JOURNAL OF BALTIC SCIENCE EDUCATION
ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

A NEXUS OF SCIENTIFIC INVESTIGATIONS, SCIENCE PROCESS SKILLS, AND SUSTAINABLE DEVELOPMENT GOALS: PRE-SERVICE TEACHERS' VIEWS CONCERNING MANGROVES FIELDWORK

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Abstract. *Initial teacher education should mould well-rounded teachers proficient in scientific investigations, and advocate sustainability amid global ecosystems' degradation. The research sought to explore pre-service science teachers' views concerning scientific investigations and sustainable development goals, and synergy between skills and different aspects of scientific inquiry within the context of the mangroves ecosystem studied. A four-part questionnaire was administered to 82 students registered for a Bachelor of Education degree. It included items on teachers' confidence in planning and conducting scientific investigations, types of scientific investigations, sustainable development goals, science process skills and the different aspects of scientific inquiry. Statistical analysis of the data showed the importance of a constructivist approach, learner engagement and discerning and controlling variables when investigating scientific phenomena. However, only a fair number of teachers could correctly provide the scientific investigation they conducted during the mangroves study, the sustainable development goals embedded in it, and the synergy between science process skills and the aspects of scientific inquiry. The findings have implications for teacher education in terms of potential challenges in teachers' understanding of scientific investigations, the synergy between them and sustainability, and science process skills that meld with the aspects of scientific inquiry.*

Keywords: *pre-service teachers, science process skills, scientific inquiry, scientific investigations, sustainable development goals*

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Introduction

Initial teacher education should prioritize key competencies in teachers if the intention is to mould an all-round science teacher. Such competencies should be focused on knowledge and understanding, skills, values and principles, methods and procedures relevant to a discipline (Molefe & Stears, 2014). They (competencies) should be emphasized in Environmental Education (EE) and education for sustainable development (ESD), where teacher professional development praxis and research have assumed central importance. First, there is a much-needed synergy between EE and science education due to concerns about sustainability (Wals et al., 2014) and the need for education *about, in* and *for* the environment. Indeed, EE has long endorsed a multidisciplinary view of the environment and most importantly, the acquisition of skills and solving of environmental problems (UNESCO, 1980). The typology thereof is analogous to science education's emphasis on skills development through scientific investigations (SciI) and connections to science and society (Pedretti, 2014). Second, skills together with methods implemented during EE activities might be applicable to science processes (McDonald & Dominguez, 2010). Science processes had long been viewed as an amalgamation of skills and procedures to be developed and utilized in SciIs (So, 2003). For Colley (2006), science content and process within the context of ecology might entail, for instance, collaborative fieldwork and SciIs. Such SciIs may be of great importance when addressing indigenous forests as focal points for aligning sustainable development goals (SDGs) with carbon mitigation and conservation (Cf. Smithwick, 2019).

The synergy of SPS and SciI itself is not new (see Arena, 1996). SPS might not only be key in cognitive development (e.g., inquiry, reasoning, and problem-solving skills) (Özgelen, 2012) and gathering new knowledge but also in the understanding of scientific processes and methods (Čipková & Karolčík, 2018) during fieldwork. For teachers to be able to grasp and then

https://doi.org/10.33225/jbse/23.22.682

address environmental problems, they should first have an in-depth knowledge and understanding of EE and a wide range of skills (e.g., thinking skills and SPS) (Dresner et al., 2014). Unfortunately, a conceptual understanding of SPS can be a challenge to teachers (Čipková & Karolćík, 2018; Hafizan et al., 2012; Mumba et al., 2018) possibly because of lack of confidence and limited understanding of the skills (Ambross et al., 2014). On the other hand, the challenges concerning the implementation of SciIs have primarily been rooted in teachers' mindset stuck in a rigid pedagogy (Ramnarain, 2011) and views about the scientific method and its role in the rigour of these activities (SciIs) (Gobalek & Amrane-Cooper, 2011), and lack of confidence in planning and implementing them for learner learning (Pepper, 2013). EE itself has also presented a challenge to teachers (Reddy, 2011). This conglomerate of challenges thereof points to the need for teachers' acquisition, for instance, of relevant skills and understanding of scientific concepts. Most importantly, they suggest a need to disrupt the pre-service teachers' understanding of SciIs and the embedded SPS during ecosystem-based studies, as well as the supremacy of science when working on environmental problems.

The new era of SDGs put emphasis on humanity rethinking its place in the world, hence the increase in the mobilisation of green life skills today (Kwauk & Casey, 2021). This is overdue considering that climate change has become the fundament global issue that threatens countries' sustainable development, hence a need to problematise teachers' roles and their understanding of the content of climate change education (Apollo & Mbah, 2021). In South Africa, mobilisations on methods and processes to lobby for change-oriented learning towards better environmental sustainability practices and/or environmental learning in a wide range of contexts (see Fundisa for Change Programme [FCP], 2013; Rosenberg et al., 2008; Shava & Schudel, 2013; Vogel et al., 2013) have since stimulated the development of science process skills and implementation of SciIs. The Natural Sciences curriculum itself advocates responsibility towards the environment while learners develop scientific skills and processes associated with investigating natural phenomena (Department of Basic Education [DBE], 2011b). Thus, it is reasonable that the curriculum envisages competent teachers whose praxis is enshrined in the understanding of "the need for using scientific knowledge responsibly in the interest of ourselves, of society and the environment" (DBE, 2011b, p. 9). In other words, the teachers should show both interest in science and environmental awareness, and proficiency in scientific knowledge (FCP, 2013). They should also understand that fieldwork is a signature pedagogy for future outdoor EE teachers (Thomas & Munge, 2017). Most importantly, they should understand that the complexity of the environment in a broader sense requires an equally extensive view of SciIs and the associated development of both SPS and SDGs.

Literature Review

Although EE has a long history, it could be envisaged as a newcomer, particularly in science education. It had to navigate, for instance, the hegemony of school-based disciplines before it could forge a mutual and compatible agenda with science education (Pedretti, 2014). The Tbilisi Conference remains the starting point for the launch of its (EE) programme in which knowledge, skills, attitudes, environmental problems and, for instance, SciIs became inextricably intertwined in a quest for environmental awareness (UNESCO, 1980). Thus, it is reasonable that the emphasis in EE is still on *methods* that "develop and support environmentally related attitudes, values, *awareness*, *knowledge*, and *skills* that prepare people to take informed action on behalf of the environment" (Ardoin et al., 2020, p. 1; emphases added). The methods such as ecological investigations have long played a major role in developing learners' thinking abilities (Kostova & Atasoy, 2008). In elaboration, it can be argued that its (EE) premises are enshrined in *environmental awareness* (see Littledyke, 2008; Moyo & Masuku, 2018; Soto-Cruz et al., 2014; Thor & Karlsudd, 2020). Inquiry-based learning might dominate *ecological investigations* (Kostova & Atasoy, 2008). Thus, it could be argued further that EE might form a springboard for the synergy between inquiry-based learning and ecology (Taylor & Bennett, 2016) and the scientific process (Tang et al., 2009; Thomas, 2012) when developing learners' *ecology-based content* and *SPS* (Colley, 2006). EE might also shed a light on the synergy between mangroves and climate change (Wimmler et al., 2021), SDGs and this (mangroves) ecosystem (see Dandabathula et al., 2021) and the SciIs themselves.

Outdoor activities had long been endorsed as means of enabling learners to use skills to promote a holistic understanding of the environment through hands-on experiences (Meredith et al., 2000). Fieldwork, in particular, could enable interaction between affective, psychomotor and cognitive domains in which learners are afforded meaningful learning of biodiversity (Scott et al., 2011), particularly in relatively less studied marine and freshwater ecosystems (Millenium Ecosystem Assessment, 2005). Indeed, Rog et al. (2017) pointed to the need to recognise mangroves' cross-realm importance amid a considerable knowledge gap in their ecology. After all, mangroves

https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

remain refuge habitats than mere marine ecosystems. Most importantly, mangroves may play a major role in greenhouse gases sequestration and alleviation of natural disasters (see Dandabathula et al., 2021) - a reason they had been advanced as part of the fundamental strategies concerning climate change such as REDD+ and blue carbon (Alongi, 2012), hence their connection with SDG 13 (climate action). That said, there are other appropriate teaching and learning methods that have been proposed to study ecological issues in tandem with fieldwork. Yli-Panula et al. (2019) pointed to the importance of inquiry-based learning, argumentation, group work, active participation and thinking skills as essential. Their argument is reasonable. Inquiry literacy and that of the environment are key for teachers to be able to develop their learners' understanding of the environment in a broader sense (Kidman & Casinader, 2019). The implication is that teachers' study of mangroves ecosystem (through *SciIs*) may enable them to be actively involved in learning scientific ideas and concepts (Abrahams & Millar, 2008) and promote critical thinking skills as they reflect on, for instance, the fauna of the ecosystem (Puche & Holt, 2012). They may not only enable collaborative learning but also inquiry and fieldwork. Indeed, the popularity of fieldwork gained traction in science education due to its ability to accommodate inquiry-based learning in which learners may engage in SciIs (Remmen & Frøyland, 2014), hence developing SPS.

Teachers should have competency in subject matter and scientific concepts as well as primary skills such as SPS (Gultepe, 2016). In terms of SPS, an average South African is expected to implement them (SPS) in the post-apartheid education system (Ambross et al., 2014). This is reasonable considering that SPS have remained the fundamental part of research over the last seven years (Čipková & Karolčík, 2018; Gultepe, 2016; Mulyeni et al., 2018; Ongowo, 2017; Susanti et al., 2018; Tilakaratne & Ekanayake, 2017; Shahali et al., 2015; Wahyuni et al., 2017) despite the long-established debates on processes and content in science education (see Millar & Driver, 1987; Wellington, 1989; So, 2003). Science process skills are means of investigating phenomena and constructing science concepts (Gultepe, 2016). They are normally grouped as either basic or integrated skills. For Shahali et al. (2015), the key to the successful utilisation of SPS and implementation of inquiry-based teaching by teachers lies in their (teachers') conceptual and operational understanding of the skills (SPS) themselves. Recently, Molefe and Aubin (2021a) highlighted the importance of conceptual understanding and context when SPS are taught and/or developed. It makes sense, therefore, that content and process should be incorporated into the teaching of science, as both are equally important (Gultepe, 2016) in any given context. Indeed, SPS can be developed in the EE context in which teachers seek to make sense of and solve environmental problems today. Their intersection with the 21st Century skills makes them (SPS) more invaluable than ever. As we venture into the digital age marked by technology and knowledge explosion, SPS and scientific literacy might provide a springboard for the development of 21st Century skills (Turiman et al., 2012). For instance, the development of SPS through an investigative study of mangroves may form the basis for the cultivation of collaborative work, critical thinking, and communication skills. Thus, it could be argued that the development of SPS by teachers should be linked to EE and engaged in and developed subsequent to conceptual understanding. In this case, that could be a holistic understanding of mangroves ecosystems in a broader sense using suitable teaching and learning strategy.

Conceptual Frameworks

The present research entailed a conglomerate of concepts - *SciIs*, *SDGs* and *SPS* - which were linked to enable the researchers to come up with a better explanation of their (concepts) relationship within the context of a phenomenon studied - mangroves ecosystem. The concepts formed the basis for frameworks that were deemed to be suitable for this research. That said, the researchers acknowledge that literature has different ways of listing and framing SPS (e.g., DBE, 2011b; Gultepe, 2016; Molefe & Aubin, 2021a, 2021b; Saban et al., 2019) and SciIs (Frost, 2010; J. Lederman et al., 2019; Moeed, 2013; Pepper, 2013; So, 2003; Watson et al., 1999).

Scientific Investigations, Sustainable Development Goals and Science Process Skills

As we migrate into the 4th Industrial Revolution (4IR), there is a need for rethinking of the curriculum in higher education in terms of creating students who can collaborate in diverse teams, have creative minds, and navigate through rapidly changing information and global challenges (Penprase, 2018). Thus, teachers' proficiency in *SPS*, understanding of aspects of *scientific inquiry* and confidence in planning and conducting *SciIs* cannot be overemphasised. Amid the rhetoric debates on the pedagogical impact of 4IR in higher education, the reality (see J. Lederman et al., 2019) is that teachers might not hold informed views of the scientific inquiry and SciIs. For instance, teachers

https://doi.org/10.33225/jbse/23.22.682

might understand science investigation or the scientific method as a stepwise and sequential process (Moeed, 2013; Molefe & Aubin, 2021a, 2021b). Molefe and Aubin (2021a) went further to argue that teachers might also encounter problems in understanding SciIs in terms of *SPS* embedded in the scientific process steps of questioning, design of experiments and making conclusions and inferences. On the other hand, UNESCO (2021) puts sustainable development at the heart of humanity's change of course as it reimagines its future in this planet. UNESCO (2020) also provides ESD for 2030 roadmap, which succinctly maps out the contribution of (science) education to the realisation and enactment of the *SDGs*. The researchers propose that the aforementioned issues related to the key concepts of this research need to be interrogated if the intention in science education, as we venture into the 21st Century, is to mould an all-round teacher that also advocates for ESD.

Conceptually, SciIs undergirded the present research. As referred to earlier, our latest work showed that the concept of SciI has not been fully understood by science teachers. Thus, the researchers drew from Pepper's (2013) and Roberts's (2004) works for a framework on teachers' confidence in *planning* and *conducting science investigations*. It should be noted that the two skills thereof are part of the SPS stipulated in the South African science curriculum (Table 1; DBE, 2011b). Furthermore, the researchers drew from Baez et al. (1987), Frost (2010), and Watson et al. (1999) for a framework concerning the *types of SciIs* (e.g., *Classifying and identifying*, *Exploring, Fair testing and comparing*, *Making things or developing systems* and *Pattern seeking*) the teachers thought they had conducted during their mangroves study.

Table 1
14 Scientific Skills Stipulated in the South African Science Curriculum

Science process skills
Accessing & recalling information
Observing
Comparing
Measuring
Sorting & classifying
Identifying problems & issues
Raising questions
Predicting
Hypothesizing
Planning investigations
Doing investigations
Recording information
Interpreting information
Communicating

As we rethink our roles in the collapse of ecosystems and climate change, a broader perspective of SciIs was essential in terms of SDGs. Thus, the study was further framed using ideas by UNESCO (2020) for SDGs. SDGs have become a *holy grail for sustainable development (SD)* and heralded great hope for humanity against global environmental issues. They were investigated within the context of SciIs related to mangroves ecosystem. Indeed, Paristiowati et al. (2022) eloquently show the synergy between the SD theme, sustainability perspectives, fieldwork, scientific skills (e.g., SPS), 21st Century skills, and environmental awareness within a course programme. The researchers went further to draw from DBE (2011b) and J. Lederman et al. (2019) for the teachers' understanding of the *aspects of the scientific inquiry* through the lens of embedded SPS.

Research Focus

The present research was based on pre-service teachers' fieldwork-based experiences, SciIs and SDGs, and SPS and different aspects of scientific inquiry within the context of a mangroves-based ecosystem. The researcher

https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

has chosen to focus on mangroves because anthropogenic impacts and natural changes are of great concern with regard to them in South Africa and globally (Hoppe-Speer et al., 2015) in the 21st Century. The concern has since pointed to the need to adhere to the longstanding call for the integration of ESD in teacher education (UNESCO, 2017). UNESCO (2017) puts emphasis on ESD's content and its teaching and learning methods. In science education, the methods may entail the utilisation of SciIs and SPS while studying ecosystems. Indeed, the study of mangroves ecosystem enabled the present teachers to utilise several SPS to study its flora and fauna. The teachers' views were also explored because, for decades, they (teachers in general) have been part of the empirical work on biology fieldwork (Lock, 2010; Tilling, 2018). In this case, they studied different ecosystems that included mangroves during their annual three-day fieldwork. This component (fieldwork) is part of an ecological studies course offered at an institution in KwaZulu-Natal.

It should be noted that global problems and threats negatively impact climate and the environment (Ivanov, 2018). Thus, it is reasonable that today there is a proposal for the inclusion of not only scientific literacy but interest in science and inquiry-based teaching in programmes intended to increase learners' environmental awareness (List et al., 2020). Such programmes may include SciIs on the life essential for the sustenance of mangroves ecosystems (Rog et al., 2017). They may also review factors that had shaped mangroves' decline, particularly in South Africa (Osorio et al., 2016). After all, mangroves ecosystems'"blue *carbon storage* and *sequestration capability* are important regulatory services since 2011 because of *global climate change* mitigation" (Sharma, 2018, para. 2; emphases added).

Research Aim and Research Questions

The aim of this research was to draw from pre-service teachers' fieldwork-based experiences to establish their views in relation to SciIs and SDGs, and the synergy between SPS and different aspects of scientific inquiry within the context of mangroves-based ecosystem.

The research sought to answer the following research questions in relation to an ecological studies course:

1) What did pre-service teachers perceive as their level of confidence in planning and conducting a scientific investigation for learners learning?
2) What type of scientific investigation was conducted by the pre-service teachers during their mangroves ecosystem study?
3) What sustainable development goals and science process skills did the pre-service teachers identify as embedded in the scientific investigation they contacted?

Research Methodology

General Background

This research adopted an approach that was quantitative in nature. This approach can accommodate quantitative questionnaires that can be used to conduct surveys with teachers (Mertens, 2014). For Cohen et al. (2018, p. 471), "the questionnaire is a widely used and useful instrument for collecting survey information, providing structured, often numerical data…". It is therefore reasonable that survey research can provide numeric descriptions of patterns or opinions from a sample of a particular population under study (Creswell, 2014). The present survey was adopted as a research strategy and utilised the questionnaire as an instrument to gather data on the pre-service teachers' views about SciIs and SDGs, and SPS embedded in aspects of scientific inquiry within the context of mangroves ecosystem studied. Although surveys usually yield information that is essentially statistical in nature (Neuman, 2014), the present questionnaire had open-ended questions. The questions allowed the teachers to provide reasons for their views. A questionnaire was utilised in this research due to its appropriateness in research based on SPS (Fugarasti et al., 2019) and teachers' views about SciIs (Pepper, 2013). Furthermore, it could also be used to study the understanding of scientific inquiry among learners (J. Lederman et al., 2019; Penn et al., 2021) and students (J. Lederman et al., 2021; Penn & Ramnarain, 2022), and for incorporating ESD's theme in pre-service teacher science programme (Paristiowati et al., 2022).

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Participants

In this research, data were collected from 82 conveniently selected pre-service teachers who enrolled for an ecological studies course at an institution in KwaZulu-Natal, South Africa. Careful selection of respondents rather than sample size is key amid several factors that influence sample size decisions (Memon et al., 2020). The sample size enabled us to compute the statistical tests we wished to make. However, the sample selection might have weakened external validity because the present teachers completed the questionnaire as part of their fieldwork exercise. The research was primarily on the participants' *views* about SciIs, not their (participants') characteristics - a reason demographic information was omitted from the research's questions and design. It should be noted that iterative practice and scaffolding approach, particularly in relation to *SPS* (Coil et al., 2010), *SciIs* and *SDGs* are key. The present teachers had studied all the aspects thereof in two content and method courses offered at the institution. Thus, the teachers were suitable participants, and they were assured of absolute anonymity.

Instrument and Procedures

The present research utilised a four-part questionnaire, which was tailored to meet the content of interest in the survey - SciIs, aspects of scientific inquiry, SPS and SDGs. It was important that the questionnaire provided complementary and/or supplementary information to the numerical data collected. Thus, the questionnaire was designed to allow the teachers to provide reasons for their responses in two of its four parts. Apart from SDGs, it also had detailed descriptions of SPS stipulated in the South African science curriculum (DBE, 2011b; also see Table 1) and various types of SciIs (Frost, 2010; Watson et al., 1999). *Part one*, a 5-point Likert scale for agreement or otherwise that was adopted from Pepper (2013), and *Part two* provided quantitative data concerning SciIs. *Parts three* and *four* provided both quantitative and qualitative data on the nexus between SciIs and SDGs, and aspects of scientific inquiry and SPS, respectively. The purpose of the questionnaire was to capture the teachers' perceived confidence and ability to plan SciIs for their learners, and the SciI they thought they used when studying mangroves ecosystem. Furthermore, it was utilised to elicit the primary SDGs that the teachers thought were associated with the mangroves-based investigations and *two* fundamental SPS that meld with *each* aspect of scientific inquiry. The students were requested to provide reasons for their responses concerning SDGs embedded in their investigation on mangroves and rationalise why the selected SPS fit into a given scientific inquiry's aspect.

Mertens (2015) pointed to the importance of clarity and pilot testing the questionnaire in surveys. Assessment by a panel of experts can also be used when establishing an instrument's face and content validity (Creswell, 2008). In this research, the questionnaire was piloted with eight pre-service teachers that enrolled for the same course during the preceding year. The subsequent findings were further interrogated at a conference (see Molefe, 2022). The post-conference questionnaire was further piloted with four students who demonstrated for the course. It should also be noted that three academics that teach Biology, Physics and Chemistry courses were invited to assess the researchers' views concerning expected SPS and the rationale behind their selection for *Part four* of the questionnaire. The refined questionnaire was administered to the teachers after multi-ecosystem fieldwork. Ethical clearance for the research was used.

Data Analysis

All data were analysed using R. First, R was used because the data obtained required an extensible statistical package that could enable the researchers to compute descriptive and analytical functions, which they needed to answer the questions of the research. Second, it was used because of its wide range of use in statistical techniques. Chi-squared tests can be conducted to "see if frequencies observed are statistically different or by chance alone" (Cohen et al., 2018, p. 789). In this research, it was important that the researchers verified that the answers were not given randomly for various questions. Thus, the preliminary results for SciIs, SPS and SDGs were based on Chi-squared tests on the frequencies. Furthermore, binomial tests on the maximum frequencies observed for the aspects of scientific inquiry were also computed. The tests were corrected using a Bonferroni correction.

https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 2
Chi-squared Test for Uniformity for SciIs and SDGs

Variables	χ^2	*df*	*p*-value
CP1: Using a constructivist model to plan science (e.g., Natural or Life Sciences) units of work	50.387	4	.00001
CP2: Planning to engage learner interest in investigating in science	50.234	4	.00001
CP3: Developing an investigation in science	35.581	4	.00001
CP4: Identifying independent, dependent and control variables in a science investigation	46.202	4	.00001
CP5: Recognising a fair test in a science investigation	41.299	4	.00001
CP6: Developing a fair test in a science investigation	36.078	4	.00001
CD1: Teaching science investigation concepts	74.707	4	.00001
CD2: Facilitating learner discussion and interpretations of science observations	85.439	4	.00001
CD3: Providing opportunities to extend learners' understanding of science observations	66.537	4	.00001
CD4: Assessing learner learning in science investigations	69.829	4	.00001
CD5: Identifying learner strengths and weaknesses in science investigations	74.829	4	.00001
CD6: Scaffolding learner learning in science investigations	72.756	4	.00001
TSI: Types of Scientific Investigation	59.603	4	.00001
SDGs: Sustainable Development Goals	72.519	16	.00001

Research Results

It was important that a test was made to check whether the answers concerning the teachers' levels of confidence in planning (CP) and conducting (CD) SciIs, the type of SciI (TSI) done concerning mangroves and the associated SDGs were given randomly. Table 2 shows the results of the Chi-squared test. The respective *p*-values ($p < .00001$) showed that the answers for those variables were not given randomly.

Pre-service Teachers Perceived Levels of Confidence in Planning and Conducting a Scientific Investigation for Learners Learning

In addition to the uniformity test, the researchers further explored the dataset. Table 3 shows that, in general, the present teachers' perceived levels of confidence in planning and conducting a SciI for their learners were at least moderate. That said, it was interesting that most of the 82 teachers rated themselves as confident concerning planning a SciI in terms of *Using a constructivist model to plan science (e.g., Natural or Life Sciences) units of work* (84%), *Planning to engage learner interest in investigating in science* (89%) and *Identifying independent, dependent and control variables in a science investigation* (85%). Even more interesting was the teachers' perception of the level of their confidence in conducting a SciI. They rated themselves as confident and the associated variables (i.e., CD1-CD6) were virtually uniform (around 83%).

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Table 3
Frequency Table for CP and CD

Variables	Frequency				
	No confidence	Limited confidence	Moderate confidence	Confident	Very confident
CP1	0	0	13	50	19
CP2	0	0	9	36	37
CP3	0	3	16	36	27
CP4	0	1	11	25	45
CP5	1	1	11	37	32
CP6	0	3	19	40	20
CD1	1	1	10	38	32
CD2	0	1	13	36	32
CD3	0	1	15	37	29
CD4	0	1	13	36	32
CD5	0	1	11	35	35
CD6	0	1	12	37	32

Type of a Scientific Investigation Conducted by the Pre-service Teachers during Their Mangroves Ecosystem Study

The study of several ecosystems, which included mangroves, built on practical and theoretical aspects concerning problem-based learning, scientific inquiry and ScIs was done at the institution. The present teachers also studied issues around biodiversity, global climate change, various ecosystems, and SDGs. Thus, one would have expected their reflections on ScIs to be effortless. Table 4 shows that most of the teachers (57%) gave *Classifying and identifying* most often than any other ScI. *Exploring* was the second most (38%) often given type of ScI.

Table 4
Frequency Table for ScI Associated with Mangroves Ecosystem Studied by the Teachers

Types of scientific investigations	Frequency
Classifying and identifying	47
Pattern seeking	0
Exploring	31
Fair testing and comparing	4
Making things or developing systems	0

Sustainable Development Goals and Science Process Skills Pre-service Teachers Identified as Embedded in the Scientific Investigation they Contacted

In this study, the SDGs of interest were those related to *Climate action*, *Life below water* and *Life on land* (i.e., SDGs13, 14 and 15; the latter was given as an example in the questionnaire) due to their indubitable connection with the mangroves ecosystem studied. The intention was to establish the teachers' views concerning SDGs (and ESD) in tandem with a particular ecosystem-based ScI. The results showed that SDG13 (27%) and SDG14 (40%) were given most often (Table 5). Two main themes - *Mangroves (ecosystem) and other life forms* and the *Impact of*

https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

climate (change) on the ecosystem and vice versa - were elicited from the most given reasons for the teachers' choices of the two leading SDGs. Below are some of the written descriptions associated with the themes:

Table 5
Table for SDGs Associated with a Mangroves Ecosystem Studied by the Teachers

Variable	Number of responses for each SDG
SDG1: No poverty	1
SDG2: Zero hunger	0
SDG3: Good health and well-being	3
SDG4: Quality education	3
SDG5: Gender equality	0
SDG6: Clean water and sanitation	7
SDG7: Affordable and clean energy	3
SDG8: Decent work and economic growth	5
SDG9: Industry, innovation and infrastructure	0
SDG10: Reduced inequalities	0
SDG11: Sustainable cities and communities	4
SDG12: Responsible consumption and production	0
SDG13: Climate action	22
SDG14: Life below water	33
SDG15: Life on land	0
SDG16: Peace, justice and strong institutions	0
SDG17: Partnerships for the goals	1

SDG14: *Mangroves are adapted to live in coastal regions,* [sic] *they are able to adapt in wet and salty ecosystems hence, they are able to maintain life below water* (Teacher 1).

SDG14: *…we find mudskippers on mangrove[s] swamps living in and out of the water* (Teacher 2).

SDG14: *…organisms like crustaceans are attached to the mangrove forests because of the variety of food, cooler water and safety that is found among the roots* (Teacher 3).

SDG14: *Mangroves require a certain climate for them to survive* (Teacher 4).

SDG13: *…if they* [sic] *is climate change due to global warming or any other cause they will not be present hence why I choose climate action as to help reduce the causes of climate change due to human activities in order to prolong and preserve ,[m]angrove ecosystems* [sic] (Teacher 5).

SDG13: *In terms of climate management, mangrove forests play a critical role since they serve as carbon-rich buffer zones between land and ocean as in this waterlogged environment leaves and other detritus do not decompose easily by doing so, the carbon in this organic matter is prevented from escaping* (Teacher 6).

It was important that further tests were made to check whether the answers concerning the teachers' views on SPS embedded in the different aspects of inquiry were given randomly. Table 6 shows the results of binomial tests. The respective *p*-values ($p < .05$) showed that the answers for those aspects were not given randomly. The researchers further explored the dataset, now for the frequencies of teachers' answers and the reasoning behind them.

Appendix A shows that, in general, the teachers were not able to correctly select the SPS that are embedded in various aspects of scientific inquiry. It was only in the case of *Observing* (55%) and Scientific investigations all begin with a question but do not necessarily test a hypothesis (SIQ), *Interpreting information* (48%) and Research

https://doi.org/10.33225/jbse/23.22.682

conclusions must be consistent with the data collected (RCD), and *Accessing & recalling information* (49%) and Explanations are developed from a combination of collected data and what is already known (EDK) that about half of the teachers seemed to have been able to select the expected SPS.

Table 6
p-values of Binomial Tests on the Maximum Frequencies Observed for the Aspects of Scientific Inquiry

Aspects of scientific inquiry	Maximum frequency observed	p-value
SIQ: Scientific investigations all begin with a question but do not necessarily test a hypothesis	12	.001
SIP: Inquiry procedures are guided by the question asked	5	.024
SIR: All scientists performing the same procedures may not get the same results	7	.001
IPR: Inquiry procedures can influence the results	5	.024
RCD: Research conclusions must be consistent with the data collected	14	.001
SDE: Scientific data are not the same as scientific evidence	14	.001
EDK: Explanations are developed from a combination of collected data and what is already known	6	.003

Discussion

When teaching in and across disciplines, it is important that students are engaged in purposeful SciIs in authentic contexts to nurture collaborative and experiential learning in which scientific inquiry forms the basis for their views and understanding of the world (Crawford et al., 2005). That said, MacDonald and Dominiquez (2010) had long pointed to the importance of EE and its methods in teacher preparation programmes. While EE field trips are hailed as a centrepiece and key for science methods and the development of a conglomerate of skills, they address the fundamental goals of EE (Rebar & Enochs, 2010). Most importantly, ESD, which broadens the concept of EE, has assumed a mantle for transformative education that underpins ideals and principles that advocate the sustainability mindset (e.g., environmental protection, ecological sustainability, climate change, etc.) (SADC, n.d.). That explains why reorienting our focus on EE and SD has been and/or is the basis for debates on the environment at national (Mabhaudhi et al., 2019; Mpandeli et al., 2018; SADC, n.d.) and international levels (Boca & Saraçli, 2019; UNESCO, 2020, 2021). The researchers acknowledge that the concept of EE and teacher education (Bodzin et al., 2010; Reddy, 2011), SDGs (UNESCO, 2020), the environment and the associated development of skills and knowledge (Colley, 2006; VanLeuvan & McDowell, 2000), the development of SPS in teacher education (Molefe et al., 2016) and inquiry (Artayasa et al., 2017), the SciIs (Baez et al., 1987; Frost, 2010; Watson et al., 1999) and teachers' views of them (Moeed, 2010), and phases (Pedaste et al., 2015) and/or aspects of scientific inquiry (see J. Lederman et al., 2021; Penn & Ramnarain, 2022) are hardly new. However, teachers' views of the mangroves ecosystem in which SciIs and a nexus of them (SciIs) and SDGs, and SPS and aspects of scientific inquiry are investigated, remains uncharted terrain. This research sets a precedent of the aspects thereof for another research to learn from.

The importance of investigative work in school science, which can be traced to the Nuffield projects of the 20th century, has long been part of the policies of some global north countries (Toplis & Cleaves, 2006). It became part of the core practical work tasks that include fieldwork (Science Community Representing Education [SCORE], 2008). The South African school science curriculum's emphasis on practical tasks and investigations has since echoed such countries' reform trends in science education. In Life Sciences, learners are expected to be "able to *plan* and *carry out investigations* as well as *solve problems* that require some practical ability" (DBE, 2011a, p. 15; emphases added). The present study's results showed teachers' confidence in the two skills thereof. Considerable confidence was evident with regard to the items related to the *constructivist model* (CP1), *planning to engage learner interest in investigating science* (CP2) and *variables* (CP4). Similar findings concerning the teachers' proclaimed confidence in the constructivist model were also found in Pepper (2013). Furthermore, teachers may recognise potential teaching and learning models to engage their future learners in SciI. Hence, the present teachers' responses may also be understood in terms of emphasis on the constructivist approach to teaching and learning in our science method

https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

courses. The influence of the South African Natural Sciences curriculum, whose scientific process is tailored on fair testing and comparing (Molefe & Aubin, 2021b; also see CP5 and CP6), resonates with variables (CP4).

While the present teachers' confidence concerning SciIs is commendable, previous research by Toplis and Cleaves (2006) had shown that learners could be alienated from SciIs even in developed countries. In the developing countries such as South Africa, emphasis on SciIs is theoretical rather than practical, and that might be a norm due to several contextual factors that include avoidance of hands-on minds-on practical activities (J. Lederman et al., 2019). Furthermore, the proclaimed use of the constructivist model (Table 2) might contradict the challenges teachers often have concerning the conceptualisation and facilitation of SciIs (Cf. Kibirige et al., 2022). Thus, it was important that the present teachers were put under a microscope concerning SciIs within the context of the mangroves' ecosystem.

Most teachers viewed *Classifying and identifying* as the SciI they executed during the mangroves study (Table 4). That is reasonable because they *observed* various species that adapted to the ecosystem. Most importantly, they *identified* and *classified* those species using their characteristic features suitable for the ecosystem. It was interesting that *Exploring* was the second most selected SciI considering that it involves making careful observations over time (Watson et al., 1999, 2006). The wrong selection justifies Molefe and Aubin's (2021b) argument that teachers might understand *Exploring* in terms of investigating species rather than making observations of them. J. Lederman et al. (2019) pointed to the challenge of understanding scientific inquiry itself for teachers. This is probably due to the cognitive load associated with conducting SciIs hence a need for scaffolding practice and iterative practice (Jerrim et al., 2019).

Today "negative trends in biodiversity and ecosystems [e.g., mangroves] are predicted to undermine 80% of the Sustainable Development Goals targets related to…climate, oceans and land" (Ometto et al., 2022, p. 2375). Thus, the present teachers were further challenged to now connect SDGs to their SciI. As referred to earlier, less than 50% of the teachers could show the connections between the studied mangroves and SDGs 13 and 14. They drew from the reciprocal connection between *climate (change)* and *the ecosystem*, and *Mangroves (ecosystem)* and *other life forms* to support their views. The connections are reasonable because the significant role of mangroves in the environment and the impact of climate change on them are well documented (Ahmed et al., 2022; Alongi, 2012; Friess et al., 2022). That said, the low percentages thereof, and the spread responses (Table 5) suggest a need to interpret the results here with caution. Notwithstanding, the spread responses might actually highlight the argument that mangroves are connected to *all* the SDGs (see Dandabathula et al., 2021), and interestingly Covid-19 (McHarg et al., 2022).

The connection between *SciIs*, *scientific inquiry* and *SPS* cannot be overemphasised in teacher education (Cf. Dudu & Vhurumuku, 2012). Due to the challenging nature of the highlighted concepts thereof, it was important that the teachers supported their views (see Appendix A - Sample of reasons given) concerning SPS embedded in the aspects of inquiry. Appendix A shows that, in general, the teachers were not able to select more than one expected SPS for the aspects - Research conclusions must be consistent with the data collected (RCD) and Scientific data are not the same as scientific evidence (SDE). Similar to SDGs results, the teachers' responses were spread. This explains the low percentages of the dominating unexpected SPS (i.e., 42% and 38%) selected for the two aspects thereof and the rest. 42% of the teachers paired *Recording information* with RCD. The combination points to the influence of the South African science curriculum concerning SPS and the scientific process: "*Recording information* [is] recording *data* from an investigation…", and inferences about *recorded observations* form the basis for *conclusions* (DBE, 2011b, p. 11-12; emphases added). For SDE, Gyllenpalm et al. (2021) discussed the ambiguity of the terms - data and evidence. A solution recommended was basically tying the two terms to conclusions, that is, asking learners to "*interpret their data to generate evidence to support a conclusion*" (p. 14; emphases supplied). The combination of *Comparing* with this aspect (SDE) by 38% of the teachers could be understood in terms, for instance, of this SPS being fundamental in differentiating between "collected information" (data) and "what is already known" (see Appendix A).

Where the teachers were able to select two expected SPS, a fair percentage (i.e., 55% and 49%) of responses were found in these aspects: Scientific investigations all begin with a question but do not necessarily test a hypothesis (SIQ) and Explanations are developed from a combination of collected data and what is already known (EDK). Tomkins and Tunnicliffe's (2001) research eloquently shows that observations form the basis for raising questions about phenomena, and formulating explicit hypotheses when teaching and investigations commence. Thus, it is reasonable that 55% of the teachers thought *Observing* melds with SIQ. For them, the phenomenon observed was life in the mangroves ecosystem and the subsequent questions raised concerned its adaptation for survival (Appendix A). On the other hand, 49% of the teachers paired *Accessing & recalling information* with EDK. Their prior knowledge (see Appendix A) could have been the springboard for their ability to interpret what was observed (Cf.

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Wiyanto et al., 2022), that is, they accessed and recalled information to explain what the results of the investigation meant prior making conclusions (Cf. DBE, 2011b).

Very low, yet correct percentage responses were also observed. For instance, 34% of the teachers thought *Measuring* blends with All scientists performing the same procedures may not get the same results (SIR). They selected this SPS most often that the rest. This is reasonable because "virtually all scientific observations involve counts, measurements, or both" and replicability of scientific results is rooted in measurement precision, methods and steps taken (National Academies of Sciences, Engineering, and Medicine [NASEM], 2019, p. 46). The selection of the SPS could also be understood through the lens of the South African science curriculum, which defines this SPS as "using measuring instruments…" (DBE, 2011b, p. 11). It was interesting that *Communicating* - an SPS that fits in all the aspects of scientific inquiry - was ignored by the teachers. It was only in relation to RCD (i.e., Research conclusions must be consistent with the data collected) where it was selected more often (26%) than in other aspects. The recognition of *Communicating* in RCD is reasonable because it entails making information known to others through textual and pictorial forms, and research conclusions require that learners *communicate* their findings consistent with recorded observations (DBE, 2011b).

Conclusions and Implications

The research aimed to draw from pre-service teachers' fieldwork-based experiences to establish their views concerning SciIs, scientific inquiry, SDGs and SPS. The research indicates that the teachers had confidence in planning and carrying out SciIs. It highlighted the importance of using the constructivist model to plan science, engaging learner interest in investigating in science and discerning and controlling variables in a science investigation.

Classifying and identifying and exploring were the common types of scientific investigations selected concerning the mangroves ecosystem studied. The selection of exploring shows that the teachers had challenges in identifying the scientific investigation they utilised. However, they succeeded in showing the connections between the studied mangroves and SDGs13 and 14. The results further highlighted the importance of observing, accessing & recalling information, measuring and communicating when executing some aspects of scientific inquiry.

It was concluded that, in teacher education, constructivism, learner engagement and understanding of the nitty-gritties of SciIs such as manipulation of variables are all important factors in a quest to introducing them (SciIs) in an ecology-based course. The study further highlights the need to leverage on natural ecosystems to strategically position and promote understanding of SDGs and SPS in terms of their connectedness to SciIs and scientific inquiry.

The present research provides small but significant ideas on how to disrupt the higher education science curriculum with regard to teacher education by tapping into pre-service teachers' views concerning SciIs' role in advocating ecosystem services restorations and environmental sustainability amid present challenges related to our natural ecosystems. It emphasises a need for further research on the connection between SPS and the different aspects of scientific inquiry. Such SPS may include *Communicating*, which is fundamental to the reporting of the nitty-gritty details of a scientific investigation before, during and after its execution. As referred to elsewhere, the study has a primary limitation that could also be addressed in future research: Our choice of a sample might have weakened external validity because the present teachers' questionnaire was part of their fieldwork exercise.

The research implies that science teacher educators that offer courses that entail fieldwork component framed around SPS and realisation and enactment of SDGs should design scientific activities and scientific investigations tailored to the constructivist model and the tenets of scientific inquiry. The challenges associated with identifying the *scientific investigation* utilised and reconciling *SPS*, such as *Communicating*, with different *aspects of the scientific inquiry* point to the need to tap into teachers' conceptual understanding of these concepts (highlighted).

Declaration of Interest

The authors declare no competing interest.

Acknowledgement

Special thanks to the academics at the institution for their valuable contributions concerning the expected SPS and the rationale behind their selection for the different aspects of scientific inquiry (Appendix A).

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

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https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Appendix A

Aspects of scientific inquiry & SPS

Scientific inquiry aspect	Expected SPS	Most selected SPS (Teachers' number)	Sample of reasons given
SIQ	Communicating, observing, and raising questions	Observing (45), Raising questions (31)	…we observed different types of plants and animals surviving in that [mangrove] ecosystem and that raised questions on how they survived…
SIP	Communicating, doing investigations, and raising questions	Raising questions (23) Doing investigations (27)	we raise [sic] the question on why the mangrove area is different, then we do [sic] an investigation by going around the mangrove and see the significant things about the mangroves.
SIR	Communicating, doing investigations, interpreting information, and measuring	Measuring (28) Doing investigations (27)	[That is] due to incorrect use of measurement tools and procedure of doing investigation...[They] may use different measuring technique...can also use diffrent methods, apparatus and procedure to do investigations.
IPR	Communicating, doing investigations, and interpreting information	Interpreting information (26) Doing investigations (19)	Since inquiry procedures can influence the results, I developed the scientific skill of interpreting information...Another skill I developed is the skill of being able to do scientific investigations as this is the skill that determines how the results will be attained.
RCD	Communicating and interpreting information	Interpreting information (39) Recording information (34)	The person doing the investigation needs to record all the findings during the investigation so that they can be used to draw a conclusion. The person also has to explain what the data means so that they draw a meaningful and appropriate conclusion from the data collected.
SDE	Communicating and sorting & classifying	Comparing (31) Interpreting information (21)	Scientific data is not the same as scientific evidence [and] people need to... compare how these two [are] related to each other and...differ. Interpreting... information is needed...to differentiate data [between] (collected information) and evidence (what is already known).
EDK	Communicating, Accessing & recalling information and interpreting information	Accessing and recalling information (40) Interpreting information (26)	Being able to access and recall information will allow the person to be able to use previous knowledge to understand new information collected. By being able to interpret this information they will be able to identify any links, similarities and differences, between what they knew and what they found in order to reach a conclusion.

https://doi.org/10.33225/jbse/23.22.682

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Received: *February 20, 2023* Revised: *April 26, 2023* Accepted: *June 07, 2023*

Cite as: Molefe, L., & Aubin, J.-B. (2023). A nexus of scientific investigations, science process skills, and sustainable development goals: Pre-service teachers' views concerning mangroves fieldwork. *Journal of Baltic Science Education*, *22*(4), 682-700. https://doi.org/10.33225/jbse/23.22.682

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