID-19. Government-approved formal online classes were for educating learners older than typical school age groups and students with physical disabilities, and some subjects not offered regularly in schools were taught through online courses (Chang & Lee, 2020). Thus, school teachers in general had no online teaching experience prior to COVID-19.

On the other hand, informal supplementary online lectures and content are broadly offered in South Korea. Online lectures have been available through public broadcasting and private learning centers (Song, 2018). These online lectures were generally used by students who wanted to excel on school tests or college entrance examinations. Also, it was common to find science teachers in the classroom using short educational video clips on the internet (Jyun & Hong, 2010). Thus, students in secondary schools were familiar with online educational content that provided information unilaterally. The degree of secondary students' use of digital learning content can be inferred from national surveys. According to a national survey in 2020 (NIA, 2020), 99.9% of teens used the internet for education in 2020, reflecting online schooling due to COVID-19, while the number was 57.8% in 2019. Thus, the difference (42.1%) indicates the proportion of teens who were unfamiliar with digital learning content for learning before COVID-19. As for teachers, there were numerous asynchronous online professional development programs for in-service teachers before COVID-19. Both students and teachers, therefore, were familiar with digital learning content. However, complete online education for all students was challenging to both teachers and students (Kim, 2020).

Without any alternative, the entire nation agreed upon online education at all school levels in Spring 2020, although there was not enough time for proper preparation for nationwide online education. As schools implemented online education, a number of changes in educational regulations such as reducing school days and changing the definition of school attendance were made nationwide to accommodate online education conditions. First of all, the Ministry of Education provided guidelines for online classes for school districts to adopt and modify for their schools. The guidelines defined three types of online classes: synchronous online interaction based (SOIB), asynchronous online interaction based (ASOIB), and project-assignment based (PAB). For these classes, the Ministry of Education provided schools with various options for learning management systems (LMS) and teachers with equipment such as webcams and tablets. Students in need were provided with tablets to participate in online classes. Also, teacher leaders across the country participated in professional development in online teaching offered by the Ministry of Education, and they relayed their learning to their colleagues through local and in-house professional development. All this happened less than 2 months before school started online education during the first week of April, 2020. Thus, most teachers began their online teaching for the first time with little professional knowledge and few skills. What kinds of online science teaching practices emerged during the unexpected mandatory online teaching? Answers to this question can provide some insight into the ways teachers adapt their face-to-face teaching practices to online teaching and provide implications for professional development for science teachers and online science teaching in particular.

The purpose of this study was to examine how high school physics teachers adapted their usual face-to-face teaching practices to the online teaching required by school lockdowns due to the pandemic. It is likely that teachers distinguish the core and expendable features of physics teaching when modifying their teaching practices for online classes while they shape new teaching practices required by online education. Thus, emerging online teaching practices could provide information on what teachers perceive to be essential in science teaching. Further, teachers could develop knowledge and skills in online teaching from their experience (Elbaz, 1981; Schon, 1983).

Based on these premises, the following specific questions were explored in this study: (a) What online physics teaching practices have emerged in response to COVID-19? (b) What professional development opportunities have teachers gained from their online teaching experience?

2 Literature Review

2.1 *Online Education*

As the study aims to examine emerging practices of physics teachers' online teaching, literature on online teaching and learning informed our understanding of online teaching practices observed in the study. We reviewed literature on online teaching and learning both in general and on science learning specifically.

2.1.1 Online Teaching and Learning

Online learning refers to distance education where instruction and assessment are carried out through the internet. Online learning has a long history, and research on it and its practices have mainly been done in higher education (Harasim, 2000). Thus, online education for schools is a relatively recent phenomenon, and many theoretical and practical implications have been drawn from research in higher education settings (Bryans-Bongey & Graziano, 2016).

As a guide to designing a collaborative-constructivist online learning environment for fully online courses, Garrison et al. (2010) identified three key elements: social presence, cognitive presence, and teaching presence. Social presence refers to students' feeling of membership in a learning community, which could be promoted by making students feel comfortable interacting with peers through questions or comments on each other's work or by working together. Cognitive presence refers to students' participation in inquiry or problem solving for learning. Teaching presence refers to a teachers' role as a facilitator of the organization or direction of social and cognitive processes of student learning. Teaching presence includes diagnosis of student learning and provision of feedback, encouragement of student participation in learning, facilitation of student collaboration, and so on. Research has found that a teacher's ongoing communication and high level of responsiveness is critical for teaching presence and students' satisfaction with the course, and social presence is positively related to cognitive presence (Garrison et al., 2010).

These three elements can be viewed with more detail from the student learning perspective. Walker and Fraser (2005) identified six elements of an online learning environment: teacher support, student interaction and collaboration, active learning, student autonomy, personal relevance, and authentic learning. These elements are consistent with those suggested by Garrison et al. (2010), as they share social constructivist learning theories as premises.

A few studies have applied the aforementioned framework of online learning environments to online schooling (Choi et al., 2016; Heafner et al., 2015).

For example, Choi et al. (2016) examined an online science gifted education program in South Korea and found that teaching presence was positively related to attitude toward the class and the outcome. Nippard and Murphy (2007) explored how social presence manifested in web-based synchronous high school classes in Canada. They showed a gap in communication practices between teachers and students. Teachers mostly used two-way audio interactions, while students utilized text-based direct messages for interactions with both the teacher and their peers. In text-based communications, students utilized discourse conventions from their everyday use of instant messages. This shows that the selection and integration of technological tools for teaching needs to consider students' experience with technologies.

Online social interactions are also important for teachers. Interviews with high school teachers in the United States who provided supplementary asynchronous self-paced online classes showed that teachers felt a sense of disconnection from their students due to the absence of physical cues and uncertainty of student understanding (Hawkins et al., 2012).

While online schooling has been limited in South Korea, use of ICT in school learning, namely smart learning or smart education (Kim et al., 2013; Zhu et al., 2016), has been promoted in South Korea for more than a decade. Smart learning broadly refers to learners' use of smart devices "to access digital resources through wireless network [*sic*] and to immerse in both personalized and seamless learning" (Zhu et al., 2016, p. 1). By using mobile technologies, learners have extended resources and diminished limitations in time and space for learning. Lim et al. (2013) identified key affordances of smart education that included contextual learning, interactive collaborative learning, adaptive learning, learner directed learning, and ubiquitous learning. These affordances are consistent with recent online learning development, but there has been a lack of research on how these affordances are utilized in school science education (Yang et al., 2015).

2.1.2 Online Science Learning

In science learning, web-based online environments have mostly been utilized as tools for science inquiry learning. For example, Hoadley and Linn (2000) examined how sixth grade students learned the concept of light through online asynchronous discussion. McCrory Wallace et al. (2000) utilized online resources for students to conduct research on their own interests. Online science learning environments have evolved for more than two decades as the Web-based Inquiry Science Environment (WISE) project has shown. The WISE project provides online environments in which student-led inquiry projects are conducted entirely online, from problem identification to data collection,

analysis, argumentation, reporting, and assessment (Linn et al., 2003; Linn et al., 2004; WISE, 2021). The WISE project hosts various types of student projects based on design principles such as making thinking visible, helping students learn from others, and promoting autonomy and lifelong learning (Slotta, 2004). A similar science online inquiry environment was also developed in South Korea (Lee et al., 2006).

The aforementioned examples of online science learning demonstrate various ways online tools are used for science learning, such as sources of information, means of content representation and communication, and sites for collaboration. These affordances may or may not change the mode of science learning in the classroom depending on how teachers utilize those online tools. McCrory Wallace (2004) examined the ways science teachers adopted using online resources as a new inquiry teaching strategy. The study found that teachers had challenges centered on the elusive nature of pedagogical context, in other words, uncertainty about student ideas and skills and ways to monitor their progress. To such uncertainty about students' learning trajectories, the teachers in the study responded differently. For example, one of the teachers used a highly constrained task so that they could predict their students' actions, which made employing a new teaching strategy futile. Obviously, affordances of new technologies can only be useful when teachers adopt and integrate technologies in science teaching with fidelity. On the other hand, teachers might be ambivalent about adopting innovations in their teaching. For example, Kang et al. (2020b) found that science teachers in South Korea demonstrated both traditional and innovative approaches to science teaching. The conclusion of McCrory Wallace (2004) clearly shows situations of teachers confronting a new teaching approach with technological innovations:

Teachers may explicitly become *curriculum makers* [emphasis added] ... as they choose resources and design activities. They may find themselves thrust into the role of *novices* [emphasis added], even though they have years of experience.... Alternatively, teachers may choose to use the internet in ways that replicate textbook use, *forgoing* [emphasis added] some of the proposed benefits ... (p. 482)

Yang et al. (2015) demonstrated the state of science teachers' use of digital technologies in South Korea prior to COVID-19. By examining science teachers' utilization of ICT tools for teaching, the study showed that science teachers were familiar with ICT tools for contextual learning, adaptive learning, and ubiquitous learning, but they rarely utilized tools for interactive collaborative learning and learner-directed learning. In particular, most teachers in the

study skillfully used online interaction programs for formative assessment purposes but only a few used such programs in facilitating student collaboration. Teachers were also found to be good at making learning resources available for students to use anytime and anywhere, but they rarely recognized the need for supporting students' self-directed learning. These findings indicate that teachers focused more on individual cognitive learning directed by themselves and less on collaborative social learning directed by learners. Similarly, in a study comparing South Korean and Canadian science and mathematics teachers' perceptions of using technologies in teaching, it was found that South Korean teachers emphasized the goal of teaching subject matter knowledge more than did Canadian teachers (Oh, 2016). These studies indicate that South Korean science teachers tended to use ICT technologies in a traditional way of teaching.

2.2 *Science Teaching Practices*

Because social practice theory informed our conceptualization of this study and data analysis and interpretation, we briefly reviewed social practice theory and the literature on science teaching practices relevant to this study.

2.2.1 Social Practice Theory

Social practices are what people do customarily or habitually in social systems such as schooling (Schatzki, 1996). Practices are "embodied, materially mediated arrays of human activity centrally organized around shared practical understanding" (Schatzki, 2001, p. 11). Practices are embodied in that cognitive capacities such as skills, tacit understandings of knowhow, social norms, and dispositions shape human social activities (Barnes, 2001). Practices are thus achieved as individuals adapt their actions according to those of others and demonstrate social norms perceived by group members. In other words, actors' cognitive resources are shown in the performance of practices.

The social norms or practical understandings of tacit rules make participation in practice possible, giving stability. At the same time, variations of practices emerge by the dynamic nature of practices (Schatzki, 2001). Practical understandings are schemas that produce usual practices, but also, "agency arises from the actor's knowledge of schemas, which means the ability to apply them to new contexts." (Sewell, 1992, p. 20). "Because the schemas implicit in arrays of resources can be 'read' in multiple and sometimes competing ways, transformation as well as continuity of structures is possible" (Swidler, 2001, p. 88). Thus, being able to enact practices implies that the actor has the ability to reinterpret or utilize resources in various ways, even with creative innovations (Barnes, 2001).

Practices are also materially mediated in that humans and materials reciprocally constitute one another. Studies of scientific practice have demonstrated “mutual tuning of social and material agency” (Pickering, 2001, p. 172) in which tools or machines produced by human agency also transform human experiences. For example, the locomotive train was invented to be used as fast transportation, but it also brought a new way of perceiving the landscape (Pickering, 2001). Similarly, information technologies not only solve practical problems inherent in their original purposes but also redefine what humans do with them.

This notion of practice helps frame our understanding of situations where teachers apply what they know as rules of science teaching to new situations, in this case, online education. Shared teaching practices provide teachers with a common framework for online teaching practices, which might result in similar online teaching practices as emerging shared practices. At the same time, variations in teachers’ improvised practices could expand the horizon of teaching practices, bringing in differences in teaching practices on site and online. Technological tools utilized for online science teaching might in turn also bring new ways of science teaching in a process of mutual tuning. Such a balance between staying the same and adopting oneself to the new situation of online teaching may vary from teacher to teacher depending on various factors such as digital tools and individual perceptions of teaching contexts.

The variation or deviation from on-site teaching practices manifested during online teaching can be conceptualized as emerging practices. Zhok (2009) proposed that learning new practices is analogous to gaining new complex habits. Gaining a new complex habit starts with an imitation without deep understanding of what it entails, and intrinsic motivation to keep adapting the initially unfamiliar imitation in response to its effects is necessary for making it a routine practice. Thus, it is likely that teachers might initially imitate on-site teaching when teaching online but keep adapting their initial trial of online science teaching until they develop their own routine practices.

2.2.2 Science Teaching Practices

From the social practice perspective, science teachers’ practices can be defined as patterns of action distinct to the role of a science teacher in a specific school context at a specific time. Science teachers’ practices identified as “traditional” typically focus on subject matter delivery where students are considered passive learners, whereas teachers’ practices identified as student centered focus on student-initiated learning or meaning making. Over the past several decades, practices for inquiry science teaching such as giving students opportunities for

doing science or talking science have been promoted for meaningful science teaching and learning (Hodson, 2014; Lemke, 1990; Mortimer & Scott, 2003).

Regarding science teaching practices promoted in recent science curriculum reforms, Kloser (2014) identified nine core secondary science teaching practices agreed upon by science education experts in the United States: engaging students in investigations, facilitating discourse, eliciting student thinking, providing feedback, constructing models, connecting science to its applications, linking science to phenomena, building classroom community, and focusing on core science ideas. These practices, Kloser noted, show recent emphasis on sociocultural learning and dialogic approaches to science teaching in which students collaboratively construct scientific meanings while teachers play the role of a facilitator (Lemke, 1990; Mortimer & Scott, 2003; Wertsch, 1985).

The core science teaching practices identified by Kloser (2014) reflect ideal practices in terms of sociocultural and dialogic learning theories that are student centered while actual classroom activities would be a mix of teacher-directed and student-centered ones. The 2015 PISA survey showed that across all participating countries, teacher-centered practices such as explanation of applications and relevance to students' lives were prevalent (Mostafa et al., 2018, p. 21). PISA 2015 also showed that students in South Korea (mostly in high schools) experience less inquiry-based science teaching and more teacher-centered instruction than their international peers (Mostafa et al., 2018, p. 18). Sociocultural and dialogic approaches to science teaching do not appear to be the norm for high school science teaching in South Korea.

3 Methods

3.1 *Participants*

Given the demanding situation, rapport was considered to be the most important factor, allowing participants opportunities to provide honest, in-depth, and rich answers without feeling emotionally burdened with disclosing their teaching practices. Thus, convenient and purposeful sampling methods were utilized. Physics teachers in a professional network with the second author of this manuscript, who is an in-service physics teacher, were contacted personally and invited to participate in the study. Among the teachers who expressed their intention to participate, five teachers who were teaching Physics I and three teachers teaching Physics Experimentation were selected to represent a range of school locations and districts, teaching experience, and types of online teaching (Table 1). In addition to gender and years of teaching, school

TABLE 1 Summary of participants' information

Subject	ID	School location (School district)	Gender	Yrs. of teaching	Online class types utilized ^a
Physics I	A	Capital city (SM)	F	9	ASOI (2)
	B	Rural area in the southwest (JB)	F	10	ASOI (3)
	C	Rural area in the southwest (JB)	M	13	ASOI (1)
	D	Rural area in the middle west (CN)	F	7	ASOI (3)
	E	Urban area in the middle west (SJ)	F	7	SOI and ASOI (3)
Physics Experimentation	F	Urban area in the southeast (EG)	F	7	PAB (2)
	G	Suburban area near the capital (KD)	M	7	ASOI (3)
	H	Urban area in the middle west (SJ)	M	3	SOI and ASOI (3)

a SOI: synchronous online interaction based, ASOI: asynchronous online interaction based, PAB: project-assignment based class.

locations and districts were considered in the selection because each school district had different levels of support for online teaching, and school locations are related to digital infrastructures and student backgrounds.

All but two teachers were graduates of undergraduate physics teacher education programs while the other two were graduates of physics program with additional teacher certification programs: a master's program in physics education (Teacher F) and an undergraduate certification program (Teacher H).

Most teachers in this study were teaching two or three subjects, but Teacher H was teaching four subjects (Physics I, Physics II, Physics Experimentation, Advanced Physics) at the time of the study. The teachers taught between 15 to 18 class periods per week, and the number of students per class ranged from 22 to 28.

3.2 Data Collection

Data for this study was collected from the beginning of the academic year (April 2020) till the beginning of the second semester (October 2020). The

sources of data included interviews with teachers, online class observations, and online content related to observed lessons. Teachers were interviewed twice, at the beginning (April 2020) and end of data collection (between September and October 2020). Interviews were semi-structured in that a set of general questions was prepared prior to the interview and sub-questions were generated during each interview based on responses to the general questions. Initial interviews were about teacher background information, online teaching conditions of each teacher's school, teachers' goals and purposes of physics teaching, and teachers' ideas about professional knowledge and skills needed for online teaching and using technology. These questions were based on the literature on science teaching practices (Kang & Wallace, 2004, 2020b; Mishra & Koehler, 2006). The initial interview included questions such as "What is the educational goal of Physics I [or Physics Experimentation]?" "What do you want your Physics I students to learn?" and "What did you focus on when preparing for online teaching and why?" The second interviews were also semi-structured, and interview questions were mainly about teachers' reflections on various aspects of their online teaching during the first semester. The second interview included questions such as "Please tell us in detail what you had to prepare for your online class and how you prepared it differently from face-to-face classes," "How are interactions with students in online classes different from those in face-to-face classes? What are the strengths and weaknesses of each?" "What are the pros and cons of your chosen learning management system, software, platform, hardware, etc.?" "How has your online teaching experience changed you?"

The second interviews were also used as member checks to help confirm teaching patterns identified in the observation. Interviews took from 1 to 2 hours each time, and all of them were transcribed for analysis.

Online classes were observed and recorded during the first semester of online schooling. Observations of each teacher's class stopped when patterns of classroom teaching were repeatedly identified. Observed class periods of each teacher ranged from 6 to 18. Online content was collected along with the observations and used to supplement observation data.

For class observations, Physics I was selected because of the expertise of the authors, and Physics Experimentation was selected because it could provide an insight into how teachers deal with an experiment-focused course in online teaching conditions. In the current South Korean curriculum, discipline-specific sciences such as physics and biology are offered to Grade 11 as elective subjects for the first time in general high school. As such, in most schools involved in this study, Grade 11 students were taking Physics I while Grade 12 students (the last year of high school) were taking Physics Experimentation

classes. The popularity of Physics I can be inferred from the ratio of students' preferred subject for their college entrance examinations. In the college entrance examination administered in 2020, about 13% of students took the Physics I test while about 28% took the Biology I test (Korea Institute for Curriculum and Evaluation, 2020).

In only one school (Teacher D's school), Grades 11 and 12 students were taking Physics I together. Students in Physics Experimentation took Physics I the prior year, and some of them were taking Physics II concurrently. As elective subjects, Physics I and Physics II are designed for those who are interested in studying STEM majors in college; thus, they are supposed to provide fundamental ideas for future STEM majors. As such, students in Physics I and Physics II classes might select the subject tests on their college entrance examinations. On the other hand, Physics Experimentation is not a subject for college entrance examination but is typically taken by students who want to generate learning experience to be included in their college application. Among the eight teachers in this study, seven were teaching in general public high schools where most students were assumed to apply for college whereas one (Teacher C) was teaching in a small private vocational school. The number of 50-minute class periods per week assigned to each subject ranged from two to three except for the case of Teacher C, who taught Physics I only one period per week.

3.3 *Data Analysis and Credibility*

Data analysis was conducted inductively (Miles & Huberman, 1994). The data was carefully read and coded by the authors separately and coding results were discussed later to come up with agreed-upon coding, categories, and themes. Data analysis began with initial interviews, and interview topics served as initial categories of data. Codes were assigned to units that were typically phrases and sentences separated by meanings. For example, codes of the educational goal of teaching physics included ways of seeing the world, logical thinking, understanding of how things work, and supporting study in college. These codes were grouped into themes such as teaching for conceptual understanding, teaching for physics perspective, and teaching for further education.

The observation data were coded based on the concepts drawn from the literature on online learning and core science teaching practices. Based on Garrison et al.'s (2010) key online lesson elements, we grouped similar concepts in the literature to identify teaching practices shown in the observation data (Table 2). These categories were regrouped into themes as we presented in the result section. Units of analysis of observation data were events that ranged from several seconds (e.g., greetings) to several minutes (e.g., performing lab

TABLE 2 Coding frame for observation data

Garrison et al. (2010)	Social presence	Cognitive presence	Teaching presence
Walker & Fraser (2005)	– Student inter- action and collaboration	– Personal relevance – Authentic learning – Active learning	– Teacher support
Lim et al. (2013)	– Interactive and collaborative learning	– Contextual learning – Learner-directed learning	– Adaptive learning
Kloser (2014)	– Facilitating scientific discourse – Building collabora- tive learning community	– Engaging in investigations – Constructing models – Relating to applications – Relating phenomena – Focusing on core ideas	– Eliciting student thinking – Providing formative feedback

procedures). Each event was coded based on indicators belonging to the coding concepts listed in Table 2. For example, teachers’ use of everyday examples was an indicator of personal relevance, assigned to cognitive presence category. Among the coding concepts, student autonomy and ubiquitous learning were excluded in reporting the results of this study because the two items are closely related to the learning system rather than teaching practices. They are not present in Garrison et al.’s (2010) categories because they are assumed to be defaults of the online learning system, and, in the same vein, they are not present in Kloser’s (2014) items, which are based on face-to-face science lessons. Thus, the two concepts were more for comparing affordances of online and offline teaching, which was not examined in this study.

The observational data analysis results were compared with those from the initial interview data analysis to identify consistent patterns across different data sources for each participant. Profiles of each teacher’s teaching practices were constructed through repeated comparison. Once teachers’ profiles

were constructed, they were compared to extract commonalities and differences between teachers. At the end, teacher profiles were grouped based on the degree of interactions, student participation, and student self-directedness that were the most distinctive features to emerge from the data. The initial analysis results were confirmed through member checking during the second interview. The second interview provided explanations of teachers' actions in the words of participants, which helped further refinement of data analysis. In so doing, data from the three sources for each teacher were triangulated, and consistency and inconsistency in the data were identified to understand each teacher's teaching practices.

For credibility, analyst triangulation, multiple data source triangulation, and member checking were used (Patton, 2014). Both researchers conducted all the data analysis processes separately and then came together, at which point commonly agreed-upon analysis results were drawn. The consistency of findings generated by data from various sources was checked, and member check was also conducted during the second round of participant interviews to validate previously identified patterns of teaching.

4 Results

In the context of being underprepared for involuntary online teaching, this study aimed at identifying emerging online physics teaching practices and professional development opportunities from the experience of online teaching. From a social practice theory perspective, it is important to point out up front that the teaching practices illustrated in the results are snapshots of evolving social practices originated from mutual tuning between the teacher, students, and/or educational system and between the teacher and their technological tools (Pickering, 2001; Sewell, 1992). Findings of this study were organized into three themes: features of online teaching practices that distinguished teachers from one another, essential practices of physics teaching commonly found across teachers, and professional development opportunities.

4.1 *Teaching Emphasis*

The eight teachers' online physics teaching was distinguishable by their teaching emphases. Three discernible physics teaching emphases emerged across the eight teachers including content explanation (Teachers A, B, C, and D), participatory learning (Teachers E, G, and H), and independent first-hand experience (Teacher F).

4.1.1 Content Explanation Emphasis

Explanation of content is a signature practice of teaching, and as such was common across all teachers. Teacher in this group, however, used lectures as the main part of their physics lessons and had minimal interactions with students. They organized all of their online lessons with digital video recordings of physics concept explanations and related student work. All student work was to ensure that students were watching and understanding the pre-recorded lectures. This two-part lesson resembles a lecture and worksheet form of on-site lesson. As demonstrated by the following excerpt from Teacher B's interview, teachers in this group commonly stated that they wondered whether students watched the lecture videos attentively or just played them while doing something else. Thus, these teachers created worksheets that students should complete and submit online as assignments to prove they studied the content to some degree.

I told the students to just take a picture [of the completed worksheet] and upload it on Google Classroom. And during the inspection process, I would send them back if incomplete after marking zero points, sending a note, "Submit it again," in a private comment.

Teacher B, post-interview

The worksheets included quizzes about the content and content summary statements with blanks that students needed to fill in. Due to the lack of interaction with students, teachers made special efforts to make the lecture comprehensible, "Because I can't meet students in person, I am not sure whether I will get questions from students [when they don't understand]. So [when filming] I try to explain things in detail as much as possible" (Teacher A, pre-interview).

In providing lectures, teachers' application of technology varied. Teacher D selected physics lectures provided by the public educational broadcasting system (EBS lectures) and edited and uploaded them to the LMS each week of the semester. Teacher D chose to use the EBS lectures because her colleague who was teaching Physics I together wanted that, and she "did not have enough time to record lectures of all three subjects" she was in charge of (pre-interview).

According to Teacher D, utilizing EBS lectures seemed to be common, and Physics I is appropriate for such an approach:

The content of Physics I is fairly standardized [by the national curriculum] and has less degree of freedom than other subjects [because of the college entrance examination]. So, I think the EBS lectures are good enough.... Typically, teachers, including us, edit the EBS lectures to reduce the content, because the content is too much, and then upload it

[to LMS]. Then, we upload supplementary materials such as quizzes or summary activities ... and then we ask students to complete the supplementary materials.... However, I would have filmed my own lecture, if I taught Physics I to all classes in our school.

Teacher D, post-interview

In line with the tradition of assessing all students who are taking the same subject in a school with the same written exam, the two teachers of Physics I in Teacher D's school used EBS lectures to standardize teaching content across all students. However, Teacher D, as shown in the excerpt, indicated her perception that a better choice would have been to record lectures on her own.

The EBS lectures were online content used by students prior to COVID-19 to study after school in preparation for college entrance examinations. The Ministry of Education made them available to all teachers to use by clearing copyright issues to reduce teaching demand required by a quick switch to online schooling. Just as was indicated by Teacher D, use of EBS lectures was not desirable in the teachers' perceptions:

Personally, this is my job and work to do, and my students are the ones who have been taking classes from me. They will be assessed by me. Given these facts, uploading lectures made by others doesn't fit my conscience. So, I film my own lecture.

Teacher B, pre-interview

Actually, teachers in my school use EBS lectures for general subjects. For special subjects on which EBS lectures are not available, they record their voices over PowerPoint slides. In my case, I film my lectures on my own because Physics I has only one class period per week, and I know what my students need.

Teacher C, pre-interview

The other three teachers in this group recorded their lectures on their own. Teachers A and B used pen tablets, recorded lectures using a digital whiteboard, and uploaded them to LMS. On the other hand, Teacher C filmed himself giving a lecture in the classroom writing on a whiteboard using a cell phone on tripod because he wanted to make his students "feel as if they are attending a class in person" (pre-interview). After the semester, however, Teacher C lamented that he was not able to utilize benefits of filming:

Filming a lecture with a smartphone has the advantage of not having to buy additional equipment and not having to learn functions [of technical

tools and programs].... The weakness is that it was hard to film alone. It's hard to take a close-up shot by myself, so all the scenes look the same.

Teacher C, post-interview

On the other hand, both Teachers A and B recorded lectures using tablets. Teacher A sometimes used textbook pages accompanied by shots of the digital whiteboard where she wrote, and other times used only digital whiteboard for content explanation (Figure 1a). Teacher B recorded tablet screens using either documents she created or textbook pages on which she annotated (Figure 1b). Students of these teachers had textbooks at home and documents used in the lectures, and worksheets were available on the LMS to download so that they could watch the lectures along with textbooks and/or texts provided.

The lectures that Teachers A, B, and C recorded all looked similar to EBS lectures in that the teachers provided detailed explanation of content as monologues.

(a) Example of Teacher A's screen (textbook page and digital whiteboard shot on the same screen)

$$F = \frac{\Delta p}{\Delta t} \rightarrow \Delta p = F \Delta t$$

위 식에서 두 물체가 충돌할 때 물체의 운동량 변화량은 물체가 받은 압력힘뿐만 아니라 힘이 작용한 시간과도 관계가 있음을 알 수 있다. 따라서 물리학에서는 물체에 작용하는 힘 F 와 그 힘이 작용한 시간 Δt 를 곱한 물리량을 **충격량**으로 정의하고, 충격량 I 를 다음과 같이 나타낸다.

$$I = F \Delta t$$

충격량은 크기와 방향을 함께 나타내는 물리량으로, 충격량의 방향은 힘의 방향에 같다. 충격량의 단위는 $\text{N} \cdot \text{s}$ 이다.

충격량 (I)

① 크기만 바뀔 수 있음

② $I = F \Delta t$ 단 $\text{N} \cdot \text{s}$

(b) Example of Teacher B's screen: annotation on teacher-generated text

(v1)

처음 v_1 : → 나중

(v2)

처음 v_1 : → 나중

If, $v_1 < v_2$ $\Delta v = v_2 - v_1 = v_2 + (-v_1)$
 $\Delta v < 0$ $\therefore A$ 의 방향 : →

If, $v_1 > v_2$ $\Delta v = v_2 - v_1 = v_2 + (-v_1)$
 $\Delta v < 0$ $\therefore A$ 의 방향 : ←

☆ 가속도 방향과 속도 방향의 관계

1. 속도 방향과 가속도 방향이 같은 경우 : 속도의 크기 ↑

2. 속도 방향과 가속도 방향이 반대인 경우 : 속도의 크기 ↓

FIGURE 1 Example of screenshot of lecture videos

Among the four teachers, Teacher B was the only one who recorded a physics lab once. She performed and recorded a lab on the conservation of momentum in such a way that students could collect data from the screen to draw a conclusion. This was “a one-time event [of the semester] to celebrate the partial opening of school buildings for on-site classes” in the later part of the semester (Teacher B, post-interview). In doing so, Teacher B received “a lot of positive feedback on that” from her students (post-interview). Teacher B’s recording of a lab was similar to Teacher G’s and Teacher H’s lab videos as described in the following section except that Teacher B did not ask for a full lab report. Just like the other lectures, the lab video was followed by a worksheet in which students recorded data and reported their analysis results.

4.1.2 Participatory Learning Emphasis

Teachers in this group also made lecture videos, but not as the major component of their classes. They provided content explanations as background knowledge, but the main activity was for students to participate in problem solving or lab reporting while interacting with the teacher or classmates. Due to the different nature of the subjects, two sub-groups in this category were distinguished.

4.1.2.1 *Participation through Problem Solving*

In the beginning of the semester, Teacher E also used recorded lectures using texts she generated and gave student work matched with each lecture. However, she stopped recording lectures soon, “because it is ineffective” (post-interview), and had synchronous online classes: “I thought it would be best to call the students by name, asking questions for answers as many times as possible, so I had online classes real-time mostly. In the beginning, I recorded lectures and used them” (Teacher E, post-interview).

She used an online meeting program where she could share her screen with students and everyone in the meeting could annotate. During the synchronous online class, she questioned students to check their understanding of content and asked them to solve problems to apply what they just learned. When students were solving problems in the virtual classroom, they also annotated on screen to explain their thinking (Figure 2).

After each student shared their ideas or problem solving, Teacher E clarified or elaborated on it, and sometimes, if a student failed to make annotations or did not have the proper equipment to annotate (e.g., participation through smartphones), she did it for the student according to what the student said. Thus, in Teacher E’s classes, students spoke and shared their ideas with their classmates. While every activity occurred on screen, the interactions looked very similar to those in on-site class. To ensure universal participation from

[Problem: Finding velocities of two objects after collision]

FIGURE 2 A screenshot of student problem solving on screen (annotation on the right) and teacher elaboration (annotation on the left; Teacher E)

[Problem: 6. In the following situation, find the acceleration and the force that the object pushes against each other.]

6. 다음 상황에서 물체의 가속도와 물체가 서로 미는 힘을 각각 구하시오.

FIGURE 3 Example of student problem solving on screen as performance assessment (Teacher E)

students, Teacher E used public problem solving in the virtual classroom as a performance-assessment task (Figure 3) “so that everyone presented at least once” (Teacher E, post-interview).

4.1.2.2 Participation in Labs

It might be natural to expect Physics Experimentation class to be practical and participatory. Two of the Physics Experimentation teachers (G and H) were categorized into this group of teachers who engaged students in lab activities with slightly different learning goals. Teacher G emphasized cognitive skills while Teacher H emphasized lab process skills:

After all, Physics Experimentation is essentially about experiments, so students should figure out the difference between theory and reality through the concept of error and should learn it for the purpose of cultivating logical thinking skills.

Teacher G, pre-interview

The most important thing is experiencing experiments ... getting used to using measurement tools, learning how to write a lab report and interpret data and so on.... writing lab reports is to learn how to communicate what one knows to others.

Teacher H, pre-interview

Given the slightly different learning goals, Teachers G and H had shown similarities and differences during online laboratory classes. They both provided recorded lectures on background knowledge and recordings of lab activities. For lab recordings, they performed lab procedures in front of the camera on behalf of students while giving students opportunities to collect data from the screen in various ways (Figure 4).

The lab videos provided a sense that the teacher acted as a member of a lab group who manipulated lab equipment for the group while the students collected data. For example, in a lab recording about uniform circular motion,

(a) Time measured and shown to students

(b) Showing data imported from the recorded motion

FIGURE 4 Examples of ways teachers provided data for students

Teacher G swung an object hanging at the end of string in horizontal circles, and students were asked to watch the swirling in the video and measure the time required for the object to swing through a set number of revolutions. During experiments about motion, both teachers recorded motions of objects from a lab setup and used a computer program that transferred videotaped motion to time and location in both table and graph forms from which students could obtain data (Figure 4b). The teachers sometimes filmed labs with the help of a fellow teacher, and they included typical mistakes to try and make their classes more realistic. All these provided a sense of the teacher being a member of a lab group performing lab procedures for those watching the videos.

The teachers provided students with lab report forms in which lab procedures were already written. When the teachers performed labs, they carried out lab procedures in front of the camera as they read them aloud. All the labs they taught online, therefore, were cookbook style, mostly testing hypotheses while students practiced data analysis and drawing conclusions. Also, to complete lab reports, students had to study the teacher-recorded lectures on the necessary background knowledge for the lab.

These cookbook-style lab activities continued throughout the semester in Teacher H's case even when his school partially opened later for on-site classes. However, Teacher G was dissatisfied with cookbook-style lab classes and tried two other different types of lab activities during the semester. First, he used computer simulations to do mechanics labs. He taught simulation programs online and asked students to run the simulations on their own. Thus, students were able to test their ideas to some degree. This was reflective of his face-to-face lessons, which centered on student-initiated inquiry:

It [Physics Experimentation] was originally meant for students to write preliminary reports, study theories, and conduct experiments with an understanding of the purpose and the process of experimentation. When I taught it online, I couldn't do all of them. Because students couldn't actually do the experiments, it was not meaningful.

Teacher G, post-interview

When school opened for on-site class in the later part of the semester, Teacher G switched to the kind of lab activity he used before. He asked students to complete a physics experiment of their choice. The topics were at the students' discretion, "as long as they fit the purpose of the Physics Experimentation course" (Teacher G, student guidelines), and the project lasted 2 months, consisting of planning, carrying out, presenting, and reporting steps.

In terms of differences in the two teachers' learning goals, cookbook-style online lab activities appeared to be effective in addressing lab skills (learning goal of Teacher H), but students' cognitive involvement at a higher level such as logical thinking (learning goal of Teacher G) appeared to require either face-to-face teaching or further strategies and techniques if done online.

4.1.2.3 *Interaction Practices*

Teachers G and H clearly showed different ways of interacting online with students and between students. Teacher H's lesson structure was similar to that of the content explanation emphasis group in that he used online videos and corresponding lab report assignments. However, Teacher H interacted with students mostly in real time. He required students to log on to the online chatting program during the scheduled class period so that students could interact with him in real time while they were watching the same lab video and performing required learning activities such as data collection and analysis while texting the teacher when questions arose. Thus, the class looked almost like a real-time online lesson, although the teacher did not necessarily monitor student activities directly. In doing so, students had a choice of watching lab videos on their own schedules, and they had a scheduled time to consult their teacher. For interactions, students could choose to use private or group chat, which allowed interactions between the teacher and students and between students. Therefore, the interactions were more in control of students than the teacher.

Teacher G problematized the lack of interaction between students and wanted to accommodate students' preferred modes of interacting online:

Students are not used to online real-time communication ... Students ask questions privately so you can't share them [with other students]. Offline, when someone asks questions in class, you respond to the student, so the others could hear it. That way, the concepts that other kids have understood vaguely can be cleared up. But online, you explain it to the one who asked, one on one.

Teacher G, post-interview

Teacher G interacted with students asynchronously, which was an accommodation of students' preferred online interaction methods and also helped him to incorporate student ideas into lesson videos. For each lab, he gave students a number of assignments and encouraged them to ask any questions they had by making comments on each task posted on shared online pages either privately or publicly. Most of the time, students asked questions or commented on tasks

privately, and Teacher G responded to them individually. He then posted select student questions or comments along with his responses online so that all his students could see. In his videos, he also frequently made comments on student ideas identified in personal communications. In doing so, his videos included students' voices. Thus, most asynchronous interactions happened between the teacher and each student, but indirect idea sharing between students occurred virtually by the teacher's public sharing of student ideas and comments. For such sharing, Teacher G tried to identify student ideas routinely:

I try to communicate with students.... Feedback can be private or public by making comments on or posting questions to the work the students have uploaded. Also, in the discussion section of the lab report, I created a space for students to make comments on anything about the class or lab. Also, in quizzes I include questions about student thinking and feedback on any part of class. Once I gather student feedback, I share it with students and comment on it when filming lectures.

Teacher G, post-interview

Teacher G's emphasis on sharing ideas with and between students can be clearly demonstrated by his first lesson video. He surveyed students online prior to the first class about their expectations for the class. He reviewed the survey responses in his first lecture recording (Figure 5), which helped students get to

FIGURE 5 Teacher G: Survey responses by students shown in a video recording

know their peers' thoughts. This was a typical way that Teacher G made student ideas visible and shared. Using online tools such as online surveys and gathering and organizing student ideas "did not take much effort" (post-interview).

In some lab activities, Teacher G also uploaded and shared documents on the cloud for students to work on collaboratively. For example, on the topic of SI unit, one assignment was for students to measure the thickness of a textbook and add their measurements to a spreadsheet in a shared cloud drive. The measurements recorded in the spreadsheet were discussed in the following lecture video in relation to measurement errors. In such a way, students were able to see their own and their peers' work in the video recordings.

4.1.3 Independent First-Hand Experience Emphasis

Teacher F was unique in that she dedicated all her class time to students' self-directed projects. She had learning goals similar to Teacher G but emphasized students' first-hand experience:

I think the purpose of conducting experiments is to see for yourself that textbook results will not come out when you conduct the experiment yourself.... Direct experience is more important than indirect experience. There are plenty of opportunities to have indirect experience with YouTube or something like that. But the only thing students can do with their hands is experiments that can be done at school.

Teacher F, pre-interview

The emphasis on first-hand experience and knowing the difference between theory and reality may have originated from the fact that students in Physics Experimentation class were those who already took Physics I, which was mostly about concepts and principles. Thus, for this class, the teacher wanted students to test whether what they had learned conceptually could be observed and measured directly.

In spite of her emphasis on students' personal experience of conducting physics experiments, apparently, she was not able to provide students with any opportunity to conduct experiments physically during online class. All her online classes focused entirely on lab design projects. Seven weeks into the semester, her school opened for on-site teaching, and Teacher F had students perform the experiments they had designed.

Teacher F had one block period (100 minutes) per week for Physics Experimentation class, with 17 block periods per semester. Over the first 7 weeks, students completed three physics experiment design projects. Students were initially asked to investigate for themselves possible physics experiments that

they could conduct if school were open. They then reported their selections with rationale and obtained teacher feedback via email to finalize their selection. Teacher F asked students to have at least one experiment in mechanics and one in electricity and magnetism so that students were “exposed to various types of physics experiment in various fields” (post-interview). Teacher F provided students with project report forms that consisted of items such as topic, title, purpose, theoretical background, materials, and procedures. Once the report was submitted, Teacher F provided feedback on “how realistic the design was to perform with school lab facilities” (post-interview). Throughout the design process students were independent in that Teacher F was rarely involved in student projects:

With students, I only contacted them via email. In my other courses, I used a group chatting program to interact with students. Physics Experimentation was not a class that I directed but rather a class where students had to take their own initiative through various tasks. So, I rarely interacted with them.

Teacher F, post-interview

After the semester, Teacher F was satisfied with the class except for addressing a smaller number of experiments than before:

I think my intentions are well reflected. First, the students turned in quality assignments and the feedback was well received.... Student satisfaction was high because, I think, they were able to do the experiments that they wanted at that time. It was really good that they actually conducted experiments that they were interested in. But the unfortunate thing is that we didn't have much time to perform as many experiments as before.

Teacher F, post-interview

Teacher F's strong emphasis on student initiated first-hand lab experience and blending of online and on-site teaching for different parts of physics experiments made her class distinct.

4.2 *Essential Practices of Physics Teaching*

The features of physics teaching that the teachers tried to preserve from on-site teaching can shed light on what the teachers perceived to be essential elements of physics teaching. These features were identified from lesson observations and the teachers' comparisons between on-site and online

teaching during interviews. Three features were identified: ensuring student engagement in learning, connecting physics models to everyday phenomena, and model testing. These features were common but had varying degrees of emphasis between teachers.

4.2.1 Ensuring Student Engagement

Because they were not meeting students face to face, all teachers were concerned about students' engagement in learning. All of them created student work to ensure their engagement in learning, using the same practice they utilized in face-to-face teaching. All student work created by the Physics I teachers was similar in that it included a summary of content with blanks that students could fill in and application problems that were either solved by the teacher during the lecture or were intended to be solved by the students. The most common type of student work created by Physics Experimentation teachers was lab reports with varying degrees of openness.

As shown in the previous section, some of the teachers utilized interactions with students in various ways to engage them in learning. Obviously, real-time interactions demonstrated by Teachers E and H provided feedback immediately, which seemed to be more effective in identifying specific needs of students. However, Teacher G demonstrated that asynchronous interactions and delayed feedback were not necessarily ineffective but would require much more planning and effort by the teacher to provide students with active and meaningful interactions.

The differences in interaction practices were related to the teachers' evaluation of online teaching. The teachers who used lecture videos (Teachers A, B, C, and D) had a hard time knowing the effect of their teaching because their only means of checking was whether students had completed assignments, and they indicated regrets about missing opportunities to determine students' understanding, which had been possible during on-site teaching:

In a face-to-face [class], it is easy to grasp the needs of many, if not all, so it is easy to make modifications that reflect their needs. Online, it is difficult to know exactly what the needs of learners are, so I review my videos myself and make decisions on what to change.

Teacher A, post-interview

By resorting to students' watching videos and completing work assigned, these teachers attributed the effect of online teaching to students' self-motivation:

There is a limit to encouraging students who are passive and cannot work hard on their own. So, I think online classes are really good for kids who can do it on their own, but I think it's really bad for those who can't do it on their own.

Teacher B, post-interview

However, the teachers who had relatively more interactions with students or provided feedback frequently (teachers E, F, G, & H) demonstrated a more concern for student participation in learning rather than their motivation. A representative case would be teacher E who switched from asynchronous to synchronous online teaching that enabled her to observe and encourage student engagement directly to tailor classes to student needs. The quick switch seemed to be due to her emphasis on meeting the needs of students to engage them in learning:

I thought that there was no difference between me and a private academy instructor if I took a video and uploaded it online.... So, I decided that I should give a class that could be more tailored to learners.... It got me thinking about a way that was a little more efficient and the kids would be interested in and like.

Teacher E, post-interview

Through real time virtual interactions, teacher E was able to check student engagement in learning and their progress. In doing so, teacher E's review of the effect of online teaching was not much about student motivation but more about participation, i.e., how much she could have students be "willing to speak on screen" (post-interview).

4.2.2 Connecting Models to Everyday Phenomena

All teachers addressed physics models in relation to everyday phenomena and their application in problem solving in real life (Figure 6). This was mainly due to the fact that the content of the subject included physics models of phenomena observed and experienced by students in everyday life.

FIGURE 6 Examples of connecting models to everyday experience

4.2.3 Model Testing

All the experiments that students experienced online in this study, including Teacher B's onetime lab video, were about testing models that students became familiar with from Physics I class. Students started with studying theoretical backgrounds from which hypotheses for testing were drawn. In particular, students' study of theoretical models and evaluation of models through data analysis were emphasized. These activities were mostly limited to confirmatory experience, which lacked opportunities for students to argue about experiment design or results:

In face-to-face [classes], students get materials and set up their own experiments. They naturally become curious about [experimental] design principles.... I had to think about what to do with an experiment if I were to do it online.... [It became] observation and data sharing. That's the biggest difference.

Teacher G, post-interview

On the other hand, Teacher F was able to maintain completely student self-directed model testing in her class, from selection of topics to reporting lab

results, which was just like her on-site teaching. Through the student-designed experiments, students were able to fully experience model testing. This was possible because of the possibility of using a blended learning approach in which online classes were devoted to designing experiences, and on-site classes to conducting them. Besides on-site teaching opportunities, Teacher F “might have had students only design experiments” (post-interview). Similarly, Teacher G also had one project of student self-directed model testing when school opened for on-site teaching.

The Physics Experimentation teachers kept distinguishing physical first-hand experience from virtual or indirect experiences. From this perspective, the teachers’ goal of providing opportunities for the direct physical experience of model testing was unachievable in fully online classes. With advances in technology such as virtual or augmented reality, a new perspective on the goal of a Physics Experimentation class might be needed. Further critical reflection on the pedagogical meaning of direct experience in laboratory is necessary.

4.3 *Professional Development Opportunities*

Although teachers were forced to teach online without much preparation, the teachers in this study were able to form patterns of online teaching practices for a brief time. They learned or developed new practices, and the commonality of some online teaching practices demonstrated emerging shared practices, which were evidenced when the teachers described their online teaching practices as routines. When teachers described their online teaching practices during post-interviews, they sounded as if they had been teaching online for quite some time:

I create a worksheet and inspect it [for any error]. Then [I] convert it to PDF, upload it on the tablet, and record a lecture with it. If I record it right away, I may stutter a little. So, I print it out, practice with it, and put it next to the tablet. Then, I record my lecture on the tablet. After that, I edit the video using an editing program, upload it to YouTube, and upload the URL to the LMS.

Teacher B, post-interview

The similarity between online lectures that existed prior to COVID-19 and the ones created by the teachers during the pandemic was reminiscent of the course of practice development proposed by Zhok (2009). Based on traditional norms of teaching, meaning lecturing and worksheets, teachers seemed to naturally imitate online the in-person lectures they were familiar with. The educational implications of the imitated online lessons were understood only much

later. The teachers who recorded their own lectures initially intended to tailor their lectures to their own students. However, due to their lack of interaction with students, the teachers found that they relied heavily on student motivation, while their students' personal learning trajectories remained vague. This belated recognition could have provided the teachers with an opportunity to critically reflect on the effect of traditional content-focused teaching practices. Teacher E's quick shift in online teaching approaches demonstrated such critical reflection.

When asked about their professional learning, most teachers reported that they learned from online teaching experience and gained motivation for further professional development:

[Learning to teach online] reminded me of my thoughts when I became a teacher: wanting to learn more, and [I] didn't hesitate to take on new challenges. I want to avoid becoming an experienced teacher who lags behind.

Teacher B, post-interview

The motivation for further professional development seemed to be strengthened as the teachers gained confidence in online teaching that was seemingly formidable when started:

As I was filming a lecture for online classes, I studied how to use a digital whiteboard program and learned a recording program and editing programs. It feels like new technology skills are accumulating.... I had heard of the flipped learning approach before but didn't dare to try it. Now I have the courage to challenge myself.

Teacher A, post-interview

Also, online teaching with new technologies seemed to have encouraged the teachers to look for innovations in their teaching:

Although we had no choice but to teach online, this experience led me to the thought that I should study a new teaching method, and because society is rapidly changing, I should be interested in other methods besides the traditional teaching method.

Teacher E, post-interview

The teachers also kept adapting their initial methods of online science teaching to further develop their practices. For example, realizing the need for engaging

students in learning, some of the teachers tried to find a way to improve their lecture videos by making them more attractive and personalized:

Especially these days, I've been looking for [application] programs that can be used on smartphones.... And there's also an app called [name of application program] that makes the intro [of videos] look more like an ad.

Teacher A, post-interview

Another aspect of the teachers' continuing refinement of their online teaching practices was shown in Teacher E's quick switch to real-time online teaching and Teacher G's accommodation of students' preferred modes of online communication. These cases demonstrated the teachers' ways of offsetting some limitations of online teaching, which diversified the teachers' online science teaching practices.

As the teachers struggled with new modes of teaching, their collaboration increased, but it seemed to have functioned in a way that was not necessarily positive for developing online physics teaching practices. As shown in the cases described in this study, the usual practice of teachers who teach the same subject in one school giving all their students the same examination has typically led to teacher collaboration in curriculum design. This must have easily led to generating shared practices for online science teaching. For Teacher D, the collaboration between teachers did not help her develop unique online physics teaching practices, whereas other teachers stated how collaboration with their peer teachers helped them manage to succeed in online teaching:

From a teacher's perspective, [online teaching] made us communicate with each other because we shared new teaching methods. Since we had a lot of meetings sharing the knowhow, I think it provided an opportunity for developing a professional learning community.

Teacher H, post-interview

Teacher collaboration within schools has been promoted as an effective way of teacher development, but it has many challenges and needs support, careful design, and leadership (Dooner et al., 2008; McLaughlin & Talbert, 2006).

5 Discussion

This study examined high school physics teachers' emerging online teaching practices in South Korea during the first semester of online class mandated by

the pandemic. We identified three types of physics teaching emphases that differentiated physics teaching practices. In terms of the key elements of online teaching (Garrison et al., 2010), the participatory learning emphasis group had all three elements in balance while the other groups lacked one or two of the three elements. In particular, the type of social presence in which the teacher facilitates interactions between students and student collaboration for learning was not present in the other groups. This was consistent with findings of a prior study that science teachers used technological tools more for individual cognitive learning than collaborative social learning (Yang et al., 2015). The differences in social presence imply that teachers' online teaching practices depend on their views of learning rather than their mode of teaching. The teachers who valued interactions between students provided such opportunities online.

Although emphasis on content explanation through traditional teaching was consistent with the findings in the literature (Kang et al., 2020a; OECD, 2020; Oh, 2016), the prevalence of content emphasis among Physics 1 teachers compared to Physics Experimentation teachers indicates that the different practices were also related to teachers' perceptions of the nature of the subject or learning goals. The possible influence of teachers' views of learning, perceptions of the nature of the subject, and learning goals is part of teachers' epistemic cognition (Brownlee et al., 2017; Maggioni & Parkinson, 2008). Studies have found that teachers' epistemic cognition is closely related to teaching practices (Kang, 2008; Kang & Wallace, 2004; Chinn et al., 2011). Given the context of online teaching, in which technological tools play an important role in mediating teaching and learning, further research on how science teachers' epistemic cognition mediates their online teaching practices will shed light on understanding of science teachers' online teaching practices and role of technological tools.

As for the Physics Experimentation classes run online, first-hand experience of science labs was mostly replaced with virtual experience in which either teachers manipulated lab materials on screen or students used computer simulations. In online-only classes, missing first-hand lab experience was inevitable, which led some teachers to emphasize data analysis or design of experiment. In doing so, students' laboratory experiences were limited in comparison with on-site first-hand learning. However, by acting like lab group members, the teachers seemed to successfully preserve most student experiences in lab classes. In deciding on these approaches, teachers' decisions on how much student initiatives and how much direct experience in physics inquiry should be warranted seemed to be critical factors. On the other hand, there should be a critical reflection on preserving the old form of lab activities in online teaching. This is just like one of the choices shown in McCrory

Wallace's (2004) study where the teachers "replicate" their old ways, "forgoing" benefits that online technologies offer. Increasingly prevalent virtual experiences (OECD, 2019) require rethinking the emphasis on direct experience and the balance between virtual and real-life experience. To make full use of technological development in teaching, pedagogically meaningful forms of science laboratory experience in the digital age need to be deliberated. Online inquiry systems such as WISE have been developed and utilized, but they have not been widely adopted in schools. There should be further development and distribution of online inquiry systems, and affordances of digital technologies for meaningful and authentic online science laboratory experiences should be examined.

Among the essential physics teaching practices identified in this study ensuring student engagement in learning is an element that has been known to be the main factor of learner attrition in online learning (e.g., Kim & Frick, 2011). The existing research, however, has mostly been about online learning in higher education or adult learners enrolled by choice, rather than in mandatory education. Thus, the role of the teacher in engaging students in online learning is an important topic if mandatory school education widely adopts online or blended learning. The participatory online learning experiences shown in some cases of this study could be one way to engage students in learning, but further research on ways to engage students in online learning is needed.

The results of this study imply that professional development in online teaching in relation to learning theories, affordances of digital technologies, nature of physics or science, and online science laboratory would be effective. Over the course of a semester, teachers developed routine practices of online teaching while still refining them. The development of teaching practices followed the path suggested by Zhok (2009), from imitating existing practices to developing their own routines through social and technological tuning (Sewell, 1992; Pickering, 2001). Some practices remained in the imitation stage (content explanation emphasis, online labs) while others developed beyond. Given that these practices were from underprepared online teaching experiences, carefully designed professional development programs would help further the development of online teaching.

The findings of this study demonstrate the diversification of teaching due to the change of communication mode. Teaching in the classroom used to have globally similar practices in which verbal communication was prominent, with complementary aids from multimedia including printed materials and videos. As for science teaching, laboratory work or demonstration of phenomena accompanied by scientific argumentation in talking (lab discussion) or

in writing (lab report) also widely shared practices. However, when teaching shifted online, the traditional communication mode diversified in time and space by the inclusion of written communication through virtual meetings, emails, and comments to online posts. Given the diversity of modes of communication, some teachers tried to preserve benefits from the old mode of instant face-to-face interactions through real-time interactions. Others gave up the benefits of the old mode and used delayed text-based interactions without appropriating additional advantages from technology, decreasing interactions among students for learning. From a social constructivist view of learning, the lack of communication between students is problematic for students' meaningful learning (Wertsch, 1985). Teachers who encouraged students to share their ideas in this study demonstrated possible ways to facilitate student interactions in online learning contexts, though further strategies should be explored (Bryans-Bongey & Graziano, 2016). In addition, in online teaching, it is critical for teachers to understand students' experiences with online communication and effective online communication strategies for teaching (Nippard & Murphy, 2007; Tung & Deng, 2007). This topic should be addressed in professional development programs about online science teaching.

6 Conclusion

The application of digital technologies in education and web-based learning have been discussed for decades without much schoolwide adoption, but COVID-19 brought about the field testing of online schooling without much preparation. Given the lack of both prior online schooling practices and research on online science teaching, this study fills the gap by demonstrating the range of emerging online physics teaching practices and by providing concrete examples and images of online physics teaching. The teaching practices shown in this study can serve as vantage points in addressing online science teaching practices in professional development programs. While the online teaching practices demonstrated in this study were situated in the South Korean context, most of them are applicable to other contexts where schools and students have access to the internet. However, further research on online physics or science teaching practices in contexts with infrastructures that differ in areas such as educational system, technologies, or policies could provide different vantage points.

Given increasingly prevalent virtual experiences and educational applications of highly advanced technology such as artificial intelligence, virtual and augmented reality, and the Internet of Things (OECD, 2019), it is inconceivable

that online teaching will disappear after the pandemic. It is more likely that online teaching will be blended with on-site teaching not only to develop 21st century skills but also to increase the effect of schooling. With further research and more professional development, sophisticated physics teaching practices that appropriate the benefits of online and on-site teaching would emerge. The findings of this study shed light on the directions of professional development for science teachers when online teaching becomes a part of regular schooling. For proper understanding of online science learning and teaching, research on students' experience of online science learning is also needed.

Abbreviations

ASOIB	Asynchronous online interaction based
EBS	Educational Public Broadcasting
LMS	Learning management system
PAB	Project-assignment based
SOIB	Synchronous online interaction based

Ethical Consideration

The study was approved by the Institutional Review Board (IRB) of the first author's institution, where both authors were members at the time of the study, and informed consent forms were signed by all participants.

Publication Contexts

This paper is a re-analysis of data for the unpublished master's thesis of the second author, Juri Seo (2021) entitled, "Characteristics and TPACK of High School Physics Teacher's Remote Lessons," as part of her master's degree awarded by the Graduate School of Korea National University of Education.

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