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Science teachers' implementation of science and engineering practices in different instructional settings

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ABSTRACT

This article explores science teachers' implementation of science and engineering practices (SEPs) under different instructional settings. We compared the number of SEPs science teachers reported using in face-to-face instruction (traditional), online-only instruction (virtual), or HyFlex instruction (synchronously online and in-person) from August 2020 to May 2021. Records and artefacts of the teachers' instructional practices were collected over three one-week periods. Interview data were used to validate teachers' instructional activities, the context of SEP implementation, and their challenges when navigating the different instructional settings. Through a lens of consequential transition perspective, our findings revealed that science teachers implemented significantly more SEPs in a HyFlex or traditional setting than in a virtual setting. The results also showed that regardless of the instructional setting, elementary and secondary teachers generally implemented few investigating SEPs. Among elementary teachers, developing explanations and solutions were the most frequently used SEPs across all instructional settings. Among secondary teachers, the developing explanations and solutions SEPs and evaluating SEPs were prevalent but varied across the different instructional settings. Our findings suggest that science teachers need to continue to build their knowledge and practice of the SEPs, and have different supports to facilitate their SEP implementation in different instructional environments.

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The *Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas* [*Framework*] (National Research Council [NRC], 2012) articulates a vision for science instruction in the K-12 setting in the United States (US). In this vision, the areas of science and engineering practices (SEPs), cross-cutting concepts (CCCs), and disciplinary core ideas (DCIs) are intertwined as students engage in exploring phenomena related to science. Among these different areas, it is the SEPs that emphasise the way in which science is done. In the area of science, the eight practices consist of asking questions; planning and carrying out investigations; developing and using models; analysing

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and interpreting data; using mathematics and computational thinking; constructing explanations; engaging in arguments based on evidence; and obtaining, evaluating, and communicating information. For teachers, the SEPs ensure that students understand how to engage in investigations and what the practice entails. Given the fundamental nature of the SEPs in learning science, teachers should integrate the SEPs into their daily instructional lessons.

Educational leaders in many countries have taken note of the SEPs, which are predominant in the *Next Generation Science Standards* [*NGSS*] (NGSS Lead States, 2013). For instance, the Australian Curriculum Assessment and Reporting Authority [ACARA] (2022) emphasises the use of scientific inquiry skills, such as questioning and predicting, planning and conducting investigations, processing and analysing data and information, evaluating observations, and communicating findings. Similarly, the national curriculum in the United Kingdom also emphasises the development of science practices, such as asking questions, making predictions, planning and carrying out the most appropriate investigation, interpreting data, and evaluating data (Department for Education, 2015). Singapore's Science Curriculum Framework (Singapore Ministry of Education, 2021) also highlights the importance of practices of science, including posing/defining questions, designing investigations, analysing and interpreting data, communicating, evaluating and defending ideas with evidence, using and developing models, and constructing and designing solutions. While the specific language regarding scientific practices may vary among countries, they share a common goal of promoting science practices.

Attaining the vision of the *Framework* (NRC, 2012) is a challenge for many science teachers. Banilower et al. (2018) found that only about half of their sampled middle and high school classes had students organise and represent data, make and support claims with evidence, conduct scientific investigations, and analyse data at least once a week. They also reported that only about a third of elementary classes engaged students in these activities weekly. Across all grade bands, they found that students had limited experiences in evaluating scientific evidence and engaging in the practice of argumentation.

With the COVID-19 pandemic, many teachers had to transition their classes from the traditional face-to-face setting to a virtual (online) or a HyFlex environment (in-person and online synchronously). For many teachers, this transition was problematic (An et al., 2021). Teachers were not familiar with the online instructional platforms, nor were they familiar with teaching in an online or HyFlex modality. Unfortunately, science teachers will likely experience emergency remote teaching in the future. The occurrence of additional pandemics, climate crisis-driven weather events, and civil unrest represent possible scenarios that may prompt students and teachers to move into online environments. To better support science teachers in future emergency remote teaching events, it is important to explore how teachers navigated the quick transition that occurred during the COVID-19 pandemic. In this study, we were interested in the consequences of changing instructional settings for the instruction by science teachers. Specifically, we were interested in their use of the SEPs in the different instructional settings. The research questions specifically guiding this study are:

1. How did the teachers' use of the SEPs vary in these different instruction settings during the Fall 2020-Spring 2021 (the COVID-19 pandemic)?

2. What contributed to or hindered the use of the SEPs by the teachers in different instructional settings?

This study adds to our knowledge of the effects of the COVID-19 pandemic on science teacher instruction. The findings from this study have the potential to shape how teachers can be supported if there is another emergency event prompting remote learning.

Theoretical perspective

This study examines how teachers implement the SEPs as they transition between various instructional settings. To understand the transitions and their SEPs implementation, we use the Consequential Transition Perspective (CTP) to account for teachers' movement across settings and their knowledge. CTP focuses on the continuity and transformation of knowledge, skills, and identity across time and various social situations (Beach, 1999, p. 112). This theory enhances traditional views of transfer by acknowledging the importance of socio-cultural settings in which people work (Beach, 1999). For teachers, this simply means that different settings, which consist of school or classroom norms, students, and colleagues, can influence their instruction in different ways.

CTP offers insight into teachers' work in different instructional settings. This theory suggests that when teachers move between different instructional settings, teachers experience both continuity and transformation in their knowledge, skills, and identity (Beach, 1999). One important dimension of CTP is the Encompassing Transition (ET), which occurs as individuals move to new initiatives/settings. In the case of this study, teachers moved to new instructional settings, yet were still expected to keep their use of the SEPs consistent from setting to setting. As teachers navigated the face-to-face, virtual, and HyFlex environments, they were not merely transferring their pre-existing knowledge. They were reshaping and fine-tuning their knowledge, skills, and teaching personas in the context of these settings. When embedding the SEPs in their science lessons, teachers selected, adjusted, redefined, or skipped SEPs based on the unique demands and affordances associated with each setting. ET offers insights into how teachers did or did not enact the SEPs as they moved between similar but distinct instructional settings.

In using the CTP, we emphasise the transformative nature of transitions and highlight that teachers do not merely replicate knowledge from one setting to another. Instead, teachers engage in a complex interplay of adapting, reinterpreting, or recomposing their teaching methodologies and ideologies. This perspective might shed light on the ways in which the SEPs are enacted in varied instructional settings. CTP also recognises the wider socio-cultural setting that underlies these transitions. By acknowledging the influence of schools and individuals, it is possible to contemplate what may facilitate or hinder the implementation of the SEPs by a teacher. In short, by using this theory in our study, we have a way to understand the complex connections, influences, and changes that occur as teachers find themselves in different instructional settings.

Related Literature

Three areas frame this study: supporting the *NGSS* vision, science teachers' use of SEPs, and teaching in different instructional settings.

Supporting the Vision of NGSS (SEPs)

The *NGSS* requires large-scale professional development for all science teachers to make substantial changes in their knowledge and practices, as well as students' science achievement (Wilson, 2013). When professional development programmes are well-structured and focused on specific content, teachers can deepen their understanding of subject matter and enhance their teaching methods (Desimone et al., 2002; Wilson, 2013). By engaging teachers in active and collaborative learning experiences that are coherent with school policies and close to their classroom instruction, professional development programmes can facilitate effective teaching strategies (Lynch et al., 2019; Wilson, 2013).

Pruitt (2014) highlighted that the SEPs encompass both knowledge and skill. In this view, implementing a SEP with students requires that teachers and students know the SEP and have knowledge about the SEP. Pruitt (2014) provides an example of using a model in a science classroom, pointing out that teachers often use models as representations in their classrooms. When a teacher has a deep understanding of models, the teacher can guide students to generate a model, make explanations and predictions from the model, or revise the model based on new evidence. Teachers can also have students determine when a model is appropriate to use during an investigation. The former example is about implementing the practice, while the latter is evidence of knowledge of the practice.

In the vision of the *NGSS* (NGSS Lead States, 2013), teachers should integrate SEPs with DCIs and CCCs during their science instruction. Students in *NGSS*-centred classrooms will then engage in the SEPs to understand DCIs and CCCs. This form of instruction has any number of the SEPs integrated and connected to one another throughout the lesson (NRC, 2012). When students experience the SEPs, they have excitement to do and know about science (Inkinen et al., 2020; Vilhunen et al., 2021). Developing models and constructing explanations (Inkinen et al., 2020), and asking scientific questions (Vilhunen et al., 2021) have specifically been linked with positive emotions about science. With an excitement for science, students can begin to appreciate the wide range of approaches used to investigate, model, and explain the world (NRC, 2012).

Science teachers' use of SEPs

As the *NGSS* (NGSS Lead States, 2013) is embraced by more states in the US, researchers have been following its use in the classroom. While studies have shown the promise of the SEPs in classrooms (Kang et al., 2019), most researchers have reported the challenge of enacting the SEPs (e.g. Banilower et al., 2018). In the study of over 1200 schools by Banilower et al. (2018), science teachers struggled to implement the SEPs in their classrooms at both elementary and secondary levels. For example, when it comes to using models in a classroom at least once a week, about a third of the middle and high school students developed models, while about 20% of elementary students developed models. Roughly 20% of these students experienced identifying the strengths or weaknesses of models at least once a week. This limited use of the SEPs is similar in the classrooms of science teachers outside of the US (Malkawi & Rababah, 2018).

Knowledge is an important factor that pertains to a teacher's limited understanding and interpretation of the science practices (e.g. Rich et al., 2019; Trygstad et al., 2016). A lack of knowledge by a teacher is often the result of limited professional development opportunities or inadequate instructional support within a school (Banilower et al., 2018). An important learning opportunity involves science teachers experiencing lessons as students would, working in an active format, or looking at student artefacts. Banilower et al. (2018) reported that less than half of the professional development programmes taken by teachers provided them with either of these types of learning opportunities. For example, among elementary teachers, only 43% reported attending a professional development programme that emphasised active learning in the last three years, while middle school teachers reported 40%, and high school teachers reported 45% (Banilower et al., 2018). Experiencing science as a student and looking at student artefacts are important approaches to improve the knowledge and instruction of science teachers (e.g. Garet et al., 2001; Heller et al., 2012).

In the absence of sound professional development programmes, teachers do not develop their understanding of the SEPs (e.g. Rich et al., 2019; Trygstad et al., 2016; Yadav et al., 2018). Teachers, for example, may not understand what argumentation entails, be unclear about what constitutes a model, and conflate mathematics and computational thinking (Trygstad et al., 2016). Computational thinking is one of the most difficult SEPs for teachers to understand, and unfortunately, elementary teachers often refer to computational thinking as doing addition, subtraction, multiplication, and division (Trygstad et al., 2016). Even experienced elementary and secondary teachers have limited knowledge of and about the use of models (Rich et al., 2019). Improving the knowledge of teachers requires well-constructed professional development programmes, which have substantial and meaningful opportunities for teachers to develop robust understandings of the practices and show teachers how to support students in their use of the practices (Zangori et al., 2013).

Teachers also need resources and curriculum materials to support student learning (Navy et al., 2020). Educational researchers have found that standards-aligned curriculum materials with educative features can help teachers promote students' engagement in the SEPs, such as engaging in argumentation and constructing evidence-based claims (Arias et al., 2016; Arias et al., 2017). The outcomes of students' learning about the SEPs still depend on how teachers define and use the SEPs (Arias et al., 2016; Arias et al., 2017; McNeill, 2009). For example, a study about middle school teachers' use of educative curriculum materials in constructing explanations revealed that the way teachers defined scientific argumentation influenced their use and their students' engagement in scientific argumentation (McNeill, 2009). Many have suggested that along with providing educative curriculum, teachers still need access to professional development opportunities in order to adequately support their use of the materials in their classrooms (Pringle et al., 2017; Schuchardt et al., 2017).

Research that specifically explores the benefit of professional development programmes focused on SEPs is emerging, and it is showing a positive impact among teachers (Luft et al., 2022; Rich et al., 2019; Yadav et al., 2018). There are different approaches that are conducive to teachers using SEPs. It is beneficial when professional development programmes consist of opportunities for teachers to learn how to use the SEPs in their own classrooms (e.g. Colclasure et al., 2022; Peters-Burton et al., 2023). For instance, when teachers studied their own use of the SEPs in a class as a form of professional development, the teachers enacted more data-based practices and computational thinking in their classrooms (Peters-Burton et al., 2023). In another yearlong programme on computational thinking, elementary teachers were able to integrate computational thinking into their classrooms with adequate instructional support (Ketelhut et al., 2020). Of course, the value of teachers working collectively in a professional learning community is central to teachers becoming more motivated to integrate the SEPs into their instruction (Brand, 2020; National Academies of Sciences & Medicine, 2015).

Teaching in different instructional settings

There are different instructional settings in which teachers can support students' learning. They can work with students in face-to-face settings that involve teachers working directly with students in a defined location, often in a school. This is the longstanding instructional setting in which teachers have worked. Virtual instructional settings appeared with the advent of the web. Over time, they have evolved from cameras linked to televisions to asynchronous platforms or synchronous systems that accommodate multiple students in a shared virtual space. HyFlex (Hybrid-Flexible) allows students to join an in-person class or use web conferencing software to join remotely (Beatty, 2019).

When the COVID-19 pandemic began, teachers were forced to move to virtual and HyFlex instructional settings. Many teachers experienced challenges in switching to remote settings as they were unfamiliar with the tools and techniques associated with virtual or HyFlex instruction (e.g. Gordy et al., 2021). Additionally, many remote instructional settings did not have adequate online instruction or materials that promoted student investigations (Arkorful & Abaidoo, 2015), which are essential in science classes emphasising the SEPs. When teachers were able to acquire the skills or knowledge to teach in these settings, they still encountered issues associated with remote teaching: lack of time to spend with students, lack of time to plan and check student work, and a lack of adequate online instructional materials (Todd, 2020).

HyFlex classes presented a new set of challenges. One of the most significant challenges involved designing and managing classroom activities for virtual and face-to-face environments. It was difficult for teachers to maintain the alignment between the different settings in order to achieve the same learning outcomes for students (Binnewies & Wang, 2019). In science, these differences were evident during investigations that required specialised science materials, which may not have been available to students in their homes. While science teachers could make some modifications to the materials used by students, there were lessons in which modifications were not possible, such as scales to record mass, specific chemicals for investigations, and organisms for investigations.

Even with the challenges of teaching in the virtual or HyFlex environment, it is possible for teachers to work effectively in these environments. Experienced virtual teachers emphasise the importance of reflecting upon the outcomes of their planning and instruction (Besser et al., 2020). Planning for virtual environments requires finding activities that are aligned with the identified standards and that are suitable for an online or hybrid setting. During instruction, teachers skilfully ensure that students interact with one another, along with materials and/or data. Effective online teachers use pedagogical strategies that foster a sense of community in online courses between themselves and their students in order to enhance the cognition and engagement of their students (Reilly et al., 2012).

Instructor training, suitable technology, and teacher knowledge are decisive factors for successfully implementing HyFlex and virtual instructional pedagogies (Abdelmalak & Parra, 2016; Beatty, 2014; Miller et al., 2013). With proper and adequate planning, teaching in virtual settings can be as effective as face-to-face teaching (Means et al., 2014). A study by Suter (2002) showed that instructors adapted to virtual settings as their courses progressed by inventing new practices. Reflection was an important part of supporting their successful transition to the virtual setting (Suter, 2002). Additionally, through professional development programmes, teachers reported having more confidence in using technology to teach online (Gordy et al., 2021). While there is a body of research about teachers' practices in virtual settings, few studies have investigated teachers' practices in HyFlex synchronous classrooms (Miller et al., 2021).

Summary

Science teachers are still learning how to implement the SEPs in their classrooms. Professional development programmes and instructional supports (e.g. curriculum, colleagues) are important in ensuring science teachers attain the vision of the *NGSS* (NGSS Lead States, 2013). The abrupt shift to virtual and HyFlex instructional settings during the COVID-19 pandemic posed challenges for science teachers in using the SEPs. It is important to understand the impact of these instructional settings on science teachers and how they enacted the SEPs in these different settings. This understanding is crucial in preparing for future remote teaching events.

Materials and methods

This study focuses on science teachers' use of the SEPs in different instructional settings. These data were collected during the 2020–2021 academic school year. Interviews and artefacts comprised the collected data. The data were analysed using descriptive and inferential statistics to depict the teachers' use of the SEPs in different instructional settings.

Participants

The participants were 38 science teachers from the Southeast region of the US. Among the teachers, 17 teachers were at the K-5 level, and 21 teachers were at the 6–12 grade level. Most of the teachers (71.4%) worked in schools with a high number of low-income students who were provided free or reduced-priced meals. As for school locations, 31% of were in cities, 14.3% were in towns, 42.9% in suburban areas, and 11.9% in rural settings. The data were collected during the COVID-19 pandemic; as a result, the teachers worked in three different instructional settings: traditional face-to-face, HyFlex, and virtual. The teachers with a complete set of data during the data collection period comprise this study.

Collection of data

Data were collected three times between August 2020 and May 2021, which was during the COVID-19 pandemic. The teachers taught in different instructional settings (face-to-face, virtual, HyFlex). Each round of data collection focused on one week of instruction, resulting in teachers reporting on 15 total instructional days. The data collected during these times included weekly overview forms, interviews about their instruction, and artefacts used to support classroom instruction (e.g. PowerPoints, handouts).

Before collecting the data from the teachers, the research team reviewed the objectives of the study and developed different protocols. The protocols were reviewed by all team members to ensure they corresponded to the research objectives of recording the instructional practices of the teachers, students' actions, instructional settings, and assessments used in the classroom. Throughout the data collection process, different team members were assigned to interview the teachers. In addition, the data were collected at similar times over the school year in specific two-week windows. As the interviews were conducted, the researchers were non-judgmental and tried to establish relationships with the teachers by demonstrating respect and interest in understanding their experiences (Seidman, 2019). These different processes, review of the objectives, assigning different researchers to interview teachers, consistency in the instructional setting, and creating a welcoming atmosphere contributed to the validity of the data collection process (Merriam & Tisdell, 2015).

Data for this study came from weekly overview forms, interviews, and corresponding classroom artefacts. The teachers completed a weekly overview form describing their instruction, assessment, instructional format, and origin of the lessons for a week of teaching. The teachers sent the form and any appropriate classroom artefacts to the interviewers before their interviews. The artefacts included lesson plans, slides, worksheets, links to videos, and any other materials used for the teaching. The interviews were conducted individually with teachers and lasted for about 40 minutes. Each interview covered a five-day week of teaching. The developed interview protocol was used three times (approximately every two months during the school year) during the data collection period.

Prior to each interview with a teacher, interviewers reviewed the teachers' backgrounds and the weekly overview forms teachers sent prior to the interviewer. The interview format followed a standardised, semi-structured process as recommended by Patton (1990). During the interviews, the researcher's responses to the teachers were a combination of non-leading questions and low-inference paraphrasing (Carspecken, 2013). For instance, the interviewers asked the teachers to describe in detail (DeMarrais, 2004) the goals of the lessons, what they did during each day of instruction, and what the students did in each teacher's classroom over a week. The researchers also asked clarifying questions and summarised the key points to ensure that all the essential aspects of the instructions were recorded.

The weekly interview protocol included three parts: opening questions, weekly update questions for lessons, and closing questions. The opening questions were, for example, 'Have you had any changes at your school? How is your teaching going in general? Have you participated in any professional learning opportunities? Are you teaching virtually, in person or a HyFlex setting?' After asking the opening questions, researchers asked questions to learn specifically about the teachers' five days of instruction. The questions consisted of, for instance, 'What were the goals for the lesson on Monday? How was the lesson delivered on Monday? What would I see you doing if I were sitting in the back of your classroom or in a virtual/HyFlex setting? What would I see the kids doing? Were they working in whole groups, small groups, or individually?' After asking these questions and follow-up questions for details, interviewers summarised what they heard regarding that day of instruction. This procedure was repeated for each of the five days of the week. Finally, the interviewer asked closing questions about the lessons, such as 'How do you feel these lessons went? What did you like about them? What would you do differently? How engaged do you think the students were during the lessons?'

All interviews were done over Zoom, but only the audio file was retained. The audio files were transcribed through Otter.ai. The interview, transcript, and all associated documents were placed in a secure digital location that had no identifying information about the teachers.

Data analysis

To answer the research question, we conducted the analyses in three parts. First, we created an analysis sheet in Excel to document the instructional format, content focus, teacher actions, student actions, SEP implementation, and assessments, which were involved in the lessons. A research team of four graduate students in science education and a science education professor were responsible for developing this analysis sheet.

To create the analysis sheet, all the graduate students and faculty members listened to the audio file of a teacher interview and reviewed the teacher's weekly overview form and artefacts. This allowed the team to understand what the week of teaching entailed for the teacher. During this review, an inductive process (Bogdan & Biklen, 1997) was used by the graduate students and the faculty member to identify different teacher actions, student actions, and assessments. The SEPs, however, were called out specifically because they were a specific area of interest. The SEPs were defined using the descriptions in the National Science Teachers Association [NSTA] (2013) matrix table of SEPs. The team came together and described the areas they identified and reviewed the SEPs. Through discussions, the research team developed the instructional analysis sheet.

To test the adequacy of the instructional analysis sheet, the team listened to and reviewed the audio file transcripts and documents of four more teachers. Discussing each teacher's set of data, the team added, removed, and refined different codes and ultimately honed the instructional analysis sheet. A sample final coding sheet is in Appendix 1. By the fifth coded interview, the research team agreed on all of the coded items in the interview and documents. The team used these codes to calculate the interrater reliability. The interrater reliability was 0.77, suggesting an acceptable consistency between coders.

The research team, composed of graduate students, coded the remaining interviews. Two people were assigned to code each interview and associated documents. Each person would code the interview independently, and then the two coders would come together to compare their codes. If they disagreed with their coding, it was resolved through discussion (Herrera & Herrera-Viedma, 1996) and by referring to the matrix table of SEPs (NSTA, 2013). If needed, a third person was brought in to negotiate the coding. When the codes were agreed upon, they were placed in a master instructional analysis sheet.

The second part of the analysis involved examinations of the different settings in which teachers worked. To begin this analysis, the different types of instructional settings that existed for the teachers were recorded. Teachers could move between different instructional settings because the data were collected over three different time points. The different instructional settings were noted in order to identify the overall trends in the instructional settings of the teachers. For instance, teachers could have been face-to-face during the entire year or face-to-face at one-time point and then in a HyFlex setting during the other two-time points.

Following the classification of the teachers, descriptive statistics were used to determine whether the implementation of SEPs depended upon the instructional setting of the teacher. This analysis allowed us to understand if some SEPs were more prevalent in specific instructional settings. The follow-up analysis involved grouping the SEPs into three distinct categories: (1) investigating (asking questions and defining problems, and planning and carrying out investigations), (2) developing explanations and solutions (developing and using models, and constructing explanations and designing solutions), and (3) evaluating (analysing and interpreting data, using mathematics and computational thinking, engaging in argument from evidence, and obtaining, evaluating, and communicating information). These groupings recognise 'three spheres of activity,' or the ways in which scientists and engineers do their work (NRC, 2012, p. 45). This type of categorisation has been used by other researchers (e.g. Aleixandre & Crujeiras, 2017). With this data, tables and figures were created to show the frequency patterns of the implementation of SEPs across instructional settings.

The final phase of the analysis involved a re-examination of the interviews to elaborate upon the quantitative analysis. Using a pattern coding approach (Saldaña, 2021), the interview data were examined in order to elaborate on what and why something happened in the instructional setting. This coding was appropriate because it expanded upon the use of SEPs in the different instructional settings. In this analysis, additional areas were explored to understand the teacher's use of the SEPs in the different settings. For instance, a closer examination was made into the years of experience and the grade levels of the teachers. This process is similar to the construction of explanatory matrices, which look at different variables (Miles & Huberman, 1994).

Research credibility, consistency, and limitations

In this analysis process, there was a focus on credibility and consistency (Merriam & Tisdell, 2009). Credibility occurred through different sources of data that were collected over time and analysed by different researchers. Different sources of data (interviews and artefacts) resulted in triangulation. The different sources represented a coded area that was ultimately noted by research team members. Also, different researchers analysed the data collectively. Sometimes one researcher worked alone but then joined with another to continue the analysis. When different explanations were explored, other researchers were used to review the emerging coding and analysis. Contributing to the consistency of these findings was the data collection process, which was guided by specifically described procedures that were discussed regularly. In addition, an audit trail existed in terms of the collected and analysed data.

This study has four notable limitations. The first limitation is that we have no pre-COVD-19 pandemic data. It would have been useful to have data regarding the actual instruction of the teachers prior to the pandemic. Without this data, we assume that the face-to-face instructional reports of the teachers represent their practice pre-COVID-19. Second, this study relied on teachers' self-reported use of classroom activities. Due to the COVID-19 pandemic, school districts did not allow researchers into the classrooms of teachers. To navigate this limitation, we collected classroom artefacts from the teachers, had teachers fill out overviews of their classroom instruction, and interviewed teachers about five days of their instructional practices. The collection of multiple data sources contributes to our confidence in the findings, even though we could not observe teachers in the classroom. Third, in coding the SEPs, we may have misjudged the SEPs. However, coders were trained, there were standardised discussions of the SEPs (NSTA, 2013), and each week of instruction was coded by two individuals. This process gives us reasonable confidence in our determination of the SEPs. The fourth limitation is the small sample size for each group of teachers in each instructional setting. With the small sample size, the results of this study may not be representative and generalisable. Even with these limitations, we have confidence in our conclusions resulting from this exploratory study.

Results

This study is focused on understanding teachers' use of the SEPs in different instruction settings during the 2020–2021 academic school year. To answer this question, different analyses were conducted. The first analysis focused on the science teachers' use of SEPs in the three known instructional settings that occurred during the COVID-19 pandemic: face-to-face, HyFlex, and virtual. Chi-squared tests of independence were performed to examine the relationships between these instructional settings and the implementation of SEPs. The relationship between these variables was significant, , $p = .003$. A similar test between face-to-face and virtual settings also revealed a significant difference, $\chi^2(1,\ N = 347) = 8.65$, $p = .003$. The comparison of the implementation of SEPs also differed significantly between virtual and HyFlex settings, $\chi^2(1,\ N = 276) = 11.18$, $p < .001$. However, the implementation of SEPs between face-to-face and HyFlex settings was not significant, $\chi^2(1, N = 399) = .49$, $p = .482$. These results suggest that science teachers in this study implemented more SEPs in HyFlex and face-to-face settings than they did in virtual settings (Figure 1).

To take into consideration the changing nature of instructional settings for science teachers, an analysis was conducted to determine the movement of teachers between the different instructional settings. Our analysis of the instructional settings that teachers experienced during the 2020–2021 academic year revealed six different types of

Figure 1. The mosaic plot of the instructional settings and the implementation of SEPs.

instructional settings: (1) staying in face-to-face, (2) staying in a HyFlex setting, (3) staying in a virtual setting, (4) switching between face-to-face and HyFlex settings, (5) switching between face-to-face and virtual settings, and (6) switching between HyFlex and virtual settings. Table 1 reports on the number of teachers in the different instructional conditions. Because there were small numbers within these groupings, they were not analysed inferentially but descriptively. Table 1 shows that most teachers stayed in the face-to-face setting or HyFlex setting.

In the descriptive analysis of the different settings, we separated teachers into two grade levels: elementary (K-5) and secondary teachers (6-12). This was done because prior studies have suggested a different use of SEPs between elementary and secondary teachers (Banilower et al., 2018). Our results show that the elementary teachers implemented fewer investigating SEPs when compared to developing an explanation and evaluating SEPs (see Figure 2). The frequency of the implementation of SEPs varied across the instructional settings, with a higher implementation of SEPs in virtual settings (Figure 2). Among the secondary teachers, there was little to no implementation of any investigating SEPs when compared to the presence of developing an explanation and evaluating SEPs (see Figure 3). The implementation of the SEPs varied, with low levels of evaluating SEPs when the secondary teachers stayed in

Table 1. Number of teachers in the six types of instructional-setting conditions.

Grade Level	Stay in Face-to-face	Stay in HyFlex	Stay in Virtual	Face-to-face & HyFlex	Face-to-face & Virtual	HyFlex & Virtual
Elementary	8	3	1	2	1	2
Secondary	4	2	2	4	3	6

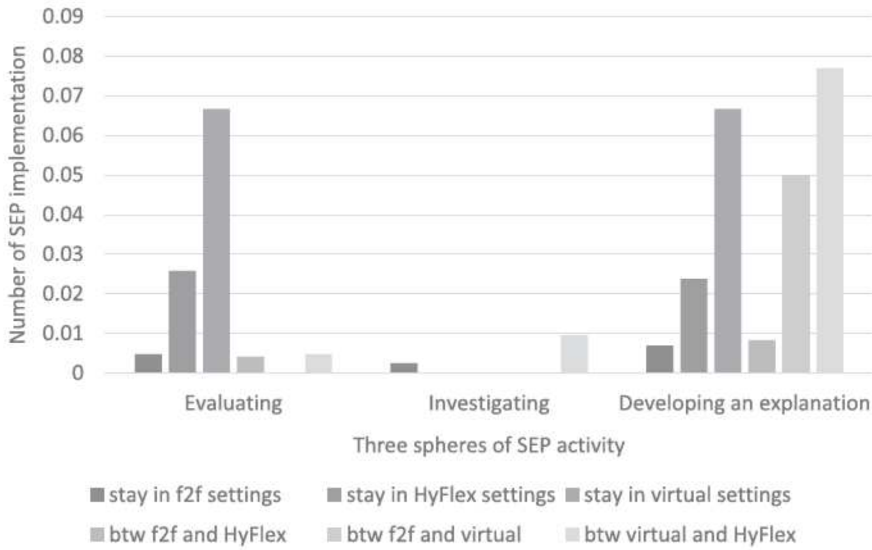

Figure 2. Elementary teachers' implementation of the three spheres of activity under instructional settings. Note. Unit: the average number of a SEP implemented every instructional day per teacher

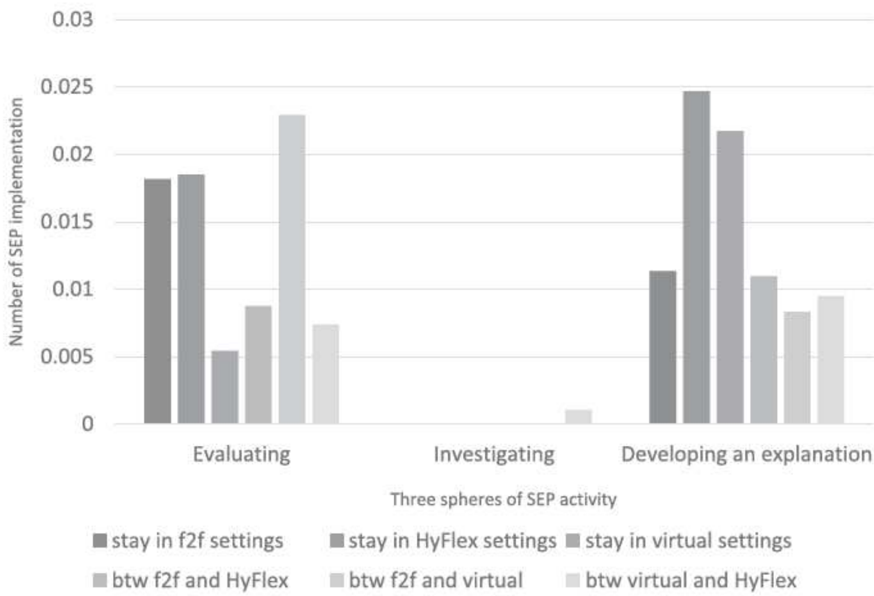

Figure 3. Secondary teachers' implementation of the three spheres of activity under instructional settings. Note. Unit: the average number of a SEP implemented every instructional day per teacher

virtual settings, and low levels of developing an explanation when the secondary teachers went between virtual and other settings.

The pattern analysis revealed insights into the differences of the elementary and the secondary teachers. Illustrative quotes are shared to provide insights into these differences.

To begin with, *elementary teachers benefited by staying in one setting, and found it challenging to move settings.* When they stayed in one setting, elementary teachers were more likely to implement SEPs associated with evaluating and developing an explanation. Their use of the SEPs were often attributed to the professional support they experienced in or out-of-school. One teacher, for example, stated, 'Most of the professional development programmes are technology focused, like how to engage students virtually in all subjects. And I've gotten a lot of resources for science virtual field trips.' In contrast, when elementary teachers moved settings, they felt the new protocols and current instructional resources constrained their use of the SEPs. One teacher touched on both of these areas when she shared, 'I teach kindergarten. So social distancing is very difficult. … a lot of our science curriculum … is very hands on. … we're not in groups where they sit separate.'

Regardless of the challenges of implementing SEPs in these different settings, *elementary teachers repeatedly emphasised how they adapted materials.* One teacher shared her focus on students, regardless of the setting, 'half of the students are online, and half of the students are in person. So, I've definitely had to adapt and find ways to make sure the students online aren't feeling like they're getting left behind.'

The *secondary teachers found the virtual setting to be the most challenging.* Their comments pertaining to virtual instruction were diverse. One teacher, for instance, expressed the difficulty of engaging students in learning to critique in a virtual setting and pointed to the difficulty of managing an online class to engage all students. Another teacher noted the difficulty of teaching online but expressed appreciation for the support he received from his district science coordinator. He found the online school that was set up by the district science coordinator to be helpful in implementing different science lessons.

The *secondary teachers were also challenged when they moved between the different learning environments.* One teacher, for example, stated how hard it was to move to in-person instruction during the COVID-19 pandemic: 'the social distancing aspects … makes things hard. And a lot of stuff I used to do as group work [will not work], … I have to find a replacement [activity].' These teachers also commented that 'having to do a hybrid thing – teach virtually and physically at the same time – is stressful,' and that students were still 'struggling to log in on … and take the class seriously.' One teacher noted the consequences regarding the ongoing shift between different instructional environments: 'I just don't think you can replace the face-to-face interaction.'

Discussion

This study was conducted to understand the different instructional settings of science teachers during the COVID-19 pandemic and how their implementation of the SEPs may have varied as a result of their instructional settings. Before discussing the role of the instructional environment on the teachers' use of the SEPs (Question 1), it is important to point out there were no pre-pandemic data. However, the face-to-face condition can be assumed to be the pre-pandemic condition as this is the setting in which teachers normally work. The data from this study are consistent with other researchers who have documented the limited use of the SEPs by science teachers (e.g. Banilower et al., 2018; Trygstad et al., 2016). Among the teachers in this study, they used on average about three SEPs every two weeks. When they used the SEPs during instruction, the SEPs were more likely to emphasise evaluation and developing explanations. There was little use of the investigating SEPs among the teachers. The vision of the *NGSS* (NGSS Lead States, 2013) involves the regular use of the SEPs in order for students to understand how they are both a knowledge and a skill (Pruitt, 2014). Clearly, there is more to be done to support teachers in implementing all SEPs.

In terms of the first question, which compares the settings, we found a difference between the instructional environment and the low use of the SEPs. The simple analysis of comparing instructional settings revealed that the teachers used significantly more SEPs in a HyFlex or traditional (face-to-face) setting than they did in a virtual setting. This may result from teachers' prior experience with the SEPs in a face-to-face setting, which was part of their instruction in the HyFlex setting. Beach (1999) would suggest that there was enough continuity between these settings that teachers could transfer their use of SEPs. The familiarity of the face-to-face setting, which included the actions of students and the work of teaching science, was likely the primary anchor in the HyFlex setting. This resulted in a positive consequential transfer in that the SEPs were used in both face-to-face and HyFlex settings. It is still unclear how the teachers tailored their instruction to the virtual side of the HyFlex setting. It is likely they made no adaptation to their teaching. CTP would suggest that the virtual setting had none of the socio-cultural cues or similarities found in the face-to-face environment. This would result in lower implementation of SEPs in a virtual setting, indicating a negative consequential transfer.

The second question, which is focused on understanding what contributed to or hindered the use of the SEPs in these different instructional environments, requires additional discussion. To begin with, it is important to recognise that most teachers during the COVID-19 pandemic did not experience just one educational setting, but rather different settings. This study identified six different settings that involved shifting or not shifting between instructional settings. Among these six different settings, there was still a low-level use of investigating SEPs among the teachers. The low-level use of investigating SEPs in varied settings (including face-to-face) suggests again that teachers were likely not supported adequately prior to the COVID-19 pandemic in using or learning about investigating SEPs (e.g. Banilower et al., 2018; Trygstad et al., 2016). Without this necessary experience in using or learning about the SEPs, it is unforeseeable that teachers would use the SEPs in novel environments.

However, elementary teachers' use of evaluation and developing explanations SEPs in the virtual environment exceeded that of their secondary peers. According to CTP (Beach, 1999), the setting in which teachers work can support their transfer of knowledge and practices. In this instance, elementary teachers were provided with professional development programmes to support their instruction in the virtual environment. It is likely that these professional development programmes provided opportunities for the teachers to work collectively to understand how to instruct in the virtual environment. Collective work is essential in science professional development programmes (Lynch et al., 2019; National Academies of Sciences & Medicine, 2015), and it is central to CTP (Beach, 1999). As the elementary teachers worked together, they refined their knowledge and skills to meet the demands of teaching virtually. The secondary teachers were not as fortunate. The different disciplinary areas that comprise the instruction of secondary science teaching would have been difficult to support through professional development programmes. As a result, they did not have the experience of working collectively with their peers.

Additionally, elementary teachers likely found the resources provided during the professional development programmes useful. While professional development programmes focusing on student learning often support the instruction of teachers (Heller et al., 2012), the resources in the programmes were likely helpful to the teachers as they worked in the virtual setting (Beach, 1999). These resources may have also provided insights into the learning of students (Navy et al., 2020), which also supported their use of the SEPs focused on evaluating and developing explanations in the virtual environment. The resources likely provided enough cues about the learning of students that the teachers were able to navigate the virtual environment and focus on adapting the lessons to the students. When instructional resources are educative, they can help teachers build their instruction in ways that they can respond to students (McNeill, 2009). Again, the secondary teachers did not report having these types of resources.

The COVID-19 pandemic underlines the importance of support and resources in navigating new instructional settings, which likely supported elementary teachers and hindered secondary teachers from adapting and reshaping their teaching to the unique demands of the different settings. These findings highlight the imperative for educational institutions to prioritise comprehensive support systems that include collaboration, reform-oriented instructional materials, educative curriculum, and adequate professional development programmes (e.g. Brand, 2020; Luft et al., 2022; Peters-Burton et al., 2023). This will ensure that science teachers and students seamlessly navigate between traditional and evolving instructional settings.

Conclusion

While we hope another remote learning event does not occur, there will likely be another event that necessitates emergency remote learning. Teachers will be required to move between different instructional settings, and without adequate support or guidance during this transition, they will struggle to provide sound science learning experiences. For most teachers, working in virtual settings will be the most challenging for a variety of reasons.

In knowing the challenges ahead of the teachers, this study underscores the importance of consistently supporting teachers in enhancing their use of the SEPs. There is a pressing need to develop teachers' use of the SEPs through ongoing professional development programmes. In these programmes, teachers need to work collaboratively integrating the SEPs into their classroom lessons. By fostering a sense of community among educators, teachers will be able to collectively navigate the unique demands and challenges presented by virtual and HyFlex learning environments. This approach echoes the emphasis on socio-cultural learning within CTP. A residual outcome may be the development of a resilient and adaptable teaching community. Such a community is capable of ensuring the continuity and transformation of knowledge, skills, and identity in different settings.

Like many studies, this study left us with more questions than answers. Future studies can explore whether teachers use new SEPs in different settings when they have adequate access to professional development programmes and instructional materials. The professional development programmes can be comprised of teachers working collectively or a specific programme that emphasises the use of SEPs in classrooms. It will also be important to examine if there are anchor SEPs, which are SEPs that should be learned initially and can be linked to other SEPs. Finally, examining the unique combination of instructional materials and professional development support will be important in understanding how they can work synergistically with the different instructional needs of elementary and secondary teachers.

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Declaration of interest statement

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Ethics statement

This research was approved by the University of Georgia Institutional Review Board.

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Appendix 1 Coding sheet

Day of the week	1	2	3	4	5
Cohort					
ID					
Group					
Interview					
Coder					
Socioemotional learning					
Science					
Math					
Literacy					
Engineering					
Technology					
Other					
Nature of science					
5E model/inquiry					
Understand science concepts					
Learn how to do science					
Develop student confidence					
Learn vocab/facts					
Increase student interest					
Learn how to do engineering					
No clear goals					
Other (type one sentence to describe the goal)					
Teacher lectures					
Teacher conducts a demonstration or simulation					
Teacher facilitates a whole-class discussion					
Teacher facilitates in-class work – reading a book, review, handout, worksheet, notes, or other					
Teacher guides scientific investigations or labs					
Teacher shows a movie, video					
Teacher facilitates small group discussions					
Teacher facilitates catch-up day					
Students completing in-class work – notes, reading, review, handout, worksheet, or other					
Students planning and/or conducting their own investigations/experiments					
Students are conducting investigations prepared by the teacher					
Students giving presentations or opportunities to explain their ideas					
Students are asking questions or defining problems					
Students are creating their own models					
Students are using models given to them					
Students are analysing and/or interpreting data					
Students are using math and computational thinking					
Students are constructing explanations					
Students are designing a solution for a problem					
Students are engaging in argumentation based on evidence					
Students are obtaining, evaluating, and communicating information					
Small group					
Whole class					
Interactive notebook					
Department, district, or state assessments					
Summative – test, quiz, unit project, other					

(*Continued*)

Continued.

Day of the week	1	2	3	4	5
Formative/Pre-assessment – warm-up activity, questioning, kahoot, exit ticket, etc.					
Written or verbal feedback on content work from teacher or students					
Written or verbal feedback on behavior/socioemotional status from teacher or students					
Other					
0 = Procedural knowledge (e.g. directions, procedures, skills, how to use equipment, etc.)					
1 = Receipt of knowledge (e.g. lecture, reading, video)					
2 = Application of knowledge (e.g. practicing problems, worksheets)					
3 = Knowledge representation (e.g. organising, describing, manipulation of information)					
4 = Knowledge construction (e.g. creating new meaning, drawing conclusions, articulating an opinion)					
Modality of Instruction – Traditional					
Modality of Instruction – Virtual					
Modality of Instruction – HyFlex					
Lesson From Previous Year					
New Lesson					
Lesson Origin – Self-created					
Lesson Origin – School colleague					
Lesson Origin – Online/other resource					
Lesson Origin – District resource					