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# PRE-SERVICE SCIENCE TEACHERS' KNOWLEDGE AND SKILLS BACKLOG PERPETUATED BY EMERGENCY REMOTE TEACHING

**Hlologelo Climant Khoza**

**Abstract:** *The adoption of Emergency Remote Teaching (ERT) during the COVID-19 Pandemic brought a shift in how lecturers teach in higher education, posing a threat to the usual development of competencies in students. This study aimed to uncover the knowledge and skills backlogs experienced by pre-service teachers. The study is framed within various concepts that characterize an ideal science teacher. Using a qualitative case-study design, data were collected through interviews with nine pre-service teachers who were subjected to the ERT. Transcripts of the interviews were analyzed thematically using the established framework as a lens. The findings indicate that while the science pre-service teachers acquired some technological knowledge, there was a concurrent loss of sufficient content knowledge, a crucial prerequisite for the development of Pedagogical Content Knowledge (PCK). Additionally, the pre-service science teachers highlighted a lack of knowledge in practical work and the specific pedagogies essential for teaching science. The implications of these findings are discussed in the context of moving forward.*

**Keywords:** *case study, COVID-19, knowledge and skills backlog, pre-service science teachers, teacher education*

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## Introduction

The outbreak of COVID-19 had a severe impact on the education system not only in South Africa but across the world. Teaching and learning across institutions of higher education had to shift to emergency remote teaching (ERT). As such, there was no careful thought given to how this would be rolled out as the goal of many institutions was to 'save' the academic year. Studies show that both lecturers and students were not prepared for this mode of teaching (Tsegay et al., 2022), especially those from traditional face-to-face institutions (Ali & Khoza, 2023). Lecturers had to adapt to the situation by changing their teaching approaches (Tsegay et al., 2022). The change in lecturers' teaching approaches had implications for how students learn and their experiences thereof. Previous studies have looked at students' experiences of ERT they were subjected to during the pandemic both internationally (e.g. Shim & Lee, 2020) and in the South African context (see, for example, Maphalala et al., 2021). Although the studies provided a starting point to understand how students can be supported as well as planning for future crises, the findings and recommendations are generalized and not specific disciplines or content areas. Building on Grodotzki's (2021) findings on students' learning experiences during ERT, the argument in this study is that each discipline in higher education institutions has its outcomes regarding the knowledge and skills that students need to acquire during training. This study looked at pre-service science teachers' experiences of ERT. The reason for studying specifically pre-service science teacher is that there is a global agreement that initial teacher education is a problematic context (Korthagen, 2001). Pre-service science teachers do not only learn the content of teaching but also learn how to teach others (Nyamupangedengu & Lelliott, 2016). Therefore, the ERT may have presented some challenges in terms of the necessary knowledge and skills that students need to acquire, thus leading to a deficit in pre-service science teachers. The problem that this study explored is the lack of studies regarding pre-service science teachers' experiences of ERT as well as studies that focus on challenges in terms of student competencies. This study was guided by the following research question:

1. What knowledge and skills backlogs do the pre-service science teachers have due to the ERT?



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*Aim*

The aim of this study was to explore pre-service science teachers' experiences of ERT. The focus was specifically on the knowledge and skills backlogs that the pre-service science teachers may have. The term backlog is defined as the knowledge and skills that the pre-service teachers should have gained but did not as a result of ERT.

*Emergency Remote Teaching*

According to Hodges et al. (2020), ERT is different from online teaching. ERT is described as a temporary teaching mode due to crises that affect education (Hodges et al., 2020). This can take the traditional distance education form where students get hard copy material delivered to them or online form where material can be accessed online. During the pandemic, the ERT was done online due to the advancements of digitalization in education (Chomunorwa et al., 2023).  Lecturers made use of their institutions' learning management systems to conduct lectures synchronously and disseminate learning material like narrated presentations to students (an asynchronous form of teaching) (Dlamini & Ndzinisa, 2020). Both synchronous and asynchronous forms of teaching have their advantages and shortfalls.

Generally, in the synchronous form, lecturers facilitate students' learning virtually, and both lecturers and students get an opportunity to have real-time interactions. This is usually done via an institution's learning management system. In the asynchronous learning environment, students access learning materials including pre-recorded lectures allowing them to learn at a convenient time (Shahabadia & Uplane, 2015). One of the main factors that influence students' experiences in the asynchronous form is the lecturer's teaching competencies and how the curriculum is designed (Zhu et al., 2022). If the lecturer is not well-trained to design a module for asynchronous form, students will have negative perceptions and experiences regarding this mode. A study conducted by Fabriz et al. (2021) revealed that students who studied mostly in synchronous settings appreciated the support, such as feedback, in comparison to students in mostly asynchronous settings. On the contrary, a study by Watson et al. (2023) found that students preferred pre-recorded lectures during the ERT. This is because students usually get immediate feedback from their lecturer, thus improving their learning. Similarly, Francescucci and Rohani (2019) found that some students prefer face-to-face learning as the extent of interaction is far more than what happens in synchronous form. In Chandran et al.'s (2021) study with postgraduate students, it was found that students experienced virtual and face-to-face as equally effective in their learning. Mohammad Zadeh et al. (2023) looked at how engineering students perceive synchronous and asynchronous settings. The authors found that there was no clear preference for any form of online learning. Instead, students argued for a cognitive and online presence that can aid their learning. These studies have shown that the experiences are influenced by the level of students and their disciplines. The argument in this article is that regardless of the form of online or ERT used, students need to acquire the knowledge and skills that are peculiar to the discipline.

*The Nature of Teacher Education*

Generally, the focus of higher education institutions is to prepare students for their workplace by equipping them with the necessary competencies. However, within higher education, initial teacher education is a new context in itself. Korthagen (2001) described teacher education as a problematic enterprise.  In initial teacher education, pre-service teachers are prepared to teach in schools. It is therefore very crucial that the preparation is well-thought. Across initial teacher education programs, pre-service teachers need to acquire knowledge of the subject matter or content knowledge and the knowledge of how to teach that subject matter. Content knowledge is usually taught in content modules and the knowledge of how to teach that content is taught in methodology modules (Khoza, 2022). The special knowledge that these pre-service teachers are equipped with is the Pedagogical Content Knowledge (PCK) that would allow them to transform the subject matter knowledge into ways that are understandable to their students (Shulman, 1986). In the context of this study, this means equipping students with, for example, the knowledge of science instructional strategies and how to assess (Rollnick et al., 2008).

Studies suggest that teaching pre-service teachers does not only entail teaching them the subject matter knowledge and how to teach that but also showing them how this can be done. This is explained by the concept of modelling best teaching practices (Lunenberg et al., 2007). Loughran and Berry (2005) defined modelling as "doing in our practice that which we expect our students to do in their teaching" (p. 194). In modelling teaching


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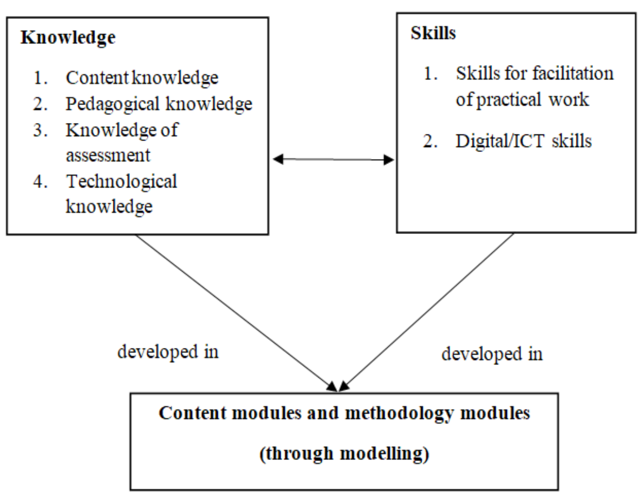
practices, teacher educators think about the messages about teaching portrayed to pre-service teachers (Boyd, 2014) regardless of the mode of teaching used. Nyamupangedengu and Lelliott (2016) found that modelling practice when teaching science pre-service teachers can be achieved through practising all the aspects of teaching that pre-service teachers need to practice when they are teaching. Therefore, pre-service teachers can imagine their future teaching contexts, thus building their teacher identity (Khoza, 2022).

Initial science teacher education presents itself with further challenges in terms of the knowledge and skills that need to be instilled in pre-service teachers. This is because a fundamental commitment of science is that claims and explanations should be consistent with observational data that can be gathered and explained through practical work and instilling process skills (Chabalengula et al., 2012). Practical work is an important aspect of science as it helps students visualize abstract concepts as well as develop the students' practical and scientific skills (de Winter & Millar, 2023). In pre-service science teacher education, Khoza (2022) notes that practical work is what defines science teachers. Learning theoretical content through practical work can come in many forms. In face-to-face teaching mode, students have the opportunity to be hands-on and manipulate the material that they would be working with specific to the content (de Winter & Millar, 2023). There have been arguments that science students can also do practical work online using 'virtual labs' and many lecturers adopted this approach in ERT (see Alvarez, 2021). According to Aljuhani et al. (2018), virtual labs are interactive and designed to increase students' learning approaches. Other studies suggest that students can also do practical work at home by manipulating objects in their homes. However, Velarde (2022), home practical activities need to be accompanied by effective feedback mechanisms from lecturers as in any other activities in online teaching and learning.

*Conceptual Framework*

To frame this research, several concepts were used to characterize an ideal science teacher. An ideal science teacher is defined in terms of certain knowledge and skills. These knowledge and skills are defined below (see Figure 1).

**Figure 1**
*Conceptual Framework for the Study*




As can be seen in Figure 1, the conceptual framework has three main interrelated components. The first component is that of knowledge that a science teacher needs to have. This component draws from several domains of the general Pedagogical Content Knowledge and knowledge of technology. The first domain is content knowledge defined as the organization of subject matter in the mind of a teacher (Shulman, 1986). In this case, content knowledge is about science and the content knowledge of methodology modules where the focus is on how to teach science. Pre-service teachers need to also acquire general pedagogical knowledge, which is defined as the knowledge of how to teach, like selecting instructional strategies (Loughran et al., 2012). Knowledge of assessment has to do with strategies for assessing learners. Technological knowledge emerging from Mishra and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Koehler's (2006) Technological PCK was added to the conceptual framework. This is because we are living in the digital era where technological tools are used. The second component of the framework points to skills that the pre-service teachers need to have to teach science effectively. The first significant skill is how to facilitate practical work. Aligned with the technological knowledge are the competencies for using technological tools (Mavhunga et al., 2023). Without this kind of skill, pre-service teachers will be unable to select powerful strategies to implement their technological knowledge when teaching science. It is important to note that knowledge and skills are interrelated. When completing modules where the aim is for aim for the pre-service teachers to learn the content, the expectation is that they also do practical work as it is the fundamental aspect of science (Gericke et al., 2022). In the last component, the assumption is that these knowledge domains and skills can be developed in both the content and methodology courses, as argued by Khoza (2022).

## Research Methodology

### *Design*

The research approach used in this study was qualitative (Kivunja & Kuyini, 2017). The qualitative approach was used to delve deeply into the pre-service science teachers' experiences of ERT. An exploratory case study was used as a research strategy. According to Yin (2014), exploratory case studies are used to explore a phenomenon under study. In this case, the case study was used to understand the pre-service science teachers' experiences of ERT.

### *Sample and Context*

The participants in this study were nine (9) pre-service science teachers who were doing their final year in the year 2022 at one South African university. These pre-service teachers were either majoring in Life Sciences or Physical Sciences. There were 8 Physical Sciences final year pre-service teachers and 4 agreed to participate in this study. There were 9 Life Sciences final year pre-service teachers and only 5 agreed to participate in this study. The 9 pre-service teachers further agreed that the interviews could be used for this study. The pre-service teachers were sampled using both convenience and purposive sampling methods. For purposive reasons, the pre-service teachers were selected because they were first exposed to face-to-face traditional teaching in 2019. In this institution, the pre-service science teachers complete their main science content modules with the mainstream students in their first 2 years then proceed to the education faculty for methodology modules. However, they also completed some of the methodology modules in their first two years (see Khoza, 2022 for a full description of this context). As such, they were exposed to both the content and methodology modules in face-to-face teaching and ERT. Table 1 shows the participants' major science subjects.

**Table 1**
*Major Subjects of the Participants (Pseudonyms used)*

| Participant | Major science subject |
|---|---|
| Lebo | Life Sciences |
| Thato | Physical Sciences |
| Kate | Life Sciences |
| Leila | Life Sciences |
| Melody | Physical Sciences |
| Pluto | Physical Sciences |
| Lesley | Life Sciences |
| Skate | Life Sciences |
| Khaya | Physical Sciences |


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As can be seen in Table 1, the participants in this study were a representation of the two science subjects. Furthermore, the pre-service teachers who participated in this study were studying to become science teachers at the secondary school level.

*Ethical Considerations*

Ethical clearance was granted by University of Pretoria Faculty of Education Ethics Committee under protocol number EDU029/21. Upon inviting the pre-service teachers signed consent forms to participate in the study. Anonymity and confidentiality were ensured in the study by using pseudonyms.

*Instruments and Data collection*

Data were collected through semi-structured interviews. Semi-structured interviews were advantageous in this study as they allowed the researcher to probe the participants and get in-depth data about their experiences of learning science online. An interview schedule was developed, and the following five questions were included in the interview schedule:

- As a science pre-service teacher, what was your initial reaction when the move to online learning was announced?
- How would you describe the strengths and affordances of online learning as a science pre-service teacher?
- Describe the challenges and constraints you experienced as a science pre-service teacher during online learning.
- In what ways did the online teaching prepare you as a teacher and as a science teacher?
- How would you compare your experiences when you were learning science education in a face-to-face mode and online?

The five questions above were asked to each of the participants during the interview. The interview questions were piloted with two pre-service science teachers who were not part of the study. In other words, although they agreed to be interviewed, they did not give their consent for their interviews to be used in the study. The questions above are refined as a result of this piloting. The participants were also probed based on the responses they provided to acquire a deeper understanding of their experiences. Six of the interviews were conducted online using Microsoft Teams, and three were conducted in person. Each interview took between 42 to 57 minutes. The interviews were audio-recorded and transcribed verbatim for analysis. The transcripts were then sent back to the participants to check for the credibility of the data.

*Data Analysis*

The data were analyzed using a thematic analysis approach. This approach is described as thematic analysis as "…a method for identifying, analyzing, and reporting patterns (themes) within data" Clarke and Braun (2006, p. 6). Therefore, the goal is to describe the patterns that emerge from the raw data to address the issue in question (Maguire & Delahunt, 2017). In analyzing the data, the following steps were followed:

**Step 1:** The transcripts were read alongside the audio recordings of the interviews. The goal here was for the researcher to familiarize himself with what is contained in the interviews.

**Step 2:** Codes that describe what is contained in the transcripts were allocated. In this step, the researcher started with one transcript and then extracted the codes that were emerging.

**Step 3:** Another researcher was invited to code the second transcript using the codes that emerged from the first transcript. This was done separately from the author. However, both coders were open to new codes that could emerge from this transcript and then added these to the list. Table 2 shows examples of the codes that emerged.


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**Table 2**
*Examples of Codes Used in the Analysis*

| Code | Example from transcript | Applicable theme |
|---|---|---|
| Usage of technological tool | …I did not know that you can use WhatsApp to engage learners and some lecturers use it. | Technological knowledge |
| Learning by seeing | With me, I need to see what you are doing… | Modelling exemplary pedagogical practices |
| Simulations as technology | I was exposed to simulations | Technological knowledge |
| Learning of concepts | The concepts that we learnt were not deep for me as… | Content knowledge |

**Step 4:** The author coded the rest of the transcripts and then began to categorize the codes into themes that describe the knowledge and skills acquired and lost as vocalized by the pre-service science teachers.

## Research Results

Analysis of the transcripts revealed four interrelated themes that characterize the reported knowledge and skills acquired and the backlogs perpetuated by ERT. These themes are organized in terms of the conceptual framework that guided this study. The first theme is about content and pedagogical knowledge. The second theme pertains to practical work and process skills. The third theme is about reflective and metacognitive skills, and the last theme is opportunities for modelling exemplary practices. These themes are presented and discussed below.

### *Content and Technological Knowledge*

The pre-service teachers talked about how the ERT denied them opportunities to acquire a conceptual understanding of the content. This resulted in a backlog of deep understanding of the subject matter.

**Thato:** *I can't remember everything I studied because it was online. I had all the answers, I just had to search for them. So, I do not have that conceptual depth of content…*

**Pluto:** *I feel like I don't deserve my degree because everything was at my disposal… Where we had to study for exams, I had all books and internet.*

**Skate:** *The content modules, you learn more when you are contact but online you can refer easily.…you do not put the same effort as you would on campus.*

**Leila:** *We had our books with us, so we weren't forced to sit and study the work and to make sure we understand how the things linked together.*

The extracts above reveal that the pre-service teachers felt that they did not develop a conceptual understanding of the content they were learning. For example, Thato and Pluto give the impression that they did not study the content. Instead, during assessments, they would have textbooks and the internet that helped them to get all the answers to the questions that the lecturers asked in an assessment. When Pluto was asked about how having all the textbooks and the internet at his disposal affected him, he said; "I have zero understanding of the chemistry I studied…" to denote a lack of conceptual depth of the content knowledge. Similarly, Skate says that she also referred to the resources like textbooks. She further stated; "I would not study my content because I knew I could get answers from the slides". A possible reason for this could be how the assessment was conceptualized and carried out. This is evident in the data as Lebo said; "The biggest thing with that online learning was that it was more of the assessment we were given…the assignments and tests were more of reproducing what we read from the textbooks". In the midst of not acquiring a strong conceptual understanding of the content knowledge, ERT was an opportunity for them to acquire technological knowledge. Acquiring this kind of knowledge allowed the pre-service teachers to think about how they could use it in their teaching contexts. Leila shared the following:


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**Leila:** *It enabled us to see a different way of teaching because most of the time you only stand in front of the class, but now you have all these different methods that you can use. You have Google Classroom, Kahoot and others.*

Leila learnt about a technological tool that she did not know before as she stated: "I would not have known about simulations and how to use them if we were coming to campus". Similarly, Skate also argued, "I don't want to lie neh, I now know a lot of technologies and apps in education…". This indicates that pre-service teachers were able to gather technological knowledge as their lecturers used technological tools and when their lecturers requested them to use these tools to complete certain assessments in the modules. For example, Melody stated; "…our lecturer wanted us to use an app [inaudible]…to set questions of different cognitive levels…" to explain how he got to know about the app.

*Practical Work and Process Skills*

In terms of the theme of practical work and process skills, the analysis of interviews revealed that all the science pre-service teachers who participated in this study did not acquire this knowledge.

**Khaya:** *All our practicals were just non-existent… they gave us reports to write, but it was nothing, nothing practical within chemistry or physics or something…we did not do practicals in an online setting at all…*

**Skate:** *I believe they could have tried to do something like collecting leaves and then. Making a cross section… I think they could have been more accommodating. we didn't have that, so I think I lack that experience for going and teaching.*

**Kate:** *I've never dissected anything because everything was online and this might be a problem when I start teaching. I don't want to say I'm going to avoid doing practicals, but it's gonna be a challenge. It's not gonna come naturally to me, so I'm gonna have to make a conscious effort because we didn't do it.*

**Pluto:** *You can't just have knowledge [referring to content knowledge], you need to do the practical part of it to to teach it especially. Like they give us a platform where we could do like, measurements of plans and stuff, but it's not like for a science teacher. So, we never learned those stuff.*

In the extracts above, the pre-service teachers are sharing their gaps in terms of practical and process skills. Khaya, who is in Physical Sciences, emphasizes the absence of practical work as a physical sciences student. This applied to Skate, who felt like she was not accommodated. Skate further argues that he lacks experience in that regard while noting that the lecturers could have done something for them to acquire practical and process skills. Pluto alludes to this by saying that as a science teacher, having content knowledge is not enough – one needs to acquire practical skills as these impact how one would teach in their future context. However, despite the absence of real-time practicals in laboratories, some of the Physical Sciences pre-service teachers appreciated the use of simulations, virtual laboratories and home practical work. For example, two of the pre-service teachers said the following.

**Melody:** *I learnt something with the simulations where I could measure voltage, current and all that…I could see electrons flowing…Like, it is something I always imagined from high school.*

**Thato:** *Being able to add and remove stuff on the simulation was fascinating…I think Dr X was also able to explain it better…*

Melody and Thato are of the view that the simulations worked for them in terms of manipulating some of the functionalities that could help them acquire process skills. Melody was able to have a sense of how the movement of electrons in a conductor looks like, thus, satisfying not only visualization but also process skills such as inferring and predicting. Thato was virtually able to manipulate the objects using simulations, which to some extent, may have given him a 'feel' of manipulating real objects. Furthermore, Khaya, who seemed to define practical work in terms of being in a physical lab (see above) further argued; "for me, it makes no difference if I cannot see the real apparatus that I can work with…maybe use online labs there and there but keep us in the real labs most of the time" to denote that his learning loss in terms of practical work during the ERT.


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*Knowledge of Pedagogy and Opportunities for Modelling Exemplary Science Teaching Practices*

As argued in the first theme above with regards to the pre-service teachers acquiring the technological knowledge only and not how they can use that in their classrooms, they also shared how online learning during the pandemic has denied them the opportunities to see science teaching practices from teacher educators' actions in both content and methodology modules.

**Khaya**: *Like I think we need that face-to-face learning in order to teach because we are teachers, we have to see how our teachers teach like when we were just given narrated slides. So the online made it difficult.*

**Lesley**: *In the methodology, I also look at how the lecturer teaches and in online I did not get that because the teaching was mostly one-directional. When I was doing contact, I would look at how the lecturer interacted with us*

**Leila:** *Our science modules were treated like any other module and this was a problem for me because I did not learn how to teach science and what he or she emphasizes…*

All the pre-service teachers' utterances allude to losses in terms of the knowledge for teaching that could have been modelled in both their content and methodology modules. Khaya attributes this to asynchronous sessions where the lecturer would make narrated slides instead of synchronous sessions. This is not surprising as narrated slides do not provide opportunities for lecturers to communicate through actions on how science can be taught. Leila uttered, "I learnt about practical work in science, but I have no idea how to perform these practicals for my learners", to denote the absence of this important science-specific pedagogy. In this case, the pre-service teacher did not see himself performing the practical work using the knowledge he had learnt.

## Discussion

There are knowledge and skills backlogs that pre-service science teachers have. The first backlog is a conceptual understanding of the content knowledge. This is attributed to the lecturers' approaches to teaching and assessment as well as the students' approaches to learning, as revealed in the findings. In the literature, there are two approaches to learning; surface and deep learning. Surface learning is associated with memorizing the content, whereas deep learning is associated with making links between different concepts (Asikainen & Gijbels, 2017). This finding is also reported by Alhammadi's (2021), who found that during the pandemic, some students resorted to surface learning. In this case, students' surface learning was a result of how the content was taught and assessed. The effects of this surface learning in pre-service science teacher education would include weaker subject matter knowledge, which is a primary determinant of an effective science teacher (Azam, 2019; Rollnick et al., 2008). This is a problem as, according to van Driel et al. (1998), sufficient content knowledge is a pre-requisite to the development of science teachers' PCK. Given that the pre-service teachers did not acquire sufficient content knowledge during the ERT, there is a high possibility that their PCK may be weak, thus, raising questions about the quality of science teachers produced in this period. One might argue that these science teachers will develop PCK with experience as it is generally agreed that PCK grows with experience (Barut & Wijaya, 2020). However, Chan (2018) argued that this is not usually the case in the sense that these teachers may not have the basic content knowledge that they can capitalize on. Therefore, in the absence of this conceptual depth of science content knowledge, the pre-service science teachers may have limited capabilities to develop their PCK.

The second backlog that the pre-service science teachers have is in terms of the knowledge of practical work and the skills for performing these practicals. Scholars in science education agree that practical work in real-time laboratories is important for the development of students' practical and process skills (Özer & Sarıbaş, 2023). The pre-service teachers who were subjected to ERT may lack these skills as a result of not having real-time practical work. It is important to note that although the pre-service science teachers did not have real-time laboratory practical work, virtual labs were performed although minimal. However, some pre-service teachers noted that they had their shortfalls. Usman et al. (2021) argued that virtual laboratories do make a difference in the teaching and learning of science as they promote students' development of process skills. However, the data in this study revealed that this does now work for every student, as some prefer being in the actual laboratory to acquire practical and process skills. In line with the findings in this study, Byukuseng et al.'s (2023) study found that many students preferred physical labs. Perhaps it is about how the virtual practicals are facilitated as noted by Khaya above. Just like home practical activities (Velarde, 2022), when students are engaged during virtual labs, it is necessary to have


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effective feedback mechanisms. Therefore, going forward, practical work in online modes should be thoroughly planned and have clear facilitation.

The third backlog that the pre-service science teachers have is in terms of witnessing exemplary science teaching practices during the ERT. Pre-service teachers are supposed to witness exemplary science teaching practices when lecturers model these practices. One can ask the question of which exemplary science teaching practices need to be modelled in online teaching mode. The answer to this question is complex and multifaceted in the sense that we have generic teaching approaches that can be applied to any subject and those that are specific to science (Bicer, 2021). For example, facilitating question-and-answer sessions is a generic teaching strategy, whereas inquiry-based learning and practical work are more science-specific as they aim to develop students' process skills and scientific literacy (Shana & Abulibdeh, 2020). Of importance are the science-specific approaches like facilitating practical work, which was, according to the pre-service teachers, not modelled. However, the pre-service teachers' utterances do not necessarily mean that there was an absence of intention to model these science-specific pedagogies from the teacher educators. A teacher educator may intend to implicitly model a particular teaching approach. According to Lunenberg et al. (2006), explicit modelling can be done in two ways; the first is through 'meta-commentary' where the teacher educator would stop and highlight how a certain strategy would be used in their teaching contexts. The second is through facilitating the translation to the pre-service teachers' own practices. Both these forms of explicit modelling were absent in online learning. Under normal circumstances, the latter would be done through micro-teaching and teaching practices that the pre-service teachers did not have the opportunity for during the ERT, thus leaving a gap in their knowledge of teaching science. Fabriz et al. (2021) reported that students appreciated synchronous sessions more than asynchronous sessions since the engagements and activities that one would find in the synchronous sessions. It is through these engagements and activities that the teacher educator can model basic science teaching practices. Nyamupangedengu and Lelliott (2016) found that their pre-service teachers paid attention to the teaching and learning aids used in lectures as well as how concepts were explained by the lecturer for them to get messages about teaching science. Nevertheless, the teacher educator may explicitly point out, for example, after explaining a concept, what a good explanation looks/sounds like.

Although the pre-service science teachers reported on the knowledge and skills backlogs as seen above, they also gained some knowledge. One of the important knowledge bases that science pre-service teachers need to acquire in the 21st century is technological knowledge (Tondeur et al., 2020; Wilson et al., 2020). The pre-service science teachers in this study gained this knowledge. These findings are not surprising as there was a rise in the use of technological tools during the ERT (see for example, Antón-Sancho and Sánchez-Calvo, 2022; Aydin et al., 2023). It is important to note that the pre-service teachers in this study only reported on acquiring technological knowledge and not how to use that knowledge. As such, even though the teacher educators used these technological tools, it was not clear to the pre-service teachers how the tools may be relevant in their future contexts of teaching. Mavhunga et al. (2023) argued that not only should pre-service teachers be exposed to technological knowledge but also be equipped with the competencies for using this knowledge in their teaching. Owing to the significance of modelling exemplary practices in science teacher education as argued above, the use of these digital tools could have been modelled to pre-service teachers.

## Conclusions and Implications

This study was about revealing the knowledge and skills that the pre-service science teachers have acquired during the ERT as well as the backlogs. Since the ERT was not only adopted in South Africa during the pandemic, the findings and implications in this study apply to the international audience. Firstly, the science pre-service teachers alluded that they had learnt the content of science but did not develop a deep understanding of this content, thus threatening their development of PCK in practice. However, despite the backlog they may have in terms of science content knowledge, they had an opportunity to learn technological knowledge, which is an important knowledge base in the 21st century. Secondly, although the pre-service teachers appreciated the virtual labs and home practical work, they missed the opportunities to acquire knowledge and skills in practical work. Thirdly, the pre-service teachers alluded that they did not 'see' exemplary science teaching practices. The findings in this study serve as a starting point to think of ways that can be used to fill this knowledge and skills backlog in two ways. Firstly, the pre-service teachers who participated in this study completed their degree in 2022 after having a full 3 years of online learning perpetuated by the pandemic. As such, a recommendation is to come up with professional development courses that can fill the gaps. Secondly, a question that arises from this study is


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how the initial teacher education programs are presently working towards filling such gaps in science pre-service teachers who are yet to earn their qualifications.

**Limitations and Future Studies**

There are two limitations to this study making it difficult to make concise conclusions about the knowledge and skills gaps that may exist in teachers produced during the pandemic. Firstly, the findings in this study are based on only nine science pre-service teachers from one institution in the South African context, which is a small, contextualized sample. Secondly, the knowledge and skills backlogs reported in this study come from the pre-service teachers themselves through interviews. This may not be the case in practice. There is a need for a large-scale study that can look at these knowledge gaps using competency tests and intense observations in varied teaching contexts and other subject areas to provide a broader overview of these gaps.

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