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Pre-Service Science Teachers' Preparedness for Classroom Teaching: Exploring Aspects of Self-Efficacy and Pedagogical Content Knowledge for Sustainable Learning Environments

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ABSTRACT
The technological reconfiguration of humanity and advancement requires initial teacher training (ITE) programs that create and enhance sustainable learning environments (SLEs) where teachers are prepared to embrace posthuman pedagogy to teach confidently. This case study aims to examine pre-service science teachers' level of preparedness and teaching efficacy beliefs to teach in SLEs. The study findings revealed that teaching science requires content knowledge and an understanding of how to teach the content. Furthermore, education programs need to be responsive to the socio-economic demands and produce 21st-century-ready graduates. The participants' teaching philosophy aims to promote SLEs where quality teaching will be prioritized. Without proper training, support and resources, this aspiration will remain a mirage. Maintaining responsive classrooms will thus be a challenge that continues to be an albatross to social change. This study has some implications for ITE programs, impacting the school curriculum and educational transformation.

KEYWORDS
Confidence; Fourth Industrial Revolution; initial teacher training; posthumanism; science education; social change.

INTRODUCTION

In line with the National Policy Framework for Teacher Education and Development, South Africa's current education reform aims to foster high standards for teaching and learning. The purpose of these standards is to create a fundamental shift in what learners learn and how they are taught. Howlet (2018) argued that innovative teaching strategies are necessary to challenge entrenched paradigms and generate fresh knowledge. The post-humanist viewpoint is anticipated to bring this to the educational system (Howlet, 2018).

Compared to other countries such as Singapore and Finland, South Africa continues to perform dismally in standardized tests (The Trends in International Mathematics and Science Study [TIMSS], The Progress in International Reading Literacy Study [PIRLS], GEF-Technology Report). This poor performance, according to the Integrated Strategic Planning Framework for Teacher Education and Development in South Africa, 2011–2020, occurs in both international tests and the South African systematic assessments and matriculation examinations. National assessments still pose serious challenges to the learners' performance. These challenges emanate from, among others, the implementation of the National Curriculum Statement (2006), which shifted the assessment practices by introducing School Based Assessment (SBA) which includes a component of formative assessment (Dube-Xaba & Xulu, 2020).

Assessments are set as per the requirements of the Curriculum and Assessment Policy Statement (CAPS) guidelines to inform the content to be covered and assessed. If South African learners still perform poorly in the examination within their context, it is, therefore, imperative to explore if teachers are adequately trained to master the science concepts and the pedagogy to facilitate knowledge and teach science with confidence.

With the technological reconfiguration of humanity and the advancement and demands of the fourth industrial revolution, the problem might persist and pose more threats to the country's development. Subsequently, research (Omolara, 2008; Arends & Phurutsi, 2009; Chen & Usher, 2015) showed that poor performance of learners in science is primarily affected by, among other factors, teachers' low levels of self-efficacy beliefs. Learners' performance is associated with teachers' beliefs in their capability to teach the subject.

Accordingly, initial teacher education (ITE) programs should embrace posthuman pedagogies that promote instructional strategies supporting and enhancing future teachers' views about scientific teaching efficacy beliefs to enable them to teach science with confidence (Stevens et al., 2006). It is also crucial to recognize that instructing science does not only require knowledge of the content but also an understanding of how to teach the concepts, that is, student teachers need adequate pedagogical content knowledge (PCK) to be effective practitioners and to teach science successfully (Shulman, 1986). PCK development includes learning about approaches for improved classroom practice and instructional strategies from reflective classroom experience (Bartholomew et al., 2011; Blayi et al., 2022; Rahmadi et al., 2020). The infusion of posthuman pedagogy is of importance in finding new teaching and learning pathways (Blaikie et al., 2020).

The curriculum in higher education will need to be drastically revised in light of the impact of the evolving 4IR technology in economic and environmental terms alone to empower students to understand the technologies in detail and also to considerately scrutinize and foresee the development of networked arrangements of technology, the atmosphere, and socio-political systems (Penprase, 2018; Tsakeni, 2021).

The academic achievement of the country's future generations rests on pre-service teachers, according to Amankwah et al. (2017), who are students enrolled in educational training institutes who are pursuing teaching training (Amankwah et al., 2017). Therefore, ITE programs are necessary to "revamp the educational space and establish one that is favorable to learning" (Mamiala, 2013, p. 581). This study highlights the importance of preparedness for classroom practice during teacher training in maintaining sustainable learning environments. It proposes that the more prepared a pre-service science teacher is to teach science, the more confident they will be in presenting their lessons, and this will affect learners' outcomes. These attributes form part of the requirements for preparing effective science teachers to overcome the environmental, societal, and fiscal challenges of the 21st century. These include, amongst others, adapting to climate change (sustainability), education, economy (manufacturing), technology and communication (big data, keeping pace with technology), natural resources (water, energy, and food security), natural hazards, and risk.

The main drive behind this study was to explore how the teacher training learning environment prepares teachers for 21st-century classrooms.

This study aims to address the following research questions:

- What are the pre-service teachers' perceived personal science teaching efficacy beliefs?
- How do pre-service teachers perceive their pedagogical content knowledge toward preparedness for classroom teaching for the fourth industrial revolution?
- What are the implications of such perceptions for teacher education toward sustainable learning environments?

Role of Science Education Toward Social Change

The key purpose of science education is to empower scholars to make radical changes in their community (Du Ploy et al., 2016). These learners need conducive learning environments within their societies to enhance and promote science learning. Thus, the conditions in schools should be improved to ensure that the sustainable learning environments that pre-service teachers were trained in and about during their teacher training programs are sustained at both institutions of higher learning and the grassroots level where the spark for science should be ignited.

Subsequently, low-income families' lack of control over the goals and procedures of education is related to low levels of literacy and academic performance and the lack of access to opportunities and resources for children with disadvantages. School science can therefore begin to address power imbalances in children by promoting scientific literacy in young people, which leads to individual and community empowerment around health and environmental issues as well as the very science-related issues that divide opportunity and quality of life for low-income families (Zahur & Barton, 2010).

As pronounced in the National Developmental Plan and the Sustainable Development Goals, a policy must be aligned with the country's developmental goals to navigate the fourth industrial revolution within societies. There must also be configuration and synergy between departmental policies, such as the Department of Trade and Industry for industry 4.0, the Department of Labor for the future of work, and the Department of Higher Education, where teacher education is housed. Setlhako (2018) noted that initial teacher training programs should be tailored to target the abilities and proficiencies needed by teachers in the 21st century and prepare them for 4IR to meet the requirements and demands of future generations. The curriculum should link formal education to the outside-of-the-classroom working environment (Bada & Jita, 2021; Setlhako, 2018). Thus, there is a need for posthuman pedagogy, which Yan et al. (2020) describe as having four characteristics: posthuman pedagogy in terms of learner, instructional material, technology (nonhuman actors), and ethical behavior. According to Yan et al. (2020), posthuman pedagogy informs the rethinking of the connections implicit in pedagogy and the re-imagination of the dynamic activity of learning. This pedagogy should be addressed at ITE, which is also the focus of this study.

The purpose of teacher preparation programs is to provide training programs that will produce efficient instructors who can face today's challenges, including employability and competency, among others (Griffin et al., 2012). The creation and improvement of sustainable learning environments where instructors are equipped to instruct students in and about 4IR with confidence should be accomplished through initial teacher education (ITE) programs. Therefore, teacher education through these programs is expected to change how society perceives how science and its practices may bring communities together to effect meaningful contributions and prepare for the 4IR.

Penprase (2018) claimed that extending the capacity of on-campus courses to accommodate the learning of innovative information by students and institutional structures is necessary. A curriculum that emphasizes the interdependence of all living things and their behaviors, anchored in and outside the classroom, and innovative pedagogical techniques, would assist citizens with a global perspective and the capacity to think and act holistically (Blaikie et al., 2020). Sustainable learning environments (SLE) are resource-efficient places, offer high indoor environmental quality, and safeguard the larger environment, according to Stallman (2010).

Ineffective scientific education has been linked to several variables, including a lack of a strong grounding in science topics, a lack of preparation in science material, inadequate facilities and equipment, subpar school management, and teacher attitude (Mukhari, 2016). Moreover, resources are required to change education to accommodate 4IR demands as rooted in posthuman ideals. In light of the factors mentioned, the issue of resources and sustainability to transform education has emerged and will be discussed in the next section.

Resources Needed to Transform Education to Meet 4IR's Needs

There is a need for a pedagogy that embraces transition, as evidenced by the growth of posthuman discourses in education (Yan et al., 2020). The South African tertiary education environment is still shaped by the social, political, and economic inequities that are pervasive and visible in daily life (Waghid & Hibbert, 2018). Basic education is likewise subject to the status quo.

According to the South African School Act (SASA) of 2005, schools are classified into five quintiles based on the relative affluence of the areas in which they are located, with quintile 1 being the lowest and quintile 5 being the richest. Schools in quintiles 1, 2, and 3 do not charge tuition fees. For reasons outside the purview of this study, some no-fee institutions may not always be supported more than others.

A clear majority (90%) of the participants in this study are from lower quintile schools situated geographically in semi-urban and rural areas. However, they still prefer to plow back to their communities while undergoing experiential training or work integrated (WIL), as well as after becoming certified as teachers.

To the detriment of their training, there is a disjuncture between theory and practice due to the school conditions, and debates are still underway regarding theory and practice in ITE (Keller-Schneider et al., 2020). Addressing inequalities between different schools can only be fair and appropriate to distribute equal opportunities and privileges to all, in the interest of social justice, in line with the envisaged posthuman pedagogy.

For this study focusing on the teaching space of the science setting, the context of a sustainable learning environment goes beyond physical spaces to encapsulate science teaching and learning. This means a safe learning environment where learners feel supported and respected. The aim of SLE is to empower all students to fully discover and use their full potential to contribute to a democratic society (Mahlomaholo et al., 2013). Thus, the idea of an intelligent learning environment includes sustainability as one of its components. According to Blyth (2017), intelligent learning environments are created to assist teaching and learning and those who use them. Requirements for a learning environment should include sufficiency, effectiveness, sustainability, inclusiveness, responsiveness, agility, safety, technical capability, data-rich, support, healthy, and comfort (Blyth, 2017). The post-humanist approach to education is essential for learning in the twenty-first century, combining classroom, home, and community learning, while promoting the creation of new ways and environments that increase flexibility and provide support (Ahmed et al., 2011; Strom & Martin, 2022).

Efforts have been made to investigate science teacher PCK (Bartholomew et al., 2021, Vázquez-Bernal et al., 2022) and science teaching efficacy beliefs (Bandura, 1982, Gibson & Dembo, 1984; Shulman, 1986; Liang & Greer, 2009; Stevens et al., 2006). This study integrates the relationship between these concepts with a special emphasis on preparedness for classroom practice in sustainable learning environments. The study intends to investigate how pre-service teachers' PCK in sustainable learning contexts is impacted by their opinions about the efficacy of their scientific instruction. The information generated here will eventually be used to develop a strategy to support their confidence in teaching the subject. This aims to produce a breed of better-prepared teachers to teach science and, consequently, can positively affect performance in science.

A section included in this study about science teaching efficacy, which, according to Ginns and Watters (1999), is "a combination of a teacher's thorough scientific knowledge, understanding of the connections between the content knowledge and the teaching and learning process, a strong understanding of pedagogy, and the ability to successfully and practically apply their understanding and skills (Ginns & Watters, 1999). Similarly, preparedness forms a relationship between PCK and self-efficacy. When used in the context of teacher preparation, it is defined as "the condition or circumstance of being prepared; ready; and stresses the inclination of being prepared to do something." (Gill & Dalgarno, 2008). The more prepared science student-teachers are to teach, the more confident they will be in presenting their lessons, which will affect learners' outcomes. As a result, the purpose of teacher preparation programs is to adapt to changes and expectations by providing training programs designed to train efficient instructors who can cope with today's challenges, including employability and competency (Taole, 2013; Ono & Ferreira, 2010).

Understanding and encouraging the growth of teaching efficacy may unavoidably be crucial to reducing the current teaching profession attrition rate. Therefore, teacher instructors must be cognizant of the critical stages of teacher development where each of the four sources of efficacy—mastery experience, vicarious experience, verbal feedback, and psychological factors or emotional arousal—affects teachers' beliefs about their efficacy (Bandura, 1986).

In this case, these sources of efficacy play a critical role in shaping one's belief in their capability to perform a task. According to Stevens et al. (2006), these sources are stronger predictors of performance than mental stability. To promote efficacy beliefs, a construct of Shulman's (1986) theory, pedagogical content knowledge is of great importance in teacher education programs. This theory refers to a combination of knowledge of content and pedagogy. Moreover, PCK also includes understanding what makes learning specific topics easy or difficult (Bartholomew et al., 2011). Therefore, this study examines science teacher trainees' preparedness to teach content and their proficiency in strategies on how to teach the subject (pedagogy).

THEORETICAL FRAMEWORK

This study was guided by Shulman's theories of PCK and Bandura's self-efficacy beliefs. The social learning theory forms the basis of the concept of personal self-efficacy (1977,1981). According to the theory, environmental, behavioral, and cognitive forces are in constant interaction to shape human behavior. According to Govinden (2022), posthuman thought holds that people are a part of a larger world, with its complexity and multiplicity (Govinden, 2022). According to Hasse (2019), human learning is socio-culturally based collective epistemology from the moment of birth, and that learning also builds on prior learning. The emphasis has shifted from the individual learner to learning within communal phenomena due to this posthuman acknowledgment (Hasse, 2019). This expands on Bandura's theory of triadic reciprocity. He proposed the idea that, in terms of self-efficacy, beliefs, and behavior are tightly related. He defines self-efficacy beliefs as "rulings about how well a person can perform the actions necessary to cope with potential problems" (Bandura, 1982, p. 122). This means that teachers' confidence in their teaching abilities is reflected in their instructional strategies, subject-matter expertise, and positive and negative attitudes. This study aimed to focus on science teacher trainees' perceptions of their efficacy. Simply put, this is a teacher's conviction or confidence in teaching science effectively. Strong or high teaching self-efficacy may greatly affect a teacher's motivation to teach science, whereas poor teaching self-efficacy may cause a teacher to avoid teaching science (low or weak teaching self-efficacy).

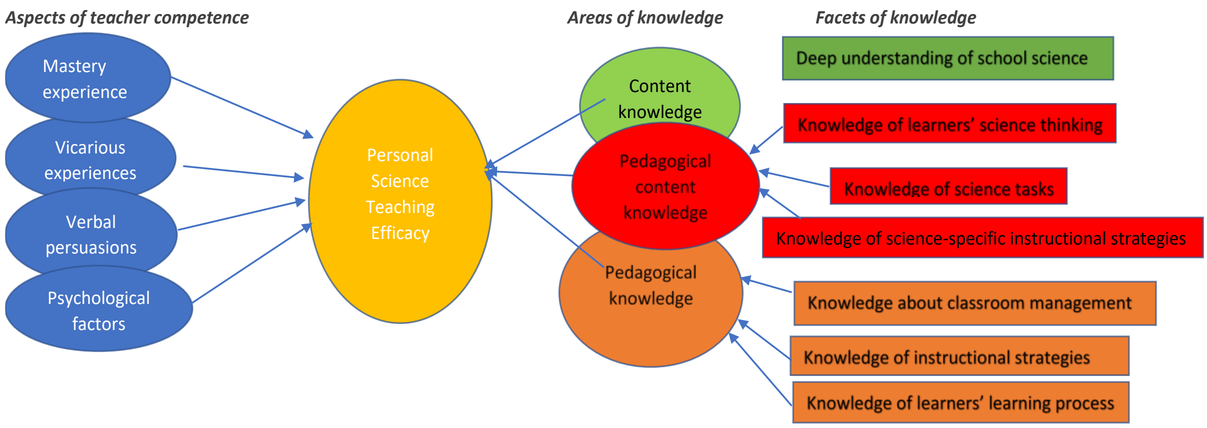

Figure 1. Conceptual Design Linking the Relationship Between Sources of Efficacy and PCK

Figure 1 illustrates the aspects of knowledge evaluated during micro-lessons and teaching practice observations. These, with sources of efficacy, guide the study in how pre-service teachers' efficacy beliefs can be explored and enhanced.

RESEARCH METHODOLOGY

This study has an open-ended, exploratory design following a transformative paradigm and utilized quantitative and qualitative data collection methods. According to Mabry (2009), a case study approach necessitates a thorough comprehension of the subject and a researcher's interest. As the researcher is a science educator at the research site, the case study is applicable to this study. The researcher's reflexive interest in the study was to examine student teachers' confidence and preparedness for classroom practice and investigate whether they are ready to teach in a 21st-century classroom.

Study Sample

Forty-five (19 females and 26 males, aged between 19 and 23 years) third-year undergraduate education students specializing in science education at the university of technology contributed to the study. A convenience sampling technique was used from a population of other specializations, including technology, computer science, languages, and social sciences.

Data Collection and Analysis

Questionnaire

The Science Teaching Efficacy Belief Instrument for pre-service teachers (STEBI-B) was used to collect quantitative data in response to research question number 1 (What are the pre-service teachers' perceived personal science teaching efficacy beliefs?). This data-gathering tool was established by Enochs and Riggs in 1990 and adapted by Bleicher in 2004, and it was tested for validity and reliability. The instrument has a five-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). The median of this scale is 3. A mean that ranges between 3 and 4 will be considered moderate to high, while a mean that ranges higher than 4 will be considered very high or positive perception.

Personal Science Teaching Efficacy (PSTE) was considered for this study because it focuses on the self-efficacy dimension, while Science Teaching Outcome Expectancy (STOE) scale is concerned with the outcome expectancy dimension dealing with learners' performance, which can further be explored at a later stage. The data at hand were analyzed descriptively using Microsoft Excel.

Observations

Classroom-based observations were performed through micro-teaching evaluations and school-based teaching practice sessions. These observations serve as a representation of the potential learning environments that aspiring teachers would encounter. In contrast to microteaching, which entails a modeled teaching event of a lesson of a duration of five to ten minutes, where candidates teach a brief lesson to their classmates, school-based teaching practice sessions, according to Ananthakrishnan (1993), expose student teachers to practice teaching in a real classroom setting.

Through a series of micro-lesson evaluations covering various abilities, PCK was utilized to gauge the student teachers' competence as well as readiness for classroom teaching. These skills include skills of illustrating with examples, skills of stimulus variation, skills of explaining, skills of classroom management, and using teaching aids to provide clarity and proper understanding of what is being taught. This simulated platform was used to determine the possibility of enhancing a sustainable learning environment and how these can inform the expected 21st-century skills that will determine their preparedness to teach with and for the fourth industrial revolution. Through these classroom observations, the evaluation sheets were analyzed as part of data collection instruments, and emerging themes were categorized.

Focus Group Discussions

After the administration of STEBI-B and classroom observations, group discussions and presentations were held during class to probe the questionnaire findings and the observations further. Data were audio recorded. Common themes emerging were thematically categorized based on the following subheadings: aspirations, experiences, and challenges.

Ethical Considerations

Permission and approval to conduct this project were sought from the institution.

Consent was obtained from the participants, and it was explained that taking part in the study was entirely optional. They were informed of the advantages of taking part in this study. Also, the privacy of their replies was protected.

FINDINGS AND DISCUSSIONS

Questionnaire Findings

Research question 1: What are the pre-service teachers' perceived personal science teaching efficacy beliefs?

The STEBI-B full-scale mean was 3.29, and the PSTE subscale average mean was 4.01, which was perceived as very high. All the negatively worded statements were reversed. As previously stated, this study focused on the PSTE subscale to concentrate on pre-service teachers' beliefs in themselves to successfully assume the role of a classroom teacher. The average PSTE score was 52.10. This means a very high perceived score, as scores of PSTE are between 13 and 65, whereas scores of STOE are between 10 and 50 (Bleicher, 2004). Table 1 presents the average mean values per item of PSTE.

Item 2 (I'll keep looking for innovative ways to educate science) scored the maximum with a score of 4.7, which is a positive sign indicating the students' preparedness to learn. In summary, the average mean of 4.01 represents a very high perceived efficacy belief of the future science teachers. This is a clear indication of their readiness for 21st-century classrooms.

Table 1. *Mean Per Item and Average Mean for the PSTE Subscale*

Item	Statement	Mean	Qualitative description
2	I'll keep looking for innovative ways to educate science.	4.70	Very high
3	Even if I work hard, I will not be able to teach science as I will most other topics.	3.73	High
5	I understand the processes required to successfully communicate science topics.	3.73	High
6	I won't be very good at keeping up with scientific ideas.	3.83	High
8	Typically, I will provide ineffective scientific lessons.	4.67	Very high
12	I am capable of teaching science well since I fully comprehend the ideas.	3.97	High
17	It will be challenging for me to explain to learners why scientific experiments are successful.	3.97	High
19	I'm not sure if I'm adequately skilled to teach science.	3.97	High
20	If given the option, I will not request the principal to review my science instruction.	4.20	Very high
21	I usually don't know how to help a learner grasp a science idea when he is having trouble with it.	3.77	High
22	In my science classes, I often encourage learners to ask questions.	4.63	Very high
23	I am unsure of how to get learners interested in science.	4.10	Very high
	Average mean	4.01	Very high

*Adopted and adapted from Enochs and Riggs in 1990

Observations Findings

Research question 2: How do pre-service teachers perceive their pedagogical content knowledge toward preparedness for classroom teaching for the fourth industrial revolution?

Observations were used to identify student-teachers' perceived PCK and focus group discussions probed their preparedness for classroom teaching for the fourth industrial revolution. Data were accumulated through student teachers' participation in micro-teaching and teaching practice evaluations. In both evaluations, pre-service teachers achieved a passing score such as 50% and above. As the evaluation is a developmental process, participants showed that they were evaluated more than once with constructive feedback to improve their performance.

Themes that emerged from evaluators' comments addressing the PCK ranged from lesson objectives, chalkboard summaries, the pace of the lesson (i.e., too hurried or too slow), teacher-learner interaction, enthusiasm, and confidence. Microteaching, like teaching practice, offers student teachers a smaller-scale chance to put the hypothetical information acquired in the various modules of their programs into practice (Mpofu & Maphalala, 2018). However, student teachers expressed their concern during the focus group discussion that it is not always possible to do so as the learning environments in schools are not as conducive as the environment at the university, which is more technologically advanced, and where they have access to computers and Wi-Fi that enable them to simulate experiments when the need arises. From data collected on the personal efficacy belief construct (research question 1) and classroom evaluations (research question 2), the results were triangulated through focus group discussions on whether their perceived confidence translated into preparedness to teach (PCK) for the 4IR through the different skills that pre-service teachers were evaluated on. The second form of content knowledge is pedagogical knowledge, which extends beyond a basic understanding of the subject to include the dimension of the subject as it relates to teaching (Wee-Loon, 2011).

Focus Group Discussions Findings

Aspirations, experiences, problems, and concerns were used to characterize the topics that arose from the focus group discussion. These are in response to pre-service teachers' preparedness for the 21st-century classroom practice and will be outlined in the next section:

Aspirations

As aspiring agents of change, the pre-service teachers' philosophy of teaching aims to promote learning-centeredness. To enhance their knowledge of science-specific instructional strategies, they want to make a difference by encouraging meaningful learning to create conducive sustainable learning environments in which quality teaching is prioritized.

The study findings are consistent with that of a Turkish study reporting that using a student-centered approach to instruction improved student teachers' affective and cognitive skills through group work activities and active participation, emphasizing the benefits of long-term learning and learning how to learn (Zeki & Güneyli, 2014).

Experiences and challenges/concerns

The initial teacher education program allows exposure through micro-lessons whereby various skills are assessed. Even though micro-lessons simulate classroom teaching and promote role-play, the experience in the actual classroom is different. Falkenberg et al. (2014, p. 340) described the incorporation of theory and practice as "not an issue of implementing theory in practice, but rather a challenge of empowering future teachers to build sound phronesis."

No matter how prepared the students feel that they are regarding the different skills, time will always be a constraint as it will become difficult to incorporate the different micro-lesson skills into one full lesson, which will negatively affect their preparedness for classroom teaching. This is consistent with the findings of a study by Zeki and Güneyli (2014). They reported that the approach's weak points were the ineffectiveness of various educational activities, the material qualities of the teaching space environment, and the length of time allotted for the activities. With proper re-alignment of the curriculum that responds to the needs of 4IR in the schooling system, the learning-centered approach can lead to improved learning of science and equip learners to thrive in the constantly transforming world. The focus should shift from an assessment-driven curriculum to more focused on promoting quality mastery experiences of basic principles and concepts.

Another challenge raised by future teachers that might hinder the implementation of a learning-centered approach is that the university modules are not responsive to inclusivity and the promotion of emotional intelligence. Moreover, learner behavior and lack of discipline in schools emerged as factors that might affect teachers' efficacy.

This indicates that the schooling routine does not keep learners occupied with cognitively demanding activities, which defeats the purpose of teaching to acquire the skills required for the 21st century.

Research question 3: What are the implications of such perceptions for teacher education toward sustainable learning environments?

Implementing a post-humanist approach to education involves re-evaluating pedagogy, knowledge production, and dissemination (Blaikie et al., 2020). According to Blaikie et al. (2020), this shows that the posthuman perspective has the potential to alter how we regard ourselves, other species, the earth, and everything else. "It implies respecting all entities and their interdependence; it necessitates considering the system as a whole rather than each entity as a perfect independent individual" (Blaikie et al., 2020, p 2). In the setting of this study, posthumanism doesn't regard pre-service teachers as not having the necessary skills but as seeking possibilities for improvement.

Following the completion of this study, methods used to boost the confidence of future teachers by exploring the sources of efficacy and level of PCK need to be embedded into subject-specific methodology modules. Consequently, different pedagogic interventions may be examined in which design-based research methodologies will be employed. Design-based research tries to both establish theories regarding definite field learning and the instruments that are developed to facilitate such learning, and it is believed that this can help close the gap between theory and practice in education (Bakker & Van Eerde, 2013). This, in turn, will further promote sustainable learning environments required for 21st-century educational settings.

When teacher trainees employ the methods they learned throughout their teacher training education programs, evidence supports the belief that novice teachers have a beneficial influence on their learners' learning, according to McGee and Cooper (2010) and Bartholomew et al. (2011). The promotion of sustainable learning environments, which are necessary for teaching and learning, will result.

The main goal of this study was to provide a setting where participants may investigate options for sustainability in line with posthumanism and share their opinions as change agents. Therefore, in order to promote the fourth industrial revolution's transformation goal for sustainable learning environments, new teaching methodologies must be used to increase the effectiveness of trainee teachers' scientific instruction during the initial teacher preparation. This was done after establishing pre-service teachers' PCK and teaching efficacy. To guide the structure of teacher education programs, it is crucial to examine and comprehend trainee teachers' perceived efficacy, opinions, and readiness. That way, teacher-educators will be better equipped to train and prepare pre-service teachers for the fourth industrial revolution attributes.

This study has some limitations. It examined a set of science pre-service teachers in a particular schooling context only. However, it suggests the need for further research on the teacher's role in maintaining sustainable learning environments among the disparities within the South African schooling system and its assessment-obsessed curriculum.

CONCLUSION

Programs for teacher education might be affected by this study on how they should respond to the needs for integration of 4IR. In the posthuman era, there are limitless possibilities for a responsive curriculum toward maintaining SLEs. Science teaching efficacy beliefs need to be embedded in subject didactics modules and content subjects.

As science is a dynamic subject, attention should be paid to creating and developing sustainable learning environments, and the impact of social change that the different strategies implored in teaching science can have on future generations of South Africa and teaching efficacy beliefs will be increased. This confirms that sources of efficacy play a pivotal role in the improving of pre-service science teachers' preparedness during 21st-century classroom teaching.

Although we want to reach the same level as other developed countries as a developing country, it is understood from the opinions of pre-service teachers that we still have a long way to go in terms of providing SLEs. Pre-service teachers can be trained to the expected qualifications as only higher education institutions have access to state-of-the-art equipment/facilities. However, these newly qualified teachers will be working in a variety of poverty-stricken environments and cannot cater to all these needs.

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