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Exploring how science process skills blend with the scientific process: Pre-service teachers' views following fieldwork experience

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In science education, only teachers that are competent in skills, methods and procedures relevant to a science discipline can help learners to develop scientific skills and processes associated with investigating natural phenomena. The purpose of this study was to explore views of pre-service science teachers with regard to science process skills that they had developed through various freshwater activities and the stepwise scientific process. Data were collected through a 4-part questionnaire that included various science process skills and the scientific process. Ninety-four 2nd- and 3rd-year pre-service teachers that registered for a Bachelor of Education degree participated in this study. The results from statistical analyses of the teachers' responses to skills they had developed showed prominence of observing, yet the teachers failed to link observing and communication to formulating a research question. Similar challenges were also evident in designing experiments. While the teachers were able to link science process skills to hypothesising, they experienced relative challenges in linking relevant skills to observation and drawing conclusions and making inferences. The findings suggest potential challenges to teachers on fair testing investigations in terms of questioning, designing of experiments, drawing of associated conclusions and making inferences.

Keywords: fieldwork; freshwater study; life sciences; pre-service teachers; science process skills; scientific investigations; stepwise scientific process

Introduction and Background

In this study we sought to explore how pre-service teachers studying a life sciences module at an institution in the KwaZulu-Natal province, South Africa, viewed science process skills (SPS) and the associated scientific process/method within the context of environmental education (EE). The study drew from the teachers' experiences based on a 3-day fieldwork experience, which comprised studies of different ecosystems that included freshwater. The freshwater ecosystem was chosen for this study because it could enable the teachers to engage in a scientific inquiry and develop a considerable number of SPS. Other ecosystems were more focused on development of the teachers' knowledge and understanding of EE concepts and critical thinking skills. In order to improve the teachers' learning and retention of knowledge of the ecosystems, it is important that laboratory work and lectures are supplemented with experiences that are based on field-based research and model the scientific process (Dresner, De Rivera, Fuccillo & Chang, 2011). In this study, such experiences were particularly important for understanding components of the ecosystems, scientific inquiry, and the development of SPS.

In South Africa, learners are expected to critically show responsibility towards the environment and develop scientific skills and processes associated with investigating natural phenomena (Department of Basic Education [DBE], Republic of South Africa [RSA], 2011). A particular science teacher education programme suggests the kind of teacher who might mould that kind of learner (Molefe, Stears & Hobden, 2016). Such a teacher should have competence, for instance in the knowledge, skills, values, principles, methods and procedures relevant to the discipline. If creativity and critical thinking are added to the development of knowledge, then those competences may specifically point to understanding of scientific inquiry itself (Lederman, Lederman, Bartels, Jimenez, Akubo, Aly, Bao, Blanquet, Blonder, Andrade, Bunting, Cakir, EL-Deghaidy, ElZorkani, Gaigher, Guo, Hakanen, Hamed Al-Lal, Han-Tosunoglu, Hattingh, Hume, Irez, Kay, Dogan, Kremer, Kuo, Lavonen, Lin, Liu, Liu, Liu, Lv, Mamlok-Naaman, McDonald, Neumann, Pan, Picholle, Rivero García, Rundgren, Santibáñez-Gómez, Saunders, Schwartz, Voitle, Von Gyllenpalm, Wei, Wishart, Wu, Xiao, Yalaki & Zhou, 2019). The teacher should also be able to navigate the controversial terrain of scientific inquiry and the scientific method, which is eloquently illustrated in Thomas (2012) and SB Watson and James (2004). That said, there have long been methods and processes to support change-oriented learning towards better environmental sustainability practices and/or environmental learning in a wide range of contexts in South Africa (see Rosenberg, O'Donoghue & Olvitt, 2008). Colley (2006) suggests that collaborative fieldwork, scientific investigations, acquiring scientific skills, and understanding ecology content could be achieved. Evidently, fieldwork is a signature pedagogy for the future outdoor EE teacher. Most importantly, it embraces scientific inquiry (Remmen & Frøyland, 2014), which is essential in enhancing students' achievement, and is driven by SPS (Mumba, Miles & Chabalengula, 2018).

The research reported on here is important. It was part of a project investigating pre-service teacher learning within science and technology education modules. Most importantly, it placed the quality of drivers of quality global education systems (i.e. teachers) under a microscope, particularly with respect to their stance on scientific skills and processes intertwined with global environmental issues. Such issues may be understood through

recognition of the importance of environmental literacy in terms of animal species, biodiversity, and environmental problems (Scott, GW, Goulder, Wheeler, Scott, Tobin & Marsham, 2012). Thus, the study set out to investigate the following research questions in relation to an EE module:

- What science process skills were embedded in the pre-service science teachers' fieldwork on a freshwater study?
- How do the teachers view the study of the freshwater ecosystem in terms of the scientific processes and the associated science process skills used?

Literature Review

Fieldwork remains a long standing pedagogy across a range of disciplines in higher education institutions, which include EE (Thomas & Munge, 2017). The popularity of fieldwork might be rooted in its ability to accommodate inquiry-based learning in which students may engage in scientific investigations (Remmen & Frøyland, 2014), understand ecology content knowledge, and develop SPS (Colley, 2006). Thus, educators' understanding of scientific inquiry, scientific investigations (Lederman et al., 2019), and the scientific method (Staddon, 2017; Thomas, 2012; Watson, SB & James, 2004) remains important. In a stream monitoring experiment, in particular, the associated tasks may challenge students' ability to use many processes and skills, and cooperative learning as they collect stream data and present their findings (VanLeuvan & McDowell, 2000).

From the literature reviewed, while SPS has remained the key part of research over the last 10 years (e.g. Coil, Wenderoth, Cunningham & Dirks, 2010; Gultepe, 2016; Molefe & Stears, 2014; Mumba et al., 2018; Yakar, 2014), they (SPS) had long been central to debates on processes and content (So, 2003; Wellington, 1989). More recently, debates around teaching and/or development of SPS, conceptual understanding, and context were reviewed (Molefe et al., 2016). SPS are skills that scientists use to learn and investigate natural phenomena (Winarti, Sarbain & Yamin, 2018). They are classified as basic and integrated SPS. Gultepe (2016:780) contends that as teaching science encompasses the content and processes and skills, "underestimating content over process or process over content is unacceptable", as both are equally important. As referred to earlier, SPS can be developed within the context of an ecosystem (or river environment [Winarti et al., 2018]). Students may have an opportunity to not only observe ecosystems but also apply techniques used to value them (Taylor & Bennett, 2016). Furthermore, despite criticism around SPS, which include the scientific tag attached to them, their development may improve teachers' understanding of environmental concepts today (Irwanto, Saputro, Rohaeti & Prodjosantoso, 2018). Thus, they should be linked to EE and engaged in and developed

subsequent to conceptual understanding, such as understanding of environment in a broader sense. Most importantly, they should be linked to the scientific process itself.

In the South African natural sciences curriculum for Grades 7 to 9, there are a set of SPS that learners should develop, together with a way of investigating phenomena (DBE, RSA, 2011). That way, which is actually a stepwise scientific process, may enable students to produce new knowledge and theories (Watson, SB & James, 2004). Furthermore, it may form the basis for fair testing-based types of investigation. However, it should be noted that there are "differences to the nature of the questions asked, and the theories, **methods** and equipment used" (Moeed, 2013:542; emphasis added) when investigating natural phenomena. Such differences can be discerned between fair testing and other types of investigation such as classifying and identifying, exploring, investigating models, making things or developing systems, and seeking patterns. Thus, teachers should understand that there is no single scientific method in all scientific investigation. EE is multidisciplinary in nature and thus may accommodate multiple science processes when students investigate the associated phenomena. Drawing from Staddon (2017), teachers should be in a position to understand how scientists investigate natural phenomena and develop a critical and informed view of the scientific process. They should understand the connection embedded in all scientific inquiry between questions and methods and/or the connection between scientific inquiry and SPS/the scientific process (Lin, Chiu, Hsu, Wang & Chen, 2018).

As referred to earlier, fieldwork has been endorsed as a core teaching strategy for many higher education institution programmes in EE. We acknowledge that fieldwork is part of entities that are not clearly defined and differentiated, such as *field activities*, educational field activities, *excursions* and study visits (Dourado & Leite, 2013). We further acknowledge Dourado and Leite's (2013:1233) conceptualisation of fieldwork as "... activities that students do outside classroom ... to learn and develop relevant competences." Remmen and Frøyland (2014) add that fieldwork could be executed as teacher-led excursions, a student-directed discovery or as an intermediate between the latter and the former.

It should be noted that environmental learning involves, among others, better understanding of one's world, development of awareness, skills and values essential for a better environment, and gaining information and new insights. Sondergeld, Milner and Rop (2014) add that EE should not only integrate multiple content areas, but also make education relevant, use social context, and promote lifelong, forward-looking education. For GW Scott et al. (2012:19), it does not only reconcile species,

biodiversity and environmental crises, it “highlights the value of an interaction between the affective, psychomotor (the physical experience of doing the fieldwork) and the cognitive domains during a task that included fieldwork.” Rosenberg et al. (2008) argue that students engage in fieldwork as an investigative method to specifically practice inquiry. Remmen and Frøyland (2014) show that, in relation to fieldwork, inquiry-based, integrated fieldwork designs could not be overemphasized as they might lead to a *deep approach* to learning. If such designs are good, they might increase development of skills, such as the practical and technical types, as well as generic areas such as critical thinking, communication, teamwork, and autonomous learning (Tilling, 2018), as students investigate natural phenomena. For students to successfully engage in investigative methods, they should understand scientific investigations. This is even more important considering that not many teachers understand a contemporary, open-ended view of a scientific investigation (Moeed, 2013). The lack of understanding of scientific investigations may also have a significant impact on their implementation. This additional challenge (its implementation) may be addressed through support of learners through the stages of scientific investigation, starting with understanding questioning. Based on Pepper’s (2013) arguments, one may also argue that teachers themselves should be challenged within the framework of scientific investigation first to increase their confidence, if the intention is to provide fruitful support.

Frameworks

In the present module, a pedagogical initiative – field trip – presented an opportunity for praxis in

which teachers could, as they actively participate in the learning process, engage in collaborative learning and collaborative construction of knowledge. We acknowledge that our pedagogical initiative could have been insufficient, considering Hodson’s (1996) arguments on the scientific process, discovery learning, process-led science, and contemporary constructivist approaches. For him, modelling, guided practice and application, as well as aspects related to scientific inquiry, such as conceptual understanding, are key. Thus, it was important that “the explicit instruction, transparent pedagogy, scaffolding approach, and iterative practice” were effected to enable the teachers to attain competence in SPS (Coil et al., 2010:534) and the associated scientific process prior to the field trip.

We also acknowledge that suitable frameworks were needed because there are various views about concepts used, namely SPS and the scientific process. Indeed, literature has different lists of SPS (e.g. DBE, RSA, 2011; Gultepe, 2016; Molefe et al., 2016; Saban, Aydoğdu & Elmas, 2019; Susanti, Anwar & Ermayanti, 2018; Uğras & Çil, 2016) and science processes (DBE, RSA, 2011; Hodson, 1996; Moeed, 2013; So, 2003; Watson, SB & James, 2004). In order to contextualise our study, we drew from SPS and the stepwise scientific process stipulated in the South African natural sciences curriculum to use as a framework. Furthermore, we drew from Molefe and Stears’s (2016) and SB Watson and James’s (2004) ideas to show how such SPS may fit into the scientific process steps themselves (Figure 1).

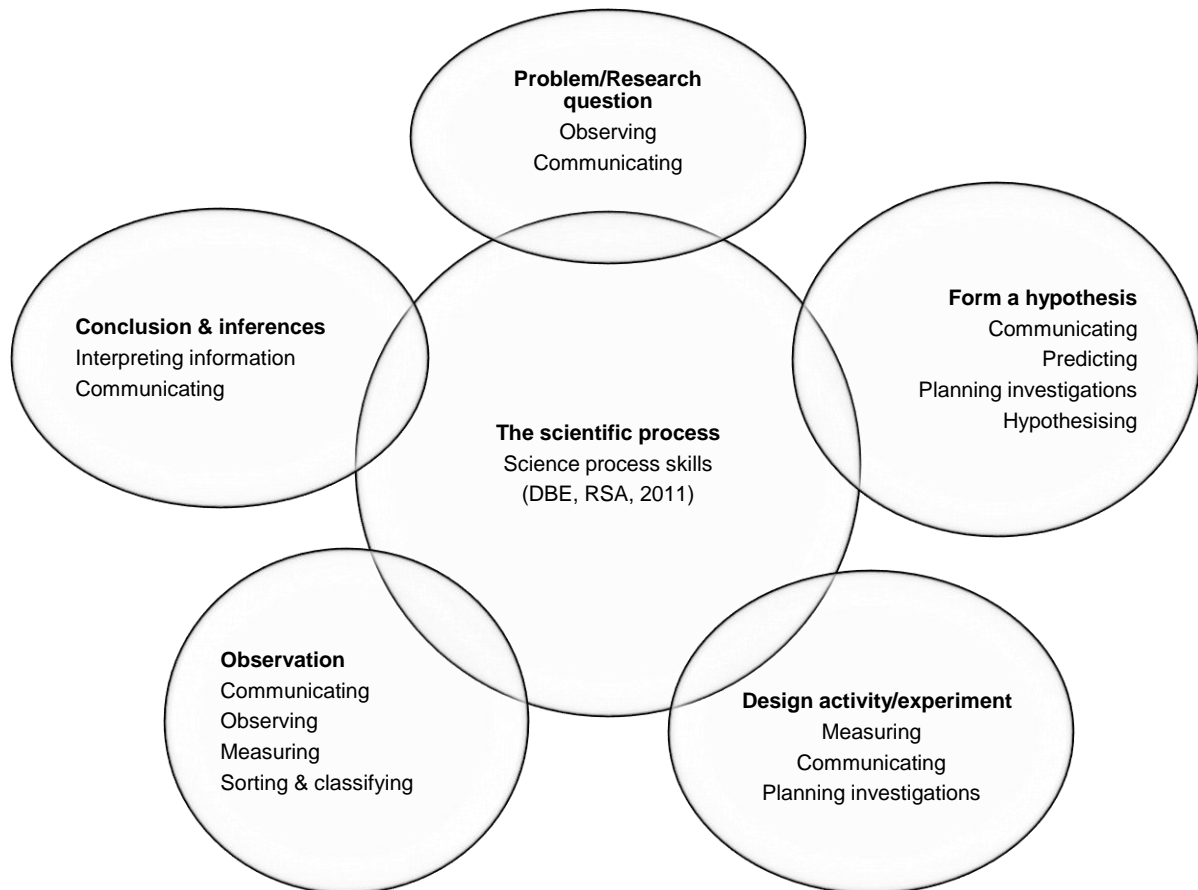


Figure 1 A model of how SPS blend with the stepwise scientific process (adapted from Watson, SB & James, 2004)

Methods

In this study, we used a simple survey design. Researchers normally use surveys to elicit people's views or beliefs about a phenomenon from a questionnaire (Neuman, 2014). Survey designs normally provide a numeric description, for instance, of trends or opinions of a sample of a particular population (Creswell, 2014). In this research, a simple descriptive survey provided a basis for the description of the pre-service teachers' views regarding the development of their SPS and the associated scientific process within the context of the freshwater study. A questionnaire was used because it could elicit teachers' views about scientific processes and skills (Coil et al., 2010; Molefe & Stears, 2016) and scientific investigations (Moeed, 2013). It could also be used to investigate learners' understanding of scientific inquiry (Lederman et al., 2019).

The questionnaire, with attached copies of the detailed description of SPS and the scientific process steps (DBE, RSA, 2011), had qualitative and quantitative components. The first and second questions of the questionnaire provided qualitative data on activities that the teachers found interesting with regard to the ecosystems they studied, and the descriptions of two EE characteristics they learnt,

respectively. The third, fourth, and fifth questions provided quantitative data on scientific investigations, SPS, and SPS and the scientific process. With regard to the last three questions, the teachers were expected to select (i.e., tick) the types of scientific investigations that they thought they had used during the freshwater study. The questionnaire included the five types of scientific investigations, namely fair testing and comparing, pattern seeking, classifying and identifying, exploring and making things/developing systems (Watson, R, Goldsworthy & Wood-Robinson, 1999). Secondly, they selected five SPS used to deduce the quality of the freshwater ecosystem studied. In order to verify that the SPS were not selected at random from the DBE, RSA (2011) list, the teachers were requested to provide (in writing) activities that enabled them to develop each of the SPS thereof. Thirdly, they selected two SPS that they viewed to fit into the DBE, RSA's (2011) scientific process steps when investigating the freshwater ecosystem using chemical test kits. The following example was provided to assist them with selection of SPS and a scientific process step that blend with them (SPS): *Communicating* and *Interpreting information* (SPS) were paired with **Research/background knowledge** (step in the

scientific process). The fourth and fifth questions formed the basis for the present study.

Pre-service teachers who have successfully completed the present EE module normally participate as demonstrators in the annual ecosystem fieldwork at the institution and in Mtunzini. Molefe and Stears's (2016) findings on SPS, the scientific process, and scientific inquiry were used to improve the questionnaire for our study. Nevertheless, further pilot tests conducted with 10 demonstrators and a tutor were used to further validate the questionnaire.

Sample

The resultant questionnaire was administered to the final purposive sample that consisted of 94 pre-service teachers who were registered for a second-year biological sciences education module at the institution. SPS can be developed through fieldwork in which students develop them (SPS) and environment-based knowledge (Ting & Siew, 2014). However, as referred to earlier, we acknowledge that a scaffolding approach and iterative practice of SPS were essential for SPS mastery before the teachers could provide views about them and how they blend with the scientific process steps. Thus, they had at least 18 months' exposure to SPS during the relevant method and content module classes, and the associated practical activities. The teachers agreed to participate in this study and were assured of absolute anonymity. The questionnaire was administered during a fieldwork period. Ethical clearance was approved for the investigation of pre-service teacher learning within science and technology education modules at the institution.

Data Analysis

Data cleansing, such as removal of inaccurate records from a record set and incomplete questionnaires, was conducted using OpenRefine. R was used as a tool for analysis of the data. Due to the complexity of the data collected, we needed a statistical package that could enable us to compute functions that could satisfy our specific needs. R enabled us to check, not only the frequencies of the pre-service teachers' selection of SPS, but also p -values for a given scientific process step to check whether the answers were given randomly. Furthermore, we used binomial tests with a Bonferroni correction to check whether the teachers' selections were given significantly more or less often than randomness.

Results

Research Question 1: What Science Process Skills were Embedded in the Pre-Service Science Teachers' Fieldwork on a Freshwater Study?

There are different factors that could be investigated with regard to SPS. In this study, we chose to focus on pre-service teachers' views regarding SPS and the stepwise scientific process, as a follow-up to Molefe and Stears's (2016) study. It was important that we investigated whether the teachers could elicit SPS in their ecosystem-based activities prior to the investigation on SPS and the scientific process. Thus, the teachers were asked to provide five SPS (Table 1) that they had developed during the freshwater study, together with the associated activities that enabled such development (Table 3). A few generic skills were also included.

We tested for the uniformity for each question (Table 2), that is, whether the teachers' answers (or selections) concerning the five SPS were given at random. The very low p -values ($p < 3.5e-3$) show that the answers were not given randomly. This step was essential before we could further explore the dataset information. After further exploration of the dataset, the results (Table 3) showed that the following SPS were given the most often (each time significantly more often than randomness): *Observing, comparing, recording information, and communicating.*

Table 1 The SPS and generic skills that were used in the present study

Science process skills		Generic skills	
1) <i>Accessing & recalling information</i>	15) <i>Critical thinking</i>		
2) <i>Observing</i>	16) <i>Problem solving</i>		
3) <i>Comparing</i>	17) <i>Experimenting</i>		
4) <i>Measuring</i>			
5) <i>Sorting & classifying</i>			
6) <i>Identifying problems & issues</i>			
7) <i>Raising questions</i>			
8) <i>Predicting</i>			
9) <i>Hypothesising</i>			
10) <i>Planning investigations</i>			
11) <i>Doing investigations</i>			
12) <i>Recording information</i>			
13) <i>Interpreting information</i>			
14) <i>Communicating</i>			

Note. The SPS are presented in italics in the document to distinguish them from the scientific process steps (shown in bold).

Table 2 *P*-values of chi-square test for uniformity for each question ($n = 94$)

The SPS	Uniformity
Question 4.1	2.4e-14
Question 4.2	2.7e-8
Question 4.3	5.2e-6
Question 4.4	3.5e-3
Question 4.5	2.1e-5

Table 3 Frequencies of SPS selected and the associated activities ($n = 94$)

Question	SPS	Frequency	The associated activity
4.1	<i>Observing</i>	61/94	" I observed the organisms in the water."
4.2	<i>Comparing</i>	24/94	"We compared the number of each species found in water."
4.3	<i>Comparing</i>	20/94	"We were told to compare the crabs according to gender, using their colour and other features."
4.4	<i>Recording information</i>	17/94	"After finding aquatic species we then classified them and recorded the data."
4.5	<i>Communicating</i>	20/94	" Presentations that we did in groups."

Note. Table 3 provides a summary of the most often given answer for each question.

Research Question 2: How Do the Teachers View the Study of the Freshwater Ecosystem in Terms of the Processes and the Associated Science Process Skills Used?

For SB Watson and James (2004), a different way of looking at the scientific process is by identifying where SPS fit into it. The pre-service teachers were asked to provide two SPS that blended with each scientific process step (Figure 1) when they tested the water quality of the stream using chemical test kits. It should be noted that the Bonferroni correction ($0.05/(14+17*4) = 0.05/82 = 6e-4$) enables us to reject the null hypothesis of randomness if the p -value was lower than $6e-4$. Since $1.7e-4$ is lower than $6e-4$, this shows that the answers (for all questions) were again not given randomly (see Table 4).

Table 4 *P*-value of chi-square test for uniformity for each question ($n = 94$)

The scientific process steps	Uniformity
Question 5.1: Research question	1.2e-11
Question 5.3: Formulating hypothesis	2.2e-16
Question 5.4: Design an activity or experiment	1.7e-4
Question 5.5: Observation	7.7e-10
Question 5.6: Conclusion	8.4e-7

Table 5 shows the numbers of answers (selections) of all the skills in relation to each scientific process step. Figure 2 specifically shows the count of the number of times any two SPS (Table 1) that positively represent the model (Figure 1) were selected by the teachers first (S1) and second (S2) for a given scientific method step. TS represents the total of the selection of given SPS. The SPS are arranged in terms of the number of answers relative to the rest in each scientific process step in descending order. Furthermore, the number of answers of SPS for each step of the scientific process (alphabetically named) show how close the teachers' selections (Figure 2) were to a good

representation of the model (Figure 1), with B showing good proximity compared to D and E (relative), as well as A and C (poor). It should also be noted that, while there were 94 participants, the sample was 188, that is, 188 answers if all participants' responses were a good representation of the model.

The teachers selected three skills that blended with **problem/research question** (Question 5.1) (Table 5), namely *raising questions* (41), *identifying problems and issues* (32), and *observing* (29) – the SPS that blended with the scientific step thereof (Figure 2). The other SPS that blended with the step – *communicating* (8) – were, however, among the least selected skills (Table 5). For **form a hypothesis, predicting** dominated (58) followed by *hypothesis* (59) (Figure 2). The SPS that does not blend with **form a hypothesis** (Figure 2), but was selected the most, was *observing* (22) (Table 5). *Planning investigations* (27) and *doing investigations* (39) (Table 5) were selected the most for **design experiment**. It should be noted that only *planning investigations* (27) blends with design experiment (Figure 2). Another SPS that blended with the step thereof – *measuring* – was, however, among the least selected skills (14). For **observation**, three SPS were selected the most, namely *observing* (45) that blends with observation, *recording information* (37), and *comparing* (26) (Table 5). The other SPS that blend with observation – *sorting and classifying* (11) – were among the least selected SPS for observation. *Recording information* (28) and *interpreting information* (23) (Table 5), which blend with **conclusion and inferences**, were both selected the most relative to the rest of the SPS under conclusion and inferences. Another SPS that blends with conclusion and inferences – *communicating* (7) (Table 5) – completed the top three SPS viewed to blend with the scientific process step thereof.

Table 5 Number of answers of SPS/generic skills selected for each scientific process ($n = 94$)

	Science process skills																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5.1	9	29+	5	1	1	32+	41+	7	21	4	8	6	9	8	3	2	0-
5.3	0-	22	7	2-	1-	7	9	58+	59+	5	9	2-	3	4			
5.4	3	7	10	14	6	5	11	11	13	27+	39+	22	15	5			
5.5	3	45+	26+	8	11	2-	11	10	4	2-	7	37+	16	4			
5.6	7		7		6	1	1	8	1	1	4	28+	23+	7			

Note. A number given in bold with + means that the number of answers associated is significantly higher than randomness with the binomial tests (with Bonferroni correction: $(0.05/(17+14*4) = 0.05/73 = 6.8e-4)$ $6.8e-4$).

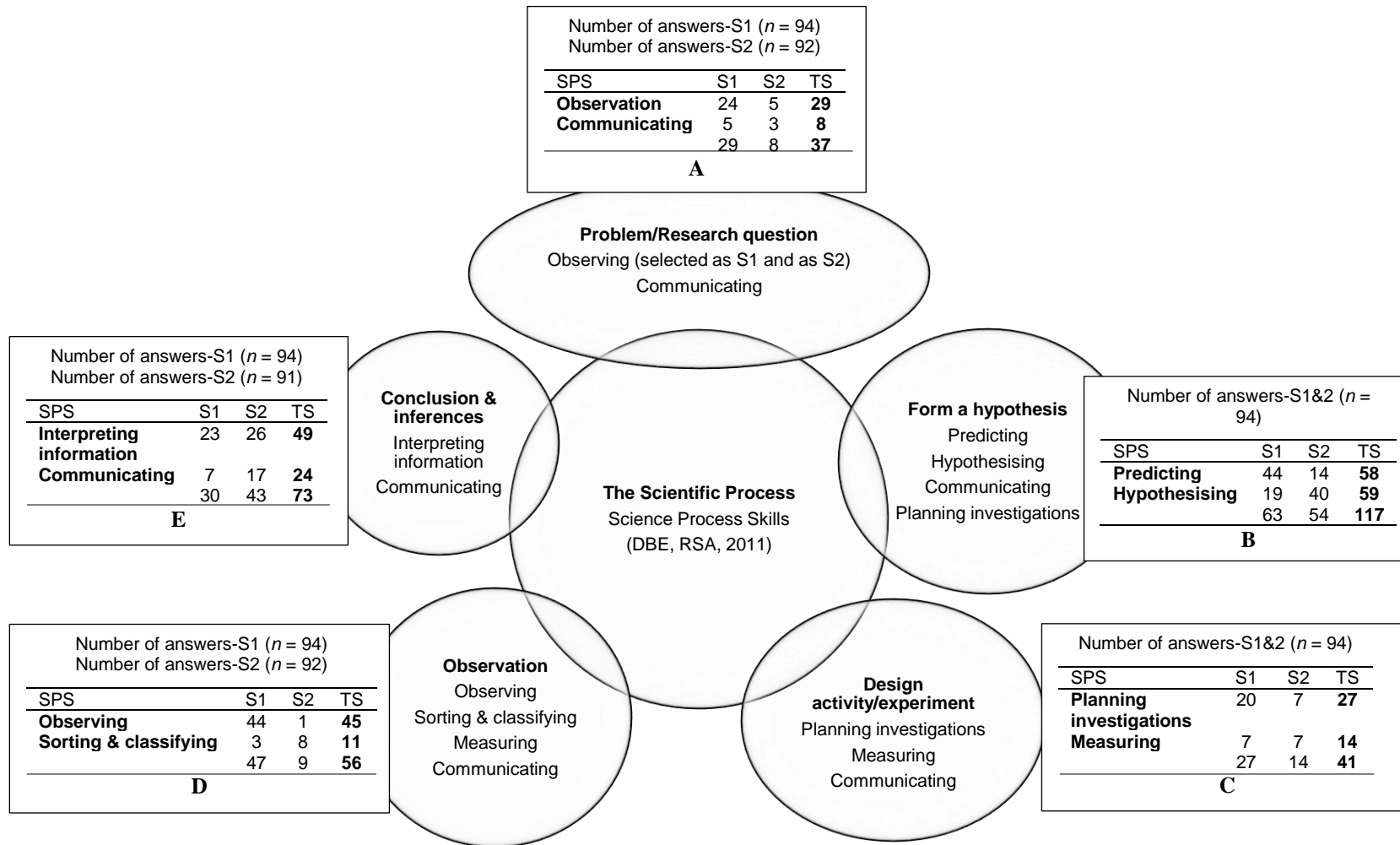


Figure 2 Number of answers (or proximity) of SPS selected in relation to the model's SPS that blend with the scientific process

Discussion and Conclusion

Studies of skills in tandem with environmental-based content have long been important (Colley, 2006; VanLeuvan & McDowell, 2000) as has the controversy around the scientific process itself (Thomas, 2012; Watson, SB & James, 2004). However, over the last 5 years, teachers' views regarding pedagogical methods used in scientific investigations (Pepper, 2013) and in the use of SPS (Özdemir & Işık, 2015), development and implementation of SPS in science (Ambross, Meiring & Blignaut, 2014), understanding of SPS (Shahali, Halim, Treagust, Won & Chandrasegaran, 2017), and the debates around teaching and/or development of SPS, conceptual understanding, and context (Molefe et al., 2016), among others, have become areas of interest. We chose to investigate a territory which has hardly been ventured into – pre-service teachers' views of SPS within science education contexts (with special reference to EE) and their views about SPS that blend with the stepwise scientific process.

Students' curiosity can be turned into meaningful learning experiences in EE, with development of SPS as a springboard (Scott, CM & Matthews, 2011). For teachers, SPS that should be part of plans of science activities should include *observation, measuring, classification, comparison, and prediction* (Uğras & Çil, 2016). The pre-service teachers in this study, in their quest to investigate the quality of the freshwater ecosystem, had an opportunity to engage in some activities that enabled development of some SPS, and included use of several resources such as bug dials. The teachers *observed and compared* aquatic life, *sorted and classified* it, *recorded and interpreted* information, and *communicated* the associated findings. The teachers viewed *observing, comparing, recording information, and communicating information* as SPS that enabled them to score the investigated stream's water quality. It was reasonable that *observing* and *comparing* dominated the five SPS selected by the teachers. Teachers might be more successful in identifying the skill of *observing* and other skills (Gultepe, 2016), and they (teachers) might claim that they use these SPS in science activities that they conducted (Uğras & Çil, 2016). *Observing* and *comparing* were the most rated SPS at the institution (Molefe et al., 2016) and should have been familiar to the teachers.

When analysing students' SPS, issues around, for instance, observation, conceptual knowledge, interpreting data and drawing conclusions may play a major role (Yamtinah, Masykuri, Ashadi & Shidiq, 2017). The pre-service teachers had an opportunity to develop some of the SPS (e.g., *observing* and *comparing, sorting and classifying, interpreting and communicating information*) in tandem with the stepwise scientific process. The pre-services teachers' responses showed a good proximity to the

expected representation of the scientific process model (Figure 2) with regard to the **formulation of hypothesis. Observation and conclusion and inferences** showed a relatively close proximity to the model. It was interesting that the teachers' responses on **research question** and **design experiment** showed a distant proximity to the model.

Bar *communicating, observing* blends with **problem/research question** while *measuring* blends with **design experiment**. Molefe et al. (2016) show that pre-service teachers might have contradicting views about the importance of *observing*. Similarly, *measuring* produced mixed results. In a recent study, Irwanto et al. (2018) suggest that undergraduate science education students may show medium level scores on those three SPS. Similar findings, with regard to *measuring* and *observing*, were also found in an earlier study on college biology students by Rabacal (2016). SPS cannot be disconnected from conceptual understanding in the teaching and learning of science (Yamtinah et al., 2017). Mumba et al. (2018) eloquently show the influence, for instance, of familiarity and conceptual understanding of SPS. The challenge of conceptual understanding and SPS has also been raised by Shahali et al. (2017).

In this study, the pre-service teachers' inability to *significantly* connect the three SPS to the appropriate scientific process steps may be understood in terms of a lack of conceptual understanding of them. Our argument was further reinforced by the selection of SPS that do not blend with the two scientific process steps, namely *identifying problems and issues, and raising questions, and doing investigations* (Figure 2). Although scientific investigations involve asking questions (Lederman et al., 2019) – which may be equated to problem/research question – *observing* phenomena and the associated *communication* thereof normally precede *identifying problems and issues* and *raising questions*. In relation to **design experiment**, we believe that the misplaced *doing investigations* may be understood in terms of the teachers' lack of understanding of *doing investigations* and/or *planning investigations*. Solving real-world problems form the basis for a better **design of experiments** and ability to lead students in scientific investigations (Cotabish, Dailey, Hughes & Robinson, 2011). **Research questions** are emphasised in inquiry-based practices and the scientific process. Thus, the two scientific process steps' distance from a good representation of the model, in terms of SPS, suggest more challenges to teachers on scientific investigations with regard to questioning and design of associated experiments.

A considerable number of teachers were, however, able to correctly show that *predicting* and

hypothesising blend with **formulating hypothesis**. The findings were important. These SPS were among those considered by pre-service teachers as not important to acquire at the institution (Molefe et al., 2016). Rabacal (2016) found that *hypothesising* was performed poorly in her study. However, average scores were found in *predicting*. Susanti et al. (2018) show that *predicting* was the most poorly performed SPS by pre-service biology teachers. On the other hand, Saban et al. (2019) found that students in a socioeconomically disadvantaged neighbourhood performed average or above in *predicting*. The results concerning *predicting* and *hypothesising* may thus be understood in terms of them being familiar skills. Contrary to them (i.e. *predicting* and *hypothesising*), *observing* was selected among the most important SPS at the institution (Molefe & Stears, 2014), and students may perform above average on this SPS (*observing*) (Saban et al., 2019). It is thus reasonable that it dominated under the scientific process step **observation**. It was also a leading SPS among the five skills that were developed by the teachers during the freshwater study (Table 3). It was further selected as a skill that blended with **formulating hypothesis**. This finding merits further research to deduce whether its (*observing*) misplaced selection here was due to the teachers' understanding that observations are central to explanations in formulating hypothesis. It was interesting that *comparing* and *recording information* were misplaced in relation to **observation** (Table 5). *Recording information* and *comparing* selections may be understood in terms of the teachers' inability to dissociate use of water life from use of chemical test kits when deducing the quality of a freshwater stream. The two SPS were part of the water life activities (Table 3). On the other hand, chemical test kits should have encompassed, for instance, measurements, quantitative observations, and communication. **Observation's** relative proximity to the model suggests the need to emphasise the contextualisation of SPS.

With regard to **conclusion and inferences**, *interpreting information* and *communicating* were correctly selected by the teachers (Figure 2). However, the teachers' responses, particularly for *communicating*, showed a relatively close proximity to the model. While the two SPS are important for an undergraduate education (Addis & Powell-Coffman, 2018), they are also conceptually challenging for students (Mumba et al., 2018). Thus, these pre-service teachers might hold unsophisticated views, especially about *communicating*, and/or the SPS was poorly understood (Lederman et al., 2019). The argument here is justified by the misplaced SPS, *recording information*, in this case (i.e., **conclusion and inferences**). One way of looking at students' SPS might include developing a rubric that might enable

one to capture fine details of their (students) performances with the processes of *recording* and *analysing data*, drawing conclusions and presenting evidence (Germann & Aram, 1996). Thus, *recording information's* misplacement may be loosely understood in terms of analysis of *recorded* data and drawing conclusions.

As referred to earlier, SPS have been extensively researched in literature. Yet, research on their association with the stepwise scientific process is very limited. Penprase's (2018) arguments on the Fourth Industrial Revolution suggest that it (the Revolution) will disrupt the notions of science education curriculum. That implies that the issues related to the implicit link between the stepwise scientific process used in schools (e.g. DBE, RSA, 2011) and SPS, science education and other disciplines (e.g. environmental science), and understanding SPS themselves, will have to be addressed with urgency in higher education institutions. Our findings thus make a small but significant contribution to science education in terms of debates on the link between SPS and the stepwise scientific process. They highlight the areas that teacher educators should focus on when investigating educators' stance on scientific skills and processes intertwined with modern-day global environmental issues.

Our findings further suggest the kind of teacher that should be envisaged by the world with regard to EE. That kind of teacher will need more than a science curriculum that promotes knowledge about SPS and processes and the scientific inquiry. Practice will be key to the understanding and/or development of these concepts. Indeed, it was emphasised in previous research (Molefe et al., 2016) that teacher educators' praxis has a significant impact on teachers' learning through own apprenticeship of observation (Lortie, 1975). Hodson (1996) articulated Lortie's (1975) views better with his emphasis on modelling, guided practice and application. Our study's findings show the prominence of *observing*, in particular, in the SPS selected by the teachers in relation to the activities they engaged in that were associated with the freshwater study. That said, the importance of questions as drivers of scientific investigations have been lauded (e.g. Lederman et al., 2019). Questions are also at the heart of inquiry-based practices and the scientific process. Bar development of knowledge about the relationship between human beings and environmental systems, communication remains enshrined in the EE outcomes for the 21st century (Powell, Stern, Frenley & Moore, 2019). Yet, the participants in this study failed to link *observing* and *communicating* to formulating a research question.

The findings of the study thus imply challenges to pre-service teachers on scientific investigations in terms of questioning, design of experiments and the

drawing of associated conclusions and making inferences. They further suggest challenges to science teacher educators with regard to ways in which they may reconcile the roles of *observing*, *communicating* scientific information, as well as questions in the stepwise scientific process and the associated scientific inquiry.

Furthermore, the findings imply that science teacher educators that offer modules that have fieldwork component that encompass SPS should design scientific investigations and science activities that may tap into pre-service teachers' conceptual understanding of SPS skills, such as *communicating* and recording science information, *comparing*, *measuring*, and *sorting and classifying*.

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Authors' Contributions

Leonard Molefe carried out the research process, reviewed the databases and wrote the general manuscript. Jean-Baptiste Aubin conducted all statistical analyses and provided data for Tables 2, 3, 4 and 5. The authors reviewed the final manuscript.

Notes

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References

- Addis EA & Powell-Coffman JA 2018. Student and faculty views on process of science skills at a large, research-intensive university. *Journal of College Science Teaching*, 47:72–82.
https://doi.org/10.2505/4/jcst18_047_04_72
- Ambross J, Meiring L & Blignaut S 2014. The implementation and development of science process skills in the natural sciences: A case study of teachers' perceptions. *African Education Review*, 11(3):459–474.
<https://doi.org/10.1080/18146627.2014.934998>
- Coil D, Wenderoth MP, Cunningham M & Dirks C 2010. Teaching the process of science: Faculty perceptions and an effective methodology. *CBE—Life Sciences Education*, 9:524–535.
<https://doi.org/10.1187/cbe.10-01-0005>
- Colley KE 2006. Understanding ecology content knowledge and acquiring science process skills through project-based science instruction. *Science Activities*, 43(1):26–33.
<https://doi.org/10.3200/SATS.43.1.26-33>
- Cotabish A, Dailey D, Hughes GD & Robinson A 2011. The effects of a STEM professional development intervention on elementary teachers' science process skills. *Research in the Schools*, 18(2):16–25.
- Creswell JW 2014. *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed). London, England: Sage.
- Department of Basic Education, Republic of South Africa 2011. *Curriculum and Assessment Policy Statement Grades 7-9: Natural Sciences*. Pretoria: Author. Available at <https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20SP%20%20NATURAL%20SCIENCE%20GR%207-9%20%20WEB.pdf?ver=2015-01-27-160159-297>. Accessed 8 July 2019.
- Dourado L & Leite L 2013. Field activities, science education and problem-solving. *Procedia - Social and Behavioral Sciences*, 106:1232–1241.
<https://doi.org/10.1016/j.sbspro.2013.12.138>
- Dresner M, De Rivera C, Fuccillo KK & Chang H 2011. Improving high-order thinking and knowledge retention in environmental science teaching. *BioScience*, 64(1):40–48.
<https://doi.org/10.1093/biosci/bit005>
- Germann PJ & Aram RJ 1996. Student performances on the science processes of recording data, analysing data, drawing conclusions, and providing evidence. *Journal of Research in Science Teaching*, 33(7):773–798.
[https://doi.org/10.1002/\(SICI\)1098-2736\(199609\)33:7%3C773::AID-TEA5%3E3.0.CO;2-K](https://doi.org/10.1002/(SICI)1098-2736(199609)33:7%3C773::AID-TEA5%3E3.0.CO;2-K)
- Gultepe N 2016. High school science teachers' views on science process skills. *International Journal of Environmental & Science Education*, 11(5):779–800. <https://doi.org/10.12973/ijese.2016.348a>
- Hodson D 1996. Laboratory work as scientific method: Three decades of confusion and distortion. *Journal of Curriculum Studies*, 28(2):115–135.
<https://doi.org/10.1080/0022027980280201>
- Irwanto, Saputro AD, Rohaeti E & Prodjosantoso AK 2018. Promoting critical thinking and problem solving skills of preservice elementary teachers through process-oriented guided-inquiry learning (POGIL). *International Journal of Instruction*, 11(4):777–794.
- Lederman J, Lederman N, Bartels S, Jimenez J, Akubo M, Aly S, Bao C, Blanquet E, Blonder R, Andrade MBS, Buntting C, Cakir M, EL-Deghaidy H, ElZorkani A, Gaigher E, Guo S, Hakanen A, Hamed Al-Lal S, Han-Tosunoglu C, Hattingh A, Hume A, Irez S, Kay G, Dogan OK, Kremer K, Kuo PC, Lavonen J, Lin SF, Liu C, Liu E, Liu SY, Lv B, Mamlok-Naaman R, McDonald C, Neumann I, Pan Y, Picholle E, Rivero García A, Rundgren CJ, Santibáñez-Gómez D, Saunders K, Schwartz R, Voitle F, Von Gyllenpalm J, Wei F, Wishart J, Wu Z, Xiao H, Yalaki Y & Zhou Q 2019. An international collaborative investigation of beginning seventh grade students' understandings of scientific inquiry: Establishing a baseline. *Journal of Research in Teaching*, 56(4):486–515.
<https://doi.org/10.1002/tea.21512>
- Lin CH, Chiu CH, Hsu CC, Wang TI & Chen CH 2018. The effects of computerized inquiry-stage-dependent argumentation assistance on elementary students' science process and argument construction skills. *Journal of Computer Assisted Learning*, 34(3):279–292.
<https://doi.org/10.1111/jcal.12241>
- Lortie DC 1975. *Schoolteacher: A sociological study*. Chicago, IL: University of Chicago Press.
- Moeed A 2013. Science investigation that best supports student learning: Teachers' understanding of

- science investigation. *International Journal of Environmental & Science Education*, 8:537–559. <https://doi.org/10.12973/ijese.2013.218a>
- Molefe L & Stears M 2014. Rhetoric and reality: Science teacher educators' views and practice regarding science process skills. *African Journal of Research in Mathematics, Science and Technology Education*, 18(3):219–230. <https://doi.org/10.1080/10288457.2014.942961>
- Molefe L, Stears M & Hobden S 2016. Exploring student teachers' views of science process skills in their initial teacher education programmes. *South African Journal of Education*, 36(3):Art. # 1279, 12 pages. <https://doi.org/10.15700/saje.v36n3a1279>
- Molefe ML & Stears M 2016. Understanding how science process skills meld with the scientific method: Student teachers' views through a lens of scientific inquiry. In W Mwakapenda, T Sedumedi & M Makgato (eds). *Proceedings of the 24th annual conference of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE) 2016*. London, England: Routledge.
- Mumba F, Miles E & Chabalengula V 2018. Elementary education in-service teachers' familiarity, interest, conceptual knowledge and performance on science process skills. *Journal of STEM Teacher Education*, 53(2):21–42. <https://doi.org/10.30707/JSTE53.2Mumba>
- Neuman WL 2014. *Social research methods: Qualitative and quantitative approaches* (7th ed). Harlow, England: Pearson.
- Özdemir O & Işık H 2015. Effect of inquiry-based science activities on prospective elementary teachers' use of science process skills and inquiry strategies. *Journal of Turkish Science Education*, 12(1):43–56. <https://doi.org/10.12973/tused.10132a>
- Penprase BE 2018. The fourth industrial revolution and higher education. In NW Gleason (ed). *Higher education in the era of the fourth industrial revolution*. Singapore: Palgrave Macmillan. <https://doi.org/10.1007/978-981-13-0194-0>
- Pepper C 2013. Pre-service teacher perceptions of using problem based learning in science investigations. *Teaching Science*, 59(1):23–27. <https://search.informit.org/doi/10.3316/aeipt.203845>
- Powell RB, Stern MJ, Frensley BT & Moore D 2019. Identifying and developing crosscutting environmental education outcomes for adolescents in the twenty-first century (EE21). *Environmental Education Research*, 25(9):1281–1299. <https://doi.org/10.1080/13504622.2019.1607259>
- Rabacal JS 2016. Test of science process skills of Biology students towards developing of learning exercises. *Asian Pacific Journal of Multidisciplinary Research*, 4(4):9–16. Available at https://www.researchgate.net/profile/Judith-Rabacal/publication/346371897_Test_of_Science_Process_Skills_of_Biology_Students_towards_Developing_of_Learning_Exercises/links/5fbf0c73299bf104cf7a3dad/Test-of-Science-Process-Skills-of-Biology-Students-towards-Developing-of-Learning-Exercises.pdf. Accessed 27 May 2021.
- Remmen KB & Frøyland M 2014. Implementation of guidelines for effective fieldwork designs: Exploring learning activities, learning processes, and student engagement in the classroom and the field. *International Research in Geographical and Environmental Education*, 23(2):103–125. <https://doi.org/10.1080/10382046.2014.891424>
- Rosenberg E, O'Donoghue R & Olivitt L 2008. *Methods and processes to support change oriented learning*. Grahamstown, South Africa: Rhodes University. Available at <https://www.sanbi.org/wp-content/uploads/2018/04/methods-and-processessupport-change-oriented-learning.pdf>. Accessed 29 May 2021.
- Saban Y, Aydoğdu B & Elmas R 2019. Achievement and gender effects on 5th grader's acquisition of science process skills in a socioeconomically disadvantaged neighborhood. *Journal of Baltic Science Education*, 18(4):607–619. <https://doi.org/10.33225/jbse/19.18.607>
- Scott CM & Matthews CE 2011. The “science” behind a successful field trip to the zoo. *Science Activities*, 48(1):29–38. <https://doi.org/10.1080/00368121.2010.496814>
- Scott GW, Goulder R, Wheeler P, Scott LJ, Tobin ML & Marsham S 2012. The value of fieldwork in life and environmental sciences in the context of higher education: A case study in learning about biodiversity. *Journal of Science Education and Technology*, 21:11–21. <https://doi.org/10.1007/s10956-010-9276-x>
- Shahali EHM, Halim L, Treagust DF, Won M & Chandrasegaran AL 2017. Primary school teachers' understanding of science process skills in relation to their teaching qualifications and teaching experience. *Research in Science Education*, 47:257–281. <https://doi.org/10.1007/s11165-015-9500-z>
- So WMW 2003. Learning science through investigations: An experience with Hong Kong primary school children. *International Journal of Science and Mathematics and Education*, 1:175–200. <https://doi.org/10.1023/B:IJMA.0000016852.19000.af>
- Sondergeld TA, Milner AR & Rop C 2014. Evaluating teachers' self-perceptions of their knowledge and practice after participating in an environmental education professional development program. *Teacher Development*, 18(3):281–302. <https://doi.org/10.1080/13664530.2014.928489>
- Staddon J 2017. *Scientific method: How science works, fails to work, and pretends to work*. New York, NY: Routledge. <https://doi.org/10.4324/9781315100708>
- Susanti R, Anwar Y & Ermayanti 2018. Profile of science process skills of preservice biology teacher in general biology course. *Journal of Physics: Conference Series*, 1006:012003. <https://doi.org/10.1088/1742-6596/1006/1/012003>
- Taylor ZP & Bennett DE 2016. Ecosystems services valuation as an opportunity for inquiry learning. *Journal of Geoscience Education*, 64(3):175–182. <https://doi.org/10.5408/15-138.1>
- Thomas G 2012. Changing our landscape of inquiry for a new science of education. *Harvard Educational Review*, 82(1):26–51. <https://doi.org/10.17763/haer.82.1.6t2r089l715x3377>
- Thomas GJ & Munge B 2017. Innovative outdoor fieldwork pedagogies in the higher education

- sector: Optimising the use of technology. *Journal of Outdoor and Environmental Education*, 20:7–13. <https://doi.org/10.1007/BF03400998>
- Tilling S 2018. Ecological science fieldwork and secondary school biology in England: Does a more secure future lie in Geography? *The Curriculum Journal*, 29(4):538–556. <https://doi.org/10.1080/09585176.2018.1504315>
- Ting KL & Siew NM 2014. Effects of outdoor school ground lessons on students' science process skills and scientific curiosity. *Journal of Education and Learning*, 3(4):96–107. <https://doi.org/10.5539/jel.v3n4p96>
- Uğras M & Çil E 2016. Determination of views of pre-school teachers on scientific process skills and level-of-effort on basic scientific process skills use in science activities. *The Eurasia Proceedings of Educational & Social Sciences*, 4:357–362. Available at <https://dergipark.org.tr/en/download/article-file/334170>. Accessed 25 May 2021.
- VanLeuvan P & McDowell S 2000. Engaging girls in environmental science. *Middle School Journal*, 32(1):34–40. <https://doi.org/10.1080/00940771.2000.11495256>
- Watson R, Goldsworthy A & Wood-Robinson V 1999. What is not fair with investigations? *School Science Review*, 80(292):101–106.
- Watson SB & James L 2004. The scientific method: Is it still useful? *Science Scope*, 28(3):37–39. Available at https://digitalcommons.liberty.edu/cgi/viewcontent.cgi?article=1010&context=educ_fac_pubs. Accessed 18 May 2021.
- Wellington J 1989. Skills and processes in science education: An introduction. In JJ Wellington (ed). *Skills and processes in science education: A critical analysis*. London, England: Routledge.
- Winarti A, Sarbain & Yamin M 2018. Designing an integrated learning strategy to develop students' awareness of river environment and science process skills. *Journal of Physics: Conference Series*, 1088:012008. <https://doi.org/10.1088/1742-6596/1088/1/012008>
- Yakar Z 2014. Effect of teacher education program on science process skills of pre-service teachers. *Educational Research and Reviews*, 9(1):17–23. <https://doi.org/10.5897/ERR2013.1530>
- Yamtinah S, Masykuri M, Ashadi & Shidiq AS 2017. An analysis of students' science process skills in hydrolysis subject matter using Testlet instrument. *Advances in Social Science, Education and Humanities Research*, 158:101–110. <https://doi.org/10.2991/ictte-17.2017.36>