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ARTICLE

Exploring Pre-service Science Teachers' Understanding of Scientific Inquiry and Scientific Practices Through a Laboratory Course

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Abstract

The intervention study presented in this paper explored pre-service science teachers' (PSSTs) understanding of scientific inquiry (SI) and scientific practices (SPs) during a laboratory application in science education course. Thirty-nine secondary school PSSTs, who study in the Science Education Department in a public university in Turkey, enrolled in a 14-week-long course and volunteered to participate in the study. The participants were exposed to a method is called *the 4-phase implementation* that includes laboratory-based inquiry activities addressing SI and SPs and they completed microteaching presentations. Their understanding of SI and SPs was examined through the course period. The main data sources included *Views about Scientific Inquiry (VASI) Instrument* and concept maps were used to track the changes in these understandings. The findings indicated that PSSTs had inadequate understanding of inquiry on some aspects even after the treatment. Yet, the method had positive impact in PSSTs' understanding inquiry especially in terms of facilitating the comprehension that scientific investigations begin with questions, there is no single method in investigations, and explanations are derived from collected data. The concept maps created by some of the participants also supported these results and revealed a more coherent and holistic understanding of SPs by integrating both epistemic and social components into their maps. However, PSSTs did not seem to have totally understood other aspects of inquiry including the inquiry procedures, the research conclusions, and the difference between data and evidence. Further implications are critically discussed in terms of designing future laboratory applications for science education courses.

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1 Introduction

The concept of *scientific literacy* is among the fundamentals of science education and has been the cornerstone of reform movements over the past four decades throughout the world (BouJaoude, 2002; National Research Council [NRC], 1996, 2012; MoNE, 2013, 2018). Many science educators have pointed out that the concept of scientific inquiry (SI) is the critical and essential component of scientific literacy, and the term nourishes both from the understanding of SI and nature of science (NOS). In sum, SI includes the processes of scientists' work within the scientific endeavor and how the scientific knowledge is generated, or in other words, SI refers to the systematic approaches embraced by scientists to answer their questions of interest or curiosity (Lederman et al., 2013; Özer & Dogan, 2019). Inquiry has also a pedagogical meaning which also refers to teachers' design of the learning environments as they provide opportunities for K-12 students to formulate and investigate scientific problems by engaging them in inquiry-based activities to develop adequate ideas about science (Flick & Lederman, 2006; Garcia-Carmona, 2020). Unfortunately, as known from the studies on pre-service and in-service teachers (Akerson & Hanuscin, 2007; Karışan et al., 2017; Mesci, & Schwartz, 2017; Dogan, 2017) and K-12 students (Senler; 2015; Leblebicioglu et al., 2017; Lederman et al., 2019; Dogan, Han-Tosunoglu, Özer & Akkan, 2020; Cetin, 2021), learners hold naïve views about these understandings. From this point of view, Erduran and Dagher (2014) criticized the traditional school science teaching which focuses on products of science and underemphasizes the relationships between different forms of scientific knowledge. They suggested understanding of the development of scientific knowledge depending on the specific criteria and standards. They also pointed out isolated teaching of science process skills without showing the interrelationship of each process and their function in the development of scientific knowledge. They suggested articulating scientific practices (SPs) to facilitate a holistic understanding of science by putting emphasis on the processes of science and formulation of science.

Inadequate understanding about SI and SPs provides rationale for interventional activities to be conducted in order to enhance these understandings of in-service/pre-service teachers and K-12 students. Specifically, pre-service science teachers (PSSTs), as prospective science teachers, have a crucial role for supporting future learners' ideas of science as well as the development of their scientific literacy and its elements. They need to know how to engage students in inquiry and how to facilitate their inquiry processes and to address knowledge acquisition (Schwarz, 2009). Studies show that pre-service science teachers complete undergraduate science courses with little experience of authentic scientific research (Roth, 1998) and those minimal experiences create a poor quality of inquiry practices on their own teaching, which would eventually affect learners' ideas and knowledge (Özer, Dogan, Yalaki, Irez & Cakmakci, 2021). Thus, inquiry in pre-service teacher education is critical (Abell et al., 2006) and implementing the elements of SI and SPs to learners during their training is essential before their own instructional practices (Jimenez-Liso et al., 2019). As the studies show, teacher candidates have difficulties in transforming understandings about inquiry into their practices (Schwarz, 2009; Yoon et al., 2012; García-Carmona et al., 2017). Thus, it is crucial to explore PSSTs' understandings of SI and SPs by engaging them in explicitly taught inquiry-based laboratory activities (Lederman et al., 2014) and incorporate the necessary aspects of SI and SPs into their own teaching. We argue in this paper that introducing and elaborating the aspects of SI and SPs and enabling PSSTs to incorporate these aspects into the hands-on and minds-on inquiry activities they designed through microteaching sessions may help to overcome difficulties on transforming their understanding into practice and understand the inquiry. Thus, the participants were exposed to a genuine method that is called *the 4-phase implementation* that includes hands-on minds-on laboratory-based inquiry activities addressing SI and SPs and completed microteaching presentations. The purpose of this study is to investigate the changes in PSSTs' understanding of SI and SPs through a laboratory application course by addressing two research questions:

- How do PSSTs' understanding of SI change with a 4-phase implementation in a laboratory application course instruction?
- How do PSSTs' understanding of SPs change with a 4-phase implementation in a laboratory application course instruction?

2 Theoretical Framework

2.1 Scientific Inquiry and Scientific Practices

The NRC (1996) defined the SI as two-folded concepts within the National Science Education Standards (NSES) document as *the abilities necessary to do scientific inquiry* and *the understandings about scientific inquiry*, which all K-8 students should develop eventually with educational activities (NRC, 1996). Necessary abilities to do scientific inquiry were defined as follows (Bybee, 2006, p.4): identifying questions that can be answered through scientific investigations; designing and conducting investigations; using appropriate tools and techniques; developing descriptions, explanations, predictions, etc.; thinking critically to make the associations between evidence and data; recognizing and analyzing alternative explanations; communicating scientific procedure and explanations; and using mathematics in all aspects. These abilities are required for K-8 students to develop a holistic understanding about SI and comprehend the nature and limitations of scientific knowledge and to eventually become informed decision-makers on a variety of issues (Flick & Lederman, 2006).

In the 2000s, the insights and critics of the scholars led to the idea that "doing science" solely would not result in a broad understanding for scientific inquiry (Bybee, 2011; Osborne, 2014). Consequently, the concept of scientific inquiry and abilities to be revised in the latest reform documents took part in the agenda of science education (NRC, 2000; NRC, 2012; Jimenez-Liso et al., 2019). In the revised framework of NSES, it was identified eight understandings related to scientific inquiry (NRC, 2000) that need to be known in order to be scientifically literate. These eight understandings of inquiry (Lederman et al., 2014) along with their definitions are provided in Table 1. And in the latest frameworks, these abilities and understandings have been considered the skills that develop together with specific practices and activities embedded in related science content, rather than the phenomena that they develop on one another separately (Beaumont-Walters & Soyibo, 2001). Therefore, the concepts, namely knowledge about inquiry and the term of "practices," instead of "skills," were gathered under a broader framework within the scope of this recent K-12 conceptual framework, and were named as *scientific and engineering practices*, along with *crosscutting concepts* and *disciplinary core ideas* (NRC, 2012). Eight SPs included in scientific and engineering practices and their descriptions are also provided in Table 1 (NRC, 2012, p.50). Similar to the abilities necessary to do scientific inquiry, by the help of these practices, it is aimed for learners to develop a broad understanding

Table 1. Understandings of scientific inquiry and scientific practices (NRC, 2012; Lederman et al., 2014)

Understandings of scientific inquiry	Understandings of scientific practices
Scientific investigations all begin with a question and do not necessarily test a hypothesis (SI 1)—scientific investigations require questioning and include processes that enable scientists to answer a question by following different scientific methodologies in a format that does not necessarily test a hypothesis. This attribute includes consideration of approaches over and above "hypothetical-deductive" methods such as inductive and deductive approaches guided by a focus question or application of known ideas	*Asking questions and defining problem for science (SP 1)*—a fundamental practice of scientists is to formulate empirically answerable questions about phenomena, to identify what is already known, and to determine which questions are not answered satisfactorily
There is no single set or sequence of steps followed in all investigations (SI 2)—related to the SI 1 aspect, within science endeavors, there is not a prescribed methodology or a singular scientific method for different disciplines of sciences to answer scientific questions as traditionally defined in some early textbooks	*Developing and using models (SP 2)*–science involves the creation and use of a variety of models and simulations to help scientists to develop explanations about a natural phenomenon
Inquiry procedures are guided by the question asked (SI 3)—despite the varieties in scientific methodologies employed within the investigations, the questions are asked to guide the trajectories within the process and shape the methodologies' appropriateness	*Planning and carrying out investigations (SP 3)*—the scientific research can be conducted in the field or in the laboratories. One of the important practices of scientists is to plan and conduct systematic research that requires identification of records, to define variables
All scientists performing the same procedures may not get the same results (SI 4)—the data presented in scientific investigations may be interpreted variously by different scientists. Thus, other scientists who follow similar patterns and perform similar methodologies might get variations with their results and the same procedures may provide different data due to observation and measurement errors	*Analyzing and interpreting data (SP 4)*—scientific research produces data that must be analyzed in order to make sense. Scientists use a range of tools to identify important features and patterns in the data
Inquiry procedures can influence results (SI 5)—the variations selected within the scientific investigations may lead to different results since they might require differentiations within data collection, measurement of variables and interpretation	*Using mathematics and computational thinking (SP 5)*—mathematics and computation in science are essential tools for representing variables and their interrelationships. Mathematics and computation can be used for a variety of tasks including creating simulations, statistically analyzing data, and recognizing, expressing, and applying quantitative relationships
Research conclusions must be consistent with the data collected (SI 6)—the conclusions must be data-driven and must be supported with evidence emerged from the investigations. Osborne (2014) noted that all claims require justification relying on a body of data and warrants to justify the claim. The degree of the reliability of an idea depends on minimization of error and accumulation of evidence	*Constructing explanations and designing solutions (SP 6)*—one of the purposes of science is to build theories that can provide explanatory explanations of the features of the world. Scientific explanations are explicit applications of theory to a particular situation or phenomenon, perhaps through a theory-based model for the system under study

Table 1. (continued)

Understandings of scientific inquiry	Understandings of scientific practices
Scientific data are not the same as scientific evidence (SI 7)—the differences between scientific data and scientific evidence must be highlighted in terms of data's various forms such as numbers, descriptions, audio, video, etc., and evidence's role as ultimate forms of data interpreted and processed	*Engaging in argument from evidence (SP 7)*—reasoning, discussion and argumentation in science is necessary to identify the strengths and weaknesses of a line of reasoning and to find the best explanation for a natural phenomenon. Scientists must defend their explanations, build evidence on data, examine their own understanding in the light of evidence and interpretation provided by others, and collaborate with colleagues to find the best explanation for the phenomenon under study
Explanations are developed from a combination of collected data and what is already known (SI 8)—scientific knowledge is the combination of current scientific knowledge and data-driven knowledge gained from empirical investigations. Thus, while scientists hold a great deal of knowledge about their discipline, they also try to expand this knowledge base by their explanations and contributions. Scientists should be able to recognize how research results differ from existing scientific knowledge and identify how to interpret data and generate explanations using existing scientific knowledge	*Obtaining, evaluating, and communicating information (SP 8)*—an important application of science is the communication of ideas and research findings, verbally, in writing, using tables, diagrams, graphs, and equations, and participating in long discussions with scientific colleagues. Science requires the ability to extract meaning from scientific texts in order to evaluate the scientific validity of the information thus obtained and to integrate this information

of processes of science and its epistemic basis (NRC, 2012; Osborne, 2014; Dogan & Özer, 2018; Saribas & Ozer, 2021). Consistent with the aforementioned literature and the NRC (1996; 2000; 2012) frameworks, mainly eight attributes of SI understandings that clearly overlap with the eight SPs were highlighted and reflected into the science education reform documents for K-16 science classrooms (Lederman et al., 2013; Antink-Meyer et al., 2016). Regardless of the changed frameworks and number of attributes of SI and SPs, it is observed that within these frameworks, some attributes remain central, such as asking questions, conducting investigations, collecting and interpreting data, and generating explanations (Grigg et al., 2013)

A broad understanding of science requires teachers to have adequate understandings of SI and SPs to orchestrate various types of instructional activities meaningfully, assess student progress, and achieve the scientific literacy vision (Lederman et al., 2013). And competent science teachers, who will improve students' capability with SPs, need to have pedagogical content knowledge as well as conceptual, procedural, and epistemic knowledge (Osborne, 2014). In-service teachers can achieve this competence through professional development programs; however, for prospective teachers, it is different. During pre-service teacher training programs, providing various courses that include a wide spectrum of experiences about SI and SPs is essential to deepen their understanding about these concepts. It is also significant to provide opportunities for pre-service teachers to plan, design, organize, and conduct inquiry-based instructions and to reflect on those work, which would deepen their understanding about how students might think, their capabilities, and what to expect from inquiry-based instructions (NRC, 2012). Since scientific investigations begin with a question, learners need to appreciate the significance of raising questions during a scientific inquiry. It also requires them to engage in modeling and constructing explanations, the practice of mathematical and computational thinking as well as argument from evidence. Interpreting data and evidence scientifically can only be achieved through gathering their own sets of data or using secondary data sets, and then establishing and justifying the best interpretation. To help learners develop a functional understanding of science, it is also necessary to engage them in the practice of designing empirical investigations (Osborne, 2014). Thus, facilitating epistemic understanding of science—that is how we know what we know—is vital and it necessitates students' engagement in SPs (Duschl & Grandy, 2013).

Erduran and Dagher (2014) stressed the necessity of a systemic approach in which the epistemic, cognitive, and social-institutional aspects are presented in a holistic perspective to communicate science to students and they proposed a heuristic that is visualized by using an analogy of benzene ring as illustrated in Fig. 1. Benzene ring is a hexagonal organic compound consisting of six carbon atoms, each of which is attached to one hydrogen atom. These atoms joined to each other in a ring that has a continuous pi bond, which is a covalent chemical bond. In this analogy, epistemic and cognitive aspects of science are represented as carbon atoms and social aspects are represented as the ring of diffuse pi bonds. This holistic representation illustrates the interrelatedness of epistemic and cognitive aspects of science, which are influenced by social aspects. We argue that this heuristic of SPs should be introduced to learners besides the eight components of SPs listed in NRC (2012) to facilitate the holistic understanding of science.

2.2 Hands-on/Minds-on Experiences in the Laboratory

Experiential learning theory by Kolb (Kolb, 1984) is a conceptual model, building on John Dewey's work, that defines learning and knowledge acquisition through experiences in a cyclic structure. Kolb defines experiential learning as a "process whereby knowledge is created through the transformation of experience" (Kolb, 1984, p.38). According to the theory, learning occurs in four steps: *concrete experience* (CE) is the step where the students actively experience a task; r*eflective observation* (RO) is the step that students consciously reflect on the task; *abstract conceptualization* (AC) is the step that students are expected to conceptualize what is being observed; and *active experimentation* (AE) is the step that students are expected to test a model or a theory by manipulating different aspects (Healey & Jenkins, 2000; Young, 2002). Even though this cyclic structure is not a necessity, Kolb (1984) suggests that learners should go through all steps for a meaningful learning and knowledge acquisition. According

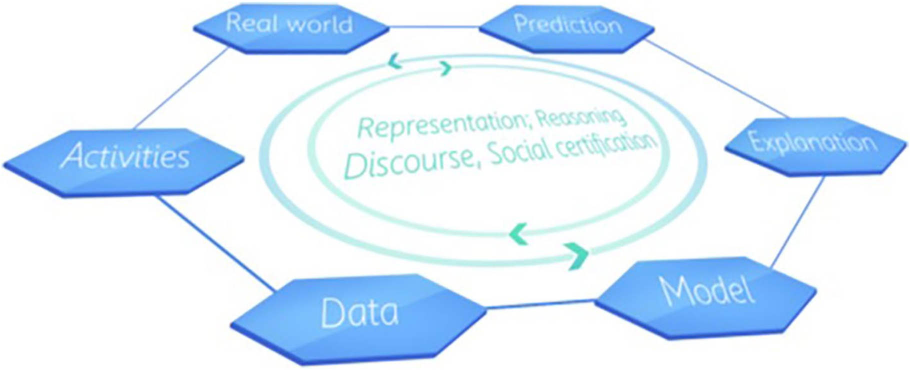


Fig. 1. Benzene Ring Heuristic (BRH) model (Erduran & Dagher, 2014)

to Healey and Jenkins (2000), the theory highlights the importance of experiential activities such as laboratory sessions, fieldwork, and hands-on and minds-on experiences. Hence, Young (2002) associates concrete experiences and active experimentation steps with the term hands-on and steps as reflective observation and abstract conceptualization with the term of minds-on. Hands-on experiences have been defined as the instructional methods and activities that involve direct experiences which provide students' concrete learning opportunities as well as actively manipulating objects to understand their nature such as laboratory activities, simulations, experiments, modeling, and demonstrations (Haury & Rillero, 1994). On the other hand, minds-on experiences require the use of higher order skills, reflection, and thinking on the task. These types of activities also require explicit expert guidance for conceptual organization and meaningful learning (Young, 2002). As a result, hands-on and minds-on experiences require and lead learners physically and mentally to be engaged in the tasks (Victor & Kellough, 1997). As one of the hands-on learning environments, laboratory instructions in science education and teaching have its roots in the nineteenth century (Hofstein & Lunetta, 1982, 2004). Experiences in the laboratory can assist learners to develop ideas about the nature of science and the nature of scientific inquiry (Hofstein & Lunetta, 2004) and science process skills (Krystyniak, 2001). Many scholars have consensus on the importance of laboratory instruction in science teaching as a way to promote the aspects of scientific thinking and scientific method (Shulman & Tamir, 1973), to foster scientific inquiry skills (Anderson, 1976), to help students, and to understand how scientists work and the role of a scientist (Hofstein & Lunetta, 1982, 2004). However, as stated in some studies, the use of laboratory instruction solely may not ensure understanding of scientific thinking and accurate views about how science works, unless they are designed as activities to encourage also for metacognitive processes such as reflection on their learning, interpretation, asking critical questions, designing experiments, and critically assessing the procedures, also known as the *minds-on* facet (Konak et al., 2014). On the other hand, according to Tobin and Gallagher (1987), Roth (1998), and Marx et al. (1998), science teachers struggle in laboratory instructions related to the factors such as lack of their own direct prior practices, lack of knowledge about how to organize and facilitate the *minds-on* aspects of the instruction, and lack of practices about how to encourage students to think about scientific methods and nature of scientific inquiry (Hofstein & Lunetta, 2004). Consequently, these factors might limit learners' development of desired knowledge and skills within these learning environments. Brown and Melear (2007) argue that initially, teacher preparation institutions should provide first-hand opportunities and learning environments that promote conducting the inquiry. NRC (1996) in the NSES document suggests a method for this preparation as for teachers "to learn science content by participating in research at a scientific laboratory" (p.58). Therefore, in-service and pre-service science teachers should be supported with direct experiences and opportunities that include hands-on and minds-on activities within laboratory settings, so that they can develop the skills and knowledge needed to organize and facilitate meaningful learning environments and enrich their instructional repertoire for their students in the school science laboratory classrooms (Tamir, 1989; NRC, 1996; Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007; Brown & Melear, 2007).

3 Methodology

The two-group pre-test-post-test case study design presented in this paper examined PSSTs' understanding of SI and SPs related to a specific 9 weeks of instructional experience and 5 weeks of data collection within a 14-week-long course. The Views about Scientific Inquiry

(VASI) instrument and pre- and post-concept maps of SPs were used to explore the participants' understanding of SI and SPs. This section includes the introduction of the activities, the microteaching sessions, and the data sources of this study.

3.1 Participants

Thirty-nine female secondary school PSSTs volunteered to participate in the study with the individual consent forms. One male participant's results were omitted from the study to avoid gender bias. The participants were 3rd year undergraduate students who study in the Science Education Department in a public university in Turkey, enrolled in the Laboratory Applications in Science Education course in Fall 2019. They ranged in age from 20 to 23. This undergraduate program of science education is a 4-year teacher education program for secondary schools, and the language of instruction is English. The course objectives were to enable PSSTs to understand the concepts of SI and SPs and to incorporate them into their laboratory instructions. The participants were enrolled in one of the equivalent sections of this course randomly. One section of the course consisted of 18 PSSTs while the other involved 21 PSSTs. The participants completed the prerequisite science content courses and the introductory pedagogical courses. They previously took only one science education course, namely, Science Education in Formal and Informal Contexts, in which they were taught instructional planning and scientific literacy in general. They were not well-informed about SPs and SI, yet.

3.2 Procedure: 4-Phase Implementation

The duration of the course was 14 weeks long and 3 h per week. However, the participants were given two additional lab hours per week to work with their group mates and to design and prepare their activities. The participants' understanding of SI and SPs was promoted through 9 weeks of intervention each of which consisted of a 3-h class. The information about phases, weeks, and the content are shown in Table 2. This intervention consisted of a 4-phase implementation which included the following: *1st phase*, introduction and discussion of the concepts of SI defined by Lederman et al. (2014) and the eight components of SPs listed in NRC (2012) as well as BRH (Erduran & Dagher, 2014). Following the introduction of SI and SPs, the participants discussed how to incorporate these concepts into laboratory instruction. The *2nd phase* includes 1st microteaching activities where the participants incorporated these concepts into the hands-on and minds-on inquiry activities they designed on a science topic and presented, and *3rd phase* involved the aspects of SI and SPs in detail and their implementation in laboratory teaching as well as elaborating theoretical knowledge about SPs and SI, such as asking questions, manipulative and non-manipulative methods of inquiry, and different types of evidence, such as direct, circumstantial, and historical evidence. During these discussions, not only cognitive and epistemic aspects of SPs, such as observation, experiment, data, evidence, modeling, and explanations, but also social aspects of SPs, such as social certification, representation, reasoning, and discourse, were also emphasized. The *4th phase* includes 2nd microteaching activities, where the participants incorporated these ideas into the hands-on and minds-on activities they designed and presented. The data collection took part in the 1st, 2nd, 12th, 13th, and 14th weeks.

Table 2. The procedure of the intervention

Phases	Week	Activity	Addressed SI or SP theme(s)
Data collection	1	Drawing the pre-concept maps of SPs	
	2	Filling the pre-test of VASI	
1st phase	3	Introduction of SPs, SI, and laboratory applications	Introductory session of SPs and SI
	4	Incorporating SPs and SI in lesson planning and laboratory teaching	Implementation of SPs and SI in generic activities
	5	Designing laboratory instruction in groups of 3 or 4	
2nd phase	6–7	1st microteaching sessions	SI 1, 2, 3, 4, 5, 6, 7, 8 SP 1, 2, 3, 4, 5, 6, 7, 8
3rd phase	8	The significance of asking questions in inquiry and differentiating data from evidence	SI 1, SI 7, SP 1, SP 4
	9	Methods and methodological rules	SI 2, SI 5, SP 3
4th phase	10–11	2nd microteaching sessions	SI 1, 2, 3, 4, 5, 6, 7, 8 SP 1, 2, 3, 4, 5, 6, 7, 8
Data collection	12	Filling the post-test of VASI	
	13	Drawing the post-concept maps of SPs	
	14	Individual interviews	

3.2.1 The Nature of Microteaching Sessions

Microteaching method is known as one of the core structures of many teacher education programs as it provides opportunities for student teachers to plan, teach, and get feedback from their instructors as well as from their peers (Lederman & Lederman, 2019). Literature shows that activities like microteaching in pre-service science teaching programs that include multiple cycles of planning and reflection help candidate teachers to overcome difficulties about transforming their knowledge into practices and enrich their instructional repertoire (Zembal-Saul et al., 2000). Thus, in our study, we had two microteaching sessions for PSSTs in groups of 3 or 4.

The activities in the 1st microteaching sessions were specifically selected to address all aspects of SI and relevant SPs. PSSTs were previously notified about the activities randomly assigned to their groups. There were mainly four types of hands-on and minds-on microteaching activities including (1) data analysis activities, (2) modeling-observing-constructing-interpreting graphs and tables, (3) scientific practices in food science, and (4) critical scientific reading activities. The information and content of these activities are provided below:

- *Data analysis activities*—PSSTs were given various data sets and were expected to analyze-interpret data, derive hypotheses, construct explanations, define the variables, and make scientifically accurate interpretations as well as to predict patterns or trends based on the data they processed. The rationale of including the activity is to encourage PSSTs to ask more questions, analyze-interpret data, use mathematics and computational thinking, and learn about patterns and stability and change.
- *Modeling, observing, constructing and interpreting graphs and tables*—these types of activities included hands-on materials along with the data and evidence sets that PSSTs were expected to investigate, describe, and classify the contents while following the scientific method by testing their hypothesis, organizing data, summarizing findings, creating a graphical display of the content, interpreting data, and determining the outcome of their hypothesis.
- *Scientific practices in food science*—by the help of these activities, PSSTs laboratory–related skills as well as using computational thinking and making relevant calculations were aimed to be promoted.
- *Activities of critical reading of scientific passages*—these activities included scientific passages about renewable and non-renewable energy sources that PSSTs were expected to read and to critically assess benefits and consequences by identifying the advantages and disadvantages in terms of climate change, population, and impacts of energy consumption. These activities listed as number 6 for each section in Table 2 were selected to allow students to evaluate and communicate information for the 1st microteaching sessions.

The authors assigned equivalent activities to each section, and the second author was the instructor of each section. The topics and the aims of the microteaching activities assigned to each group in two sections are provided in Table 3. Before and after the 1st microteaching sessions, the instructor asked the participants which aspects of SI and themes of SPs were included in the activities and explicitly discussed the inquiry level of their teaching—that is, whether the teacher or the students have control over the identification of each three components of the following: asking questions and ways to gather data, interpreting results, and drawing conclusions.

Table 3. Microteaching activities of the study

	Section 1 activities	Section 2 activities
1st microteaching activities	1. Chicken bone inquiry—biological evolution of species by modeling and observing the skeleton of a chicken	1. Fish bone inquiry—biological evolution of species by modeling and observing various species of fish
	2. Climate data—the differences between weather and climate by drawing graphs and constructing tables	2. Earthquake data—the relationship between fault lines and earthquake by drawing graphs and constructing tables
	3. Counting calories—the relationship between heat, specific heat, mass, and temperature by discussing the energy gained from foods	3. DNA extraction—DNA and its structure by conducting an activity of DNA extraction from bananas
	4. Parental care—the relationship between parental behaviors and environmental factors by drawing graphs and constructing tables	4. Island biogeography—the habitats of different species and biodiversity by designing the models of natural parks
	5. Peru current—the effect of climate change on ocean currents by providing evidence of upwelling along the Peru coastline	5. Ocean currents—the effect of climate change on ocean currents by interpreting given data of latitude vs. temperature
	6. Energy exploration—the effects of various energy sources on the environment by modeling and discussing each source	6. Energy exploration—the effects of various energy sources on the environment by modeling and discussing each source
2nd microteaching activities	1. Acids and bases—observing acids and bases by using indicators and listing daily life examples of acidic and basic substances	1. Acids and bases—observing acids and bases by using litmus paper and discussing acid rains and their effect on the environment
	2. Inclined plane—experimenting and observing the relationships between the variables of velocity, mass, length, and angle and constructing a simple machine.	2. Energy conservation—experimenting and observing the variables affecting the toy car and discussing the transformation of energy.
	3. Mixtures—observing homogenous and heterogeneous mixtures and predicting and observing how to separate them	3. Separating mixtures—predicting and observing different types of separation methods of different mixtures
	4. Electric circuits—predicting and observing the brightness of bulb in series and parallel connection of circuits and discussing the daily usage of series and parallel connection of circuits from real world	4. Absorption of light—observing the absorption of light by different colors of objects and discussing the usage of solar panels in different countries
	5. Solid pressure—experimenting and observing the effect of surface area and mass on solid pressure and discussion of solid pressure by giving daily life examples	5. Liquid pressure—experimenting and observing the factors affecting the liquid pressure and discussion of liquid pressure by giving daily life examples
	6. Solubility rate—experimenting and observing the factors influencing the solubility rate, constructing tables and graphs, peer-review of experiment results	6. Dissolution rate—experimenting and observing the factors influencing the rate of dissolving and testing hypothesis by identifying dependent, independent, and controlled variables constructing tables, peer-review of experiment results

The 2nd microteachings included the activities in which PSSTs groups made their own choice of a science topic in K-8 level. For these sessions, PSSTs were asked to include relevant components of SPs and SI into their instruction again. In addition, the 2nd microteaching sessions involved the discussions highly emphasized on scientific questions, the manipulative and non-manipulative methods that were followed, and the aspect of evaluating and communicating information employed in each activity. For instance, the instructor asked the presenters the following questions:

What were the questions and/or hypotheses that led to scientific investigation?

- Was there an inquiry process in their teaching?
- What were the steps followed by and what were the SPs used?
- Would the procedures differ from other microteaching activities and the activities conducted during class hours?
- Were there different procedures that may influence the results?
- Were the conclusions drawn from the collected data, namely as primary evidence, or gathered from other sources as secondary evidence?
- What counts as data or evidence within their activities and which of them were counted as secondary evidence?
- How do you think students would evaluate and communicate information through this activity?

During these discussions, the instructor gave feedback to correct the misunderstandings and misconceptions about SI and SPs in their activities.

3.3 Data Collection Tools

Two main data sources including Views about Scientific Inquiry (VASI) and its exploratory semi-structured interviews and concept maps were used in the study. Before the administration of pre- and post-test of VASI, 22 participants (10 in section 1; 12 in section 2) volunteered to draw concept maps of SPs. They constructed their concept maps in groups of 3 or 4.

3.3.1 Views About Scientific Inquiry (VASI) Instrument and Interviews

Views about Scientific Inquiry, also known as the VASI questionnaire developed by Lederman et al. (2014), was used as an instrument to track the changes of each participants' views about SI. The instrument consists of 7 open-ended questions of which 5 are subquestions (such as *1a*, *1b*, *1c*, *3a*, and *3b*). The questions correspond to one or two aspects of SI. The correspondence of items is given in Table 4. VASI questionnaires were administered to the participants prior to the study as pre-test and at the end of the study as post-test.

The participants filled the instrument in English. In addition to the post-test VASI administrations, 10 of the participants (25.6%) were interviewed individually, which is above the recommended rate 20% (Lederman et al., 2014). The aim of the interviews was to probe into their understanding of each aspect of inquiry and allow them to revisit critical or unclear explanations in items. The selected PSSTs to interview with were determined based on their written post-test VASI responses. During the interviews, the authors posed additional probing questions to elaborate their responses, such as "What do you mean?",

Table 4. Aspects of SI and corresponding items (Lederman et al., 2014, p.76)

Aspects of scientific inquiry		VASI item #
SI 1	Scientific investigations all begin with a question and do not necessarily test a hypothesis	1a, 1b, 2
SI 2	There is no single set or sequence of steps followed in all investigations	1b, 1c
SI 3	Inquiry procedures are guided by the question asked	5
SI 4	All scientists performing the same procedures may not get the same results	3a
SI 5	Inquiry procedures can influence results	3b
SI 6	Research conclusions must be consistent with the data collected	6
SI 7	Scientific data are not the same as scientific evidence	4
SI 8	Explanations are developed from a combination of collected data and what is already known	7

"Could you elaborate your response to this question?", or "Would you give an example?" along with VASI items. The average interview duration was about 25 min.

3.3.2 Concept Maps

The use of concept maps as assessment tools in science education literature has been extensively studied and there is a consensus on the effectiveness of these tools that demonstrates the knowledge structures and understanding of learners at various grade levels including undergraduate students. As concept maps are sensitive tools to indicate students' knowledge and distortions in their understanding, it is beneficial to use concept mapping as an assessment tool to detect students' misunderstandings (Surber and Smith, 1981). Specifically, concept maps serve as visual depictions of the minds-on processes as well as to foster abstract conceptualization in experiential learning theory (Pressley & McCormick 1995; Young, 2002). Furthermore, the open-ended nature of concept maps allows educators to assess students' idiosyncratic knowledge structures (McClure et al., 1999). Hence, educators can evaluate the change in students' understanding of a topic before and after an instruction via pre- and post-concept maps (Ekinci & Şen, 2020). Saribas & Ceyhan (2015) examined PSSTs' understanding of SPs deeply in an autoethnographic study through concept maps which are considered a beneficial tool to depict learners' understanding of SPs. Therefore, the authors decided to utilize concept maps as data sources along with the VASI. Twenty-two of the participants (10 in section 1 and 12 in section 2) volunteered to construct concept maps. They created concept maps of SPs in groups of 3 or 4 both before and after the intervention. Six participant groups (3 in section 1 and 3 in section 2) completed pre- and post-concept maps in total. The aim of using concept maps as a data source is to let the participants work in groups and look deeper into these groups' conception of SPs. Thus, this data source is an additional and supportive tool for the main instrument, namely VASI, rather than a major tool. This way of using concept maps did not entail the participation of the whole participants of the study. The group assessment of students' understanding of SPs was also used in previous studies (Saribas & Ceyhan, 2015; Saribas & Akdemir, 2020). The volunteer groups' concept maps reflect their collective understanding of SPs. Saribas & Akdemir (2020) argued that asking participants to draw concept maps collaboratively and brainstorm ideas in groups and in the whole class is an effective way to understand SPs systematically and holistically. Therefore, after groups drew their concept maps, they presented their maps to the rest of the class and discussed their drawings with the whole class.

3.4 Data analysis

3.4.1 Views About Scientific Inquiry (VASI) Instrument and Interviews

Both the administration of the VASI and the categorization of the responses were conducted conjointly by the authors. The first author, who is an experienced VASI scorer with scored more than 800 K-12 students' questionnaires, was trained for scoring the VASI questionnaire by Lederman and his colleagues at a workshop in 2015. The authors read and evaluated VASI responses of the participants, then categorized as *informed*, *mixed*, and *naïve* regarding the procedure provided by Lederman et al. (2014). The interrater agreement of the authors varied in pre- and post-tests of VASI instruments is 80% and 92.5% respectively. If the participant provided a response consistent across the entire questionnaire that is wholly congruent with the target response for a given aspect of SI, they were labeled as *informed*. For instance, an *informed* example for SI 1 aspect should include a response as follows:

> 1a: "Yes because some observation was done. He doesn't conduct an experiment on the birds, he just observes."
> 1b: "No because there is an observation. And referring to what we have done in our lab classes with acid-bases, we have just made observations. Same here, he only makes observations on birds."
> 2: "Scientific investigations begin with identifying a research question or problem. So yes. Referring to our lab classes, we always started with a question. That is a little bit different from research, but it made me think about our lab classes. It is like we are leading children to do something, something like inquiry. Then I realized, after our lab classes, we do not let children ask many questions. Yet, it should start with a question."
> If the response was either only partially explicated or not consistent with the targeted response, they were labeled as *mixed*. For instance, *mixed* view responses for SI 4 and SI 5 should include similar responses to the given below:
> 3a: "No because the same questions can have different endings after investigations."
> 3b: "Yes, they can. Different points of views, different methodologies may lead to the same thing. I mean, one could have a perspective, the other person could have a different perspective."

If the student provides no evidence of congruence with accepted views of the specific aspect of SI under examination, was scored as *naïve*, as given below:

> "Data and evidence should be the same. Then the hypothesis cannot be true. In such a case, there should be some mistake."

Apart from the coding rubric recommended by Lederman et al. (2014), the authors generated their own assessment rubric aligned with the original format based on the responses gathered from the PSSTs. The generated rubric is presented as an appendix to the manuscript (see Appendix Table 8). After the coding procedure was completed, descriptive analysis was conducted via the SPSS 25.0 quantitative data analyzing program. Although only this analysis is advised to be used for the VASI instrument by Lederman et al. (2014)

for profound analysis, the researchers of the current study used basic inferential statistics, non-parametric tests to compare the significance of interventions on results. Thus, a non-parametric Wilcoxon signed-rank test was performed, since the data was coded nominal and distribution of the group was not found to be normal. The authors also transcribed the interviewees' responses as complementary to their written VASI responses. Each interview was analyzed verbatim independently by looking at the adequate rubrics mentioned above and quoted the interviewees' explanations for each category to clarify their understanding.

3.4.2 Concept Maps

Each author independently analyzed the participant groups' concept maps of SPs before and after the intervention. The authors constructed themes of SPs based on the concepts the participant groups included in their drawings. For example, group 3 in section 1 (Appendix 2) included the components of model, variables, experiment, and general scientific inference in their pre-concept maps. The first author independently coded these responses as modeling, others, observation/experimentation, and inferring/explanation, respectively, while the second author did not include "others" in her coding because she considered the term "variables" in the experimentation coding. The first author convinced her to include it in the "others" category because this drawing indicates a misunderstanding that variables are components of the experimental process rather than a practice. After reaching the consensus on the themes in such a way, they independently recorded the participant groups' concepts by calculating the occurrence frequencies of each theme in the groups' drawings. Percentage agreement between the researchers' coding was calculated based on the following formula: the percentage agreement = (agreement in coding/total coding) × 100. The percentage agreement in coding of pre- and post-concept maps was 90% and 95%, respectively. The authors discussed their conflicts until they reached full consensus on the themes and coding. The authors also evaluated whether the participant groups' representation indicated a holistic and coherent understanding of SPs or not.

4 Findings

4.1 Pre-service Science Teachers' Understanding of Scientific Inquiry

The results of PSSTs understanding of SI across all 8 aspects are provided below with both descriptive and inferential analysis of VASI results. Descriptive test results based on the percentages of the PSSTs' scores are provided in Table 5, whereas the Wilcoxon signed-rank test results are provided as divided to significant and non-significant results in Table 6.

In this section, the findings are provided as changes on specific SI aspects in detail.

Scientific Investigations All Begin with a Question and Do Not Necessarily Test a Hypothesis (SI 1) Understandings about the SI 1 aspect of PSSTs were mostly in the categories of *mixed* (n=22, 56.4%) and *naïve* (n=12, 30.8%) at the beginning of the study. However, at the end of the study, the numbers of *naïve*, *mixed*, and *informed views* were 7 (17.9%), 20 (51.3%), and 12 (30.8%), respectively. The Wilcoxon signed-rank test results were used to test the significance of the changes in percentages. The results in the 95% confidence interval revealed statistical significance (see Table 6, T = 61.50, p=0.047, z = −1.985, r=−0.31). It can be inferred from this result that the PSSTs benefited from the

Table 5. Findings of pre- and post-administration of VASI questionnaire (N=39)

Aspect of scientific inquiry	Category	Pre-test (N=39)		Post-test (N=39)	
		f	%	*f*	%
Scientific investigations all begin with a question and do not necessarily test a hypothesis (SI 1)	*Naïve*	12	30.8	7	17.9
	Mixed	22	56.4	20	51.3
	Informed	5	12.8	12	30.8
There is no single set or sequence of steps followed in all investigations (SI 2)	*Naïve*	19	48.7	7	17.9
	Mixed	16	41	20	51.3
	Informed	4	10.3	12	30.8
Inquiry procedures are guided by the question asked (SI 3)	*Naïve*	6	15.4	3	7.70
	Mixed	11	28.2	15	38.5
	Informed	22	56.4	21	53.8
All scientists performing the same procedures may not get the same results (SI 4)	*Naïve*	7	17.9	4	10.3
	Mixed	18	46.2	24	61.5
	Informed	14	35.9	11	28.2
Inquiry procedures can influence results (SI 5)	*Naïve*	16	41	12	30.8
	Mixed	14	35.9	21	53.8
	Informed	9	23.1	6	15.4
Research conclusions must be consistent with the data collected (SI 6)	*Naïve*	2	5.1	1	2.6
	Mixed	19	48.7	27	69.2
	Informed	18	46.2	11	28.2
Scientific data are not the same as scientific evidence (SI 7)	*Naïve*	7	17.9	4	10.3
	Mixed	17	43.6	21	53.8
	Informed	15	38.5	14	35.9
Explanations are developed from a combination of collected data and what is already known (SI 8)	*Naïve*	19	48.7	3	7.7
	Mixed	14	35.9	24	61.5
	Informed	6	15.4	12	30.8

Table 6. VASI Wilcoxon signed-rank test results

Aspect of scientific inquiry		*N*	Mean rank	Sum of ranks	Z	P (sig.)	Effect size $(r = Z / \sqrt{N})$
SI 1 pre-test/SI 1 post-test	Negative ranks	6	10.25	61.50	−1.985	**.047**	−0.31
	Positive ranks	15	11.30	169.50			
	Ties	18					
	Total	39					
SI 2 pre-test/SI 2 post-test	Negative ranks	5	13.10	65.50	−2.962	**.003**	−0.47
	Positive ranks	21	13.60	285.50			
	Ties	13					
	Total	39					
SI 3 pre-test/SI 3 post-test	Negative ranks	10	9.50	95.00	−.398	.691	−0.06
	Positive ranks	10	11.50	115.00			
	Ties	19					
	Total	39					
SI 4 pre-test/SI 4 post-test	Negative ranks	9	9.50	85.50	.000	1.000	0.00
	Positive ranks	9	9.50	85.50			
	Ties	21					
	Total	39					
SI 5 pre-test/SI 5 post-test	Negative ranks	11	11.00	121.00	−.186	.852	−0.02
	Positive ranks	11	12.00	132.00			
	Ties	17					
	Total	39					
SI 6 pre-test/SI 6 post-test	Negative ranks	11	9.27	102.00	−1.342	.180	−0.21
	Positive ranks	6	8.50	51.00			
	Ties	22					
	Total	39					
SI 7 pre-test/SI 7 post-test	Negative ranks	14	14.88	59.50	−.368	.713	−0.05
	Positive ranks	13	13.85	318.50			
	Ties	12					
	Total	39					
SI 8 pre-test/SI 8 post-test	Negative ranks	4	14.88	59.50	−3.334	**.001**	−0.53
	Positive ranks	23	13.85	318.50			
	Ties	12					
	Total	39					

methods implemented in this course in terms of SI 1. The hands-on and minds-on activities implemented in this study seem to have had a positive impact in achieving this improvement. This significant change is also evident in the following quotations. The following and subsequent quotations include examples of PSSTs' explanations in VASI in pre-test while post-test quotations are gathered both from their explanations in the post-test of VASI and responses during the interview. These verbatim quotations were specifically selected from the pool of responses to reveal the changes in participants' views.

> [PSST #2, Pre-test]: "*1a*: No, the data he collected must be shown as a scientific

> document including essay, thesis etc. The data must be collected from many species, and a high number of species. The thesis must be published in a scientific book, or it must be presented in a specific meeting. *1b*: No, there is only observation. *2*: No, it can be inductive." *(naïve)*
> [PSST #2, Post-test]: "*1a*: No, because he needs to write an academic paper and this paper needs to be published in one of the "accepted" scientific journals or in the scientific meetings. *1b*: I do not think that this is an experiment. For a process to be an experiment, it needs to have dependent, independent, and controlled groups so that the conductor can observe. *2*: No, since one can make observations then may ask a question that leads to scientific papers". *(mixed)*

This participant seemed to have been confused about the data and publishing scientific papers before the intervention. She seemed to have begun thinking about the meaning of the experiment and what counts as scientific after the intervention.

> [PSST #15, Pre-test]: "*1a*: Yes, because he observes it and then he has an idea. *1b*: Yes because he investigated this event for different types of birds. *2*: No, students cannot know everything about that investigation. So, their questions are not scientific due to having no idea." *(naïve)*
> [PSST #15, Post-test]: "*1a*: Yes, because some observation was done. He does not conduct an experiment on the birds, he just observes. *1b*: No because there is an observation. And referring to the activities we have done in our lab classes with acid-bases, we have just made observations. Same here, he only makes observations on birds. *2*: Scientific investigations begin with a research question or problem. So yes. Referring to our lab classes, we always started with a question. That is a little bit different from research, but it made me think of our lab classes. It is like we are leading children to do something, something like inquiry. Then I realized, after our lab classes, we do not let children ask many questions. So, it should start with a question." *(informed).*

This participant's quotations also reveal an improvement of her understanding of scientific investigations and the role of questions during these investigations. After the interventions, she seemed to have eliminated her confusion about scientific questions and intervention.

There Is No Single Set or Sequence of Steps Followed in All Investigations (SI 2) Understandings about SI 2 aspect of PSSTs were mostly scattered on *naive* category (n=19, 48.7%) and *mixed* category (n=16, 41%) at the beginning. However, at the end of the study, the numbers of *naïve*, *mixed*, and *informed* views were 7 (17.9%), 20 (51.3%), and 12 (30.8%), respectively. Wilcoxon signed-rank test results revealed a statistically significant increase ($T = 65.50$, p=0.003, $z = -2.962$, r=−0.47). This finding shows that PSSTs improved their understanding of scientific methods throughout the intervention. The following exemplary quotations are provided as evidence for the participants' improvement in the SI 2 category. PSST #4's views changed *naïve* category to *mixed* category, whereas PSST #34's *naïve* views were transformed to *informed* categories throughout the inquiry-based interventions.

> [PSST #4, Pre-test]: "1b: Yes, because he/she used the scientific steps and found the proof of his/her theory. 1c: Yes. For example, investigation of the lifting force

> by Archimedes just by observation." *(naïve)*
> [PSST #4, Post-test]: "1b: No, because experiment needs some variables which are dependent, independent and controlled. 1c: Yes, for example investigations can also include some experiments." *(mixed).*

This participant seemed to have misunderstandings about scientific investigations in history as well as the difference between evidence and proof before the treatment. However, she was clearly able to define the experiment after the treatment.

> [PSST #34, Pre-test]: "1b: Yes, it is an experiment. He wants to do an experiment about birds' beaks, depending on their eating shapes. 1c: No, I think making an experiment is one way to conduct a scientific investigation. Because experiments are based on science." *(naïve)*
> [PSST #34, Post-test]: "1b: To be an experiment, dependent, independent and variable control groups must be. Therefore, this person's investigation is not an experiment. 1c: Yes, there could be more than one method to make a conclusion. Observation, looking at beak shapes and food types they eat. Then it might be an experiment while manipulating the types of food they eat." *(informed)*

As seen from the quoted explanation, this PSST improved her understanding of experiment, observation, and scientific investigation and experiment is not the only route to science throughout the course.

Inquiry Procedures Are Guided by the Question Asked (SI 3) In contrast to findings of SI 1, SI 2, and SI 8, most of the PSSTs held *informed* (n= 22, 56.4%) while the rest of them held *mixed* views (n=11, 28.2%) prior to interventions within this aspect. After the interventions, 3 (7.7%) PSSTs held *naïve* views, while the number of the PSSTs who held *mixed* and *informed* views were recorded as 15 (38.5%) and 21 (53.8%), respectively. However, according to the Wilcoxon test results, these changes were not found statistically significant ($T = 95.00$, p=0.691, $z = -0.398$, r=−0.06). It can be inferred from this result that more than half of the PSSTs seemed to have appreciated the guidance role of the questions in an inquiry even before the intervention. However, the 4-phase method did not have a significant impact in terms of promoting their understanding of this aspect. Exemplary quotations of one PSST are provided below.

> [PSST #38, Pre-test]: "Team B is better because they use one type of brand on different road surfaces. They must change the types of road surfaces to determine the tire problem." *(mixed)*
> [PSST #38, Post-test]: "Team A is better. Because here there are only brand types to be investigated. Different brands… It seems B is wrong, and A is correct. Variables change." *(mixed)*

All Scientists Performing the Same Procedures May Not Get the Same Results (SI 4) Another distinctive case of PSSTs views was occurred on the SI 4 aspect, whereas the big majority of PSSTs were scattered among *mixed* category (n=18, 46.2%) and *informed* category (n=15, 35.9%) at the beginning. The post-test results showed similar trends to pre-tests of this aspect, whereas few PSSTs held naïve (n=4, 10.3%) and *informed* (n=11, 28.2%) views while more than half of them held (n=24, 61.5%) *mixed* views. According to the Wilcoxon results, these changes were not found statistically significant ($T = 85.50$, $p=1.000$, $z = 0.000$, $r=-0.00$). Yet, the following exemplary quotation is noteworthy.

> [PSST #7, Pre-test]: "3a: No, because scientific questions can be too comprehensive and different results can occur with the same procedures. Also, observations and collecting data can be different because of ways of collecting or what people observe." *(informed)*
> [PSST #7, Post-test]: "3a: No, as far as I can remember from the physics experiments that we carried out at our lab classes, information about the topic, ways of collecting data, use of different sources-books-articles, personal mistakes, differences in the lab settings and other factors could be influential on the results. Yes, they might be using the same materials, same procedure and these factors could result in differentiation on the results. They can gather different evidence because of using different resources before they conduct their experiments. Reading different articles, books, and other sources about the procedures to be followed. Or even maybe the environment. For example, an ice-cube that should not be melted according to the procedure, could have been melted because of the weather conditions and this person could not use the ice-cube, so the results would be different. And personal differences, background etc." *(informed)*

Prior to interventions, PSST #7 already had *informed* views about this aspect of SI. It can be interpreted from her pre-test responses that she had more decontextualized *informed* views. However, as it can be observed in her responses by referring to the activities that were carried out during the course of these interventions, her views changed after the interventions towards more contextualized *informed* views. Consequently, it can be concluded that the interventions helped this PSST to contextualize her adequate views on this specific aspect of SI. Thus, even though in some cases the change was not found statistically significant, researchers should bear in mind that in-depth analysis of the responses is also essential to reveal the impact of the intervention.

Inquiry Procedures Can Influence Results (SI 5) PSSTs were mostly scattered on *naive* ($n=16$, 41%) and *mixed* category ($n=14$, 35.9%). However, at the end, 12 (30.8%) PSSTs held *naïve* views, while the numbers of PSSTs who held *mixed informed* views were $n=21$ (53.8%) and $n=6$ (15.4%), respectively. The Wilcoxon signed-rank test results did not reveal a statistical significance ($T = 121.00$, $p=0.852$, $z = -0.186$, $r=-0.02$).

Research Conclusions Must Be Consistent with the Data Collected (SI 6) Similar to SI 4 case results of PSSTs, the big majority of PSSTs were found either on *mixed* ($n=19$, 48.7%) or on *informed* ($n=18$, 46.2%) category prior to interventions. However, it is again interesting to note that the numbers of *mixed* and *informed* categories were recorded as $n=27$ (69.2%) and $n=11$ (28.2%), respectively, after the intervention. Besides, the number of responses in the *naïve* category was obtained as 1 (2.6%). The Wilcoxon tests showed that there was not a significant change ($T = 102.00$, $p=0.180$, $z =-1.342$, $r=-0.21$) in this aspect throughout the intervention.

Scientific Data Are Not the Same as Scientific Evidence (SI 7) The PSSTs were mostly scattered on *mixed* ($n=17$, 43.6%) and *informed* categories ($n=15$, 38.5%) at the beginning of the study. However, according to post-tests, the number of PSSTs who held *naïve* views was 3 (7.7%). Nearly half of the PSSTs held *mixed* (*n*= 24, 61.5%) views while *n*=14 (35.9%) PSSTs held *informed* views. Wilcoxon signed-rank test results revealed that there was not a significant difference in this aspect ($T = 59.50$, p=0.713, $z = -0.368$, r=−0.05).

Explanations Are Developed from a Combination of Collected Data and What Is Already Known (SI 8) It is interesting to note that the PSSTs' responses to this aspect were scattered mostly around *naive* category (*n*=19, 48.7%) at the beginning of the course while in other aspects, PSSTs had mostly mixed views before the intervention. However, at the end of the intervention, the number of PSSTs who held *naïve* views was 3 (7.7%) and *informed* views was *n*=12 (30.8%). The Wilcoxon signed-rank test results revealed a significant difference ($T = 59.50$, p=0.001, z= −3.334, r=−0.53). After treatment, more than half of the participants had *mixed* (*n*=24, 61.5%) views in this aspect. The following exemplary quotations are presented below.

> [PSST #15, Pre-test]: "7a: Dinosaur Fig. 1 in the VASI instrument (see Appendix 3), physical appearance is better than Fig. 2 (see Appendix 3). The small legs of Fig. 2 are ahead. 7b: the correlation between bonds and strength." *(naïve)*
> [PSST #15, Post-test]: "7a: I think the real posture of this is in the dinosaur Fig. 2 in the VASI instrument, the back legs are stronger. They might decide while looking at muscle mass, differences, or size. So, the legs are stronger, could be stronger, that's why that might be positioned in the way like Fig. 2. 7b: structure, process. They might also use genetic information; they may conduct research or maybe experiment…" *(mixed)*

Before the intervention, this participant made an irrelevant explanation to evaluate the structure of the bones. However, after the treatment, she discussed the structure and the posture and began to elaborate the information that scientists use more coherently and accurately. Another change on the views was observed in the exemplary quotation of PSST #7, which is given below. As she had ideas and knowledge about natural selection and the morphological structure of the bones prior to interventions, it is assumed that she also improved her views and explanations by critically assessing and questioning the changed structures and other related factors that were absent in her prior views, thanks to the interventions specifically focusing on these matters.

> [PSST #7, Pre-test]: "7a: Dinosaur Fig. 2 in the VASI instrument (see Appendix 3), because it has stronger back legs that it can stand in balance. It can collect some things more easily because it can use its arms not to stand but to eat. Also, natural selection chooses the strong ones and Fig. 2 is stronger and it's easy for the one in Fig. 2 to survive. It can stand in a balanced way on its back legs and collect its food with its hands. Figure 1 must stand with its hands so it can feed itself. It's hard for it to eat its food or fight other dinosaurs. Its' survival chance is less than Fig. 2. 7b: The information about their morphological development can help scientists to conclude with this statement". *(mixed)*
> [PSST #7, Post-test]: "7a: Dinosaur Fig. 2 in the VASI instrument (see Appendix 3), because its legs are strong. It can stand still and can use its hands to catch its prey. Figure 1 uses its front legs to stand but it cannot catch its food efficiently. The dinosaur Fig. 1 position structure how could legs be functional? In terms of body control Fig. 2 is more adequately evolved and efficient. 7b: Scientists could observe these things while looking at functions, arrangement, morphological features of the bones

and they can investigate physiologically. Also, the formation of bones, information about morphology." *(informed)*

It is evident from the VASI and interview results that PSSTs' explanations were scattered on mixed views in almost all the aspects both before and after the intervention. However, the treatment implemented in this study had some gains in PSSTs' understanding of inquiry. They seemed to have benefited from the intervention in terms of understanding that all scientific investigations begin with a question, but it is not always necessary to test a hypothesis and there is no single set of steps followed in all scientific investigations and explanations are derived from data. However, the 4-phase method implemented in this study seems to have drawbacks in terms of facilitating the understanding that inquiry procedures guided by the questions, the same procedures in a scientific investigation may not lead the same results, inquiry procedures can influence the results, research conclusions must be consistent with the collected data, and data and evidence are not the same. In sum, the 4-phase method seems to have promoted PSSTs' understanding of the role of SPs and plurality of methodological rules; however, it has been insufficient to facilitate the evaluation of the interrelatedness of questioning, inquiry, and drawing conclusions in a scientific investigation.

4.2 Pre-service Science Teachers' Understanding of Scientific Practices

After analyzing PSSTs' understanding of SIs, the authors decided to probe into their understanding of SP aspects. To achieve this purpose, the authors analyzed and coded their concept maps that they constructed in groups. They analyzed 6 concept maps for SPs. Table 7 illustrates the components that each group listed in their pre- and post-concept maps of SPs.

As shown in Table 7, the participant groups' drawings reflected dispersed and disordered conceptions of SPs before the treatment. They also listed some other irrelevant concepts such as laboratory and scientific literacy in their pre-concept maps. However, after the intervention, PSSTs seemed to have a more thorough understanding of SPs. Besides, 2 out of 6 groups drew a linear representation and 1 out of 6 groups drew contextualized concept maps of SPs, while 3 out of 6 groups drew a branched representation of SPs before intervention. At the end of the study, 5 out of 6 groups created their concept maps as a branched representation while one of the groups constructed a circular representation of SPs. Figure 2 shows Group 2's pre- and post-concept maps, respectively. Other maps of PSSTs have been provided as appendices (please Appendix 2).

As revealed in Fig. 2 in the pre-concept map, this group had a misconception that SPs include scientific investigation, rather than the opposite. This group had an interesting thought that questioning leads to SPs and/or observations, then the former leads to scientific experiments and/or experiments, while the latter leads to observations and hypotheses, respectively. Moreover, these participants listed other components in an irrelevant manner. It is also noteworthy to emphasize that they listed these components in a sequence following an order.

In their post-concept maps, they included questions and/or problems that emerged from the real world as a component of SPs. It is evident from this result that they became aware of the necessity of scientific questions in scientific investigations. The rest of the participants also included questions and/or problems that emerged from the real world in their post-concept maps, while none of them included the term "real world" in their first drawings. This result is consistent with the results of the VASI instrument that indicated the participants' understanding of this issue (SI 1). Furthermore, as illustrated in the post-concept map, they seemed to

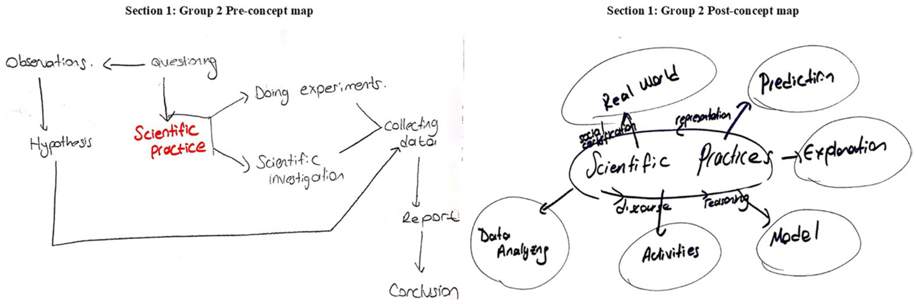
Table 7 PSSTs' pre- and post-concept maps of scientific practices

Scientific practices	Pre-concept maps	Post-concept maps
Asking questions	4	2
Modeling	0	6
Argumentation/discourse	1	6
Observation/experimentation	4	6
Data	3	6
Prediction	0	6
Inferring/explanation	1	6
Hypothesis	3	0
Real world	0	6
Social certification	0	2
Reasoning	0	3
Representation	0	4
Others	5	0

have had a more holistic and coherent understanding of SPs at the end. Their linear drawing of pre-conceptions and branched representation of post-conceptions of SPs also provide evidence for this change in their understanding. This result is also consistent with VASI findings that revealed the improvement in PSSTs' understanding that there is no single set of procedures in scientific investigations (SI 2). Their post-concept map is also significant as it includes the social aspects of SPs, such as discourse, reasoning, representation, and social certification, around a circle with arrows that provide evidence for the improvement of their understanding of SPs, which is not explicitly mentioned in the VASI list.

5 Conclusion and Discussions

The study presented here explored PSSTs' understanding of SI by using the VASI instrument and analyzing the participant groups' concept maps of SPs before and after implementing a 4-phase of SI and SP instruction in a laboratory application course. The findings of this study indicated gains in PSSTs' understandings of the importance of questions in a



Section 1: Group 2 Pre-concept map

Section 1: Group 2 Post-concept map

Fig. 2. Group 2's pre- and post-concept maps of scientific practices

scientific investigation, the plurality of methodological rules, and the significance of data to make scientific explanations.

5.1 Discussion of VASI Results

Literature shows that the knowledge about SI and SPs are not translated into instructional practices easily (Bjønness & Knain, 2018; Lederman & Lederman, 2019), which requires understanding of these components during the years of teacher training by the help of explicit inquiry-based instructional activities and engaging in pedagogical inquiry activities (Cigdemoglu and Koseoglu, 2020; Choi et al., 2019). Another study that is consistent with our findings, conducted by Mesci, Çavuş-Güngören, and Yesildag-Hasancebi (2019), found that PSSTs' views *that all scientific investigations begin with a question* (SI 1), and *there is no single methodology* (SI 2) improved, whereas their understanding that *inquiry procedures are guided by the question* (SI3), *same procedures may not get the same results* (SI 4), *inquiry procedures influence the results* (SI 5), and *conclusions are drawn from data* (SI 6) were not changed significantly throughout a science laboratory course including 5E-based lesson planning. On the other hand, the results of the current study contradict with their findings about understanding *the difference between data and evidence* (SI 7). They reported the positive impact of the 5E-based method in terms of understanding of this aspect. Contrary to the results of the current study, they noted that their method did not influence the understanding that *explanations are developed from collected data* (SI 8), while the 4-phase method employed in this study seems to have a positive impact on PSSTs' understanding of this aspect. This difference among two studies might have originated from the different methodologies used in each of them. Depending on these results, it seems necessary to integrate elaborative discussions and reflections on the *inquiry procedures are guided by the question* (SI 3), *same procedures may not get the same results* (SI 4), *inquiry procedures influence the results* (SI 5), *conclusions are drawn from data* (SI 6), and *the difference between data and evidence* (SI 7) into laboratory application course. Mesci et al. (2019) suggested to teach SI aspects in an explicit and reflective manner and encourage PSSTs to use these concepts in their own teaching. However, depending on the findings of the current study, more deliberate attempts addressing each aspect of SI seem necessary. Exploring the impact of both explicit teaching of these aspects both during introducing theoretical information of each SI aspect and their discussion after each microteaching activity in different science teaching courses may bring new insights to this issue. Overcoming the limitations of this study, further research implemented in longer durations, including longitudinal studies, may also be helpful in this respect.

5.2 Discussion of Concept Map Results

Pre- and post-concept maps of the participant groups indicated a similar result. PSSTs included more relevant components of SPs including both the epistemic aspects, such as asking questions about and modeling and representation of real-world phenomena, predicting and collecting data, observation, and experimentation, and the social aspects, such as representation, argumentation, discourse, and social certification, after the intervention comparing to their pre-concept maps. Thus, their concept maps revealed a more coherent and holistic understanding of SPs after intervention. It is vital to highlight that these improvements were gained as the result of a variety of hands-on/minds-on activities employed in microteaching activities that require PSSTs incorporate the aspects to design their investigations as well as discussion and elaboration of the concepts of SI and SPs.

Contrary to their pre-concept maps, PSSTs' inclusion of social aspects of science including argumentation, discourse, reasoning, representation, and social certification in their post-concept maps is also remarkable. On the one hand, this result is consistent with the results of a study conducted by Jimenez-Liso et al. (2019) who concluded that a teaching sequence during PSSTs' engagement in inquiry-based activities, implementation of these activities in their own teaching, and reflecting on and evaluating their teaching had positive impacts on their understanding of SPs as well as their content knowledge. On the other hand, although the authors assigned one group in each section to design a critical reading activity in their microteaching presentations, none of the participants in each section selected such a kind of activity to allow their students to critically evaluate and communicate information about scientific issues. Osborne (2014) argued that science education must provide students opportunities to experience and practice a broad range of discursive and literacy activities. Integrating critical evaluation of scientific issues into further implementations of SI and SPs may broaden our perspective for future science teacher education programs considering critical evaluation and communicating information.

5.3 Discussion of Implementation and Microteaching Presentations

The 4-phase method implemented in this study has another shortcoming with regard to understanding of the inquiry procedures (SI 3, SI 4, and SI 5) and research conclusions as well as the difference between data and evidence (SI 6 and SI 7). Morrison et al. (2020) recommended to include many experiences for PSSTs involving problem-solving and inquiry learning emphasizing the twenty-first century competencies such as critical thinking, communication, collaboration, and time management in teacher preparation programs. The experiences that PSSTs had in the implementation of the present study are an attempt to achieve this purpose. Further implications of inquiry-based teaching activities enriched with critical evaluation of information including discursive as well as reading and writing activities may bring new light to understanding inquiry in science education literature.

Another interesting finding of this study is that none of the participant groups designed their 2nd microteaching activities in a decontextualized manner by choosing traditional science concepts and skills, although the instructor assigned them highly contextualized activities for their 1st microteaching presentations and reports. This situation may have arisen from their familiarity with traditional school science that they were used to until now. Erduran and Dagher (2014) critique the traditional school sciences which mainly focus on products of science in a decontextualized way, and in this case, their criticism might be the justification for the PSSTs' activity designs and preferences for the 2nd microteaching. Kruse et al. (2021) also argued that exposing students to concrete decontextualized and moderately contextualized NOS instruction allows the activities to fit neatly into students' existing schema about science and scientists' work, while highly contextualized and abstract activities do not. Allchin et al. (2014) argued that decontextualized science lessons may not be helpful to understand NOS and sufficient to cultivate scientific literacy. Therefore, challenging students to understand highly contextualized activities requires highly skilled teachers to deepen students' understanding of NOS (Kruse et al., 2021). This study is an attempt to explore PSSTs' science activity designs. Further studies facilitating PSSTs' ability to design highly contextualized science activities may bring deeper insight into teaching science. From this background, teacher education programs should include learning outcomes to design authentic and highly contextualized science activities that enable students to understand the relationship between different forms of scientific knowledge as well as SPs.

6 Limitations

Despite the benefits of the implementation of this study, it is important to point out some limitations. For instance, the volunteer participation of nearly half of the participants in drawing concept maps obstructs the direct comparison between the results of VASI and concept maps. Therefore, concept maps were used just to have a deeper insight into PSSTs' understanding of SPs rather than comparing them to their understanding of SI. Further implications of VASI and concept maps with the participation of the whole PSSTs may bring clearer insights into their understanding of SI and SPs.

This study presented here was conducted prior to COVID-19 pandemic. Considering the possibility of online and hybrid teaching in science education courses, it seems necessary to examine PSSTs' understandings of SI and SPs in online contexts. Choi and Hand (2020) found that online asynchronous discussion combined with in-class wrap-up discussion along with argument-based inquiry engaged 5th grade students in the construct and critique of claims and evidence. Further studies investigating PSSTs' understanding of SI and SPs by implementing online hands-on/minds-on and critical reasoning activities by using simulations as well as synchronous and asynchronous discussions seem to be necessary.

The current study focused only on content knowledge of SI and SPs. This is another limitation of this study. Further studies employing various programs providing PSSTs the opportunity to interact with parents and other caregivers (McLaughlin, 2015) in science teaching courses will broaden our perspectives about teaching SI and SPs and move the content knowledge about SI and SPs to pedagogical domains. Moreover, another limitation of this study is that it explored PSSTs' understanding of SI and SPs rather than their incorporation of inquiry in real teaching settings. Capps et al. (2016) argued that teachers believed that they enacted inquiry even though they were not. On the other hand, Chen and Terada (2021) stressed the need of observation protocols directly observing on student action, engagement, and learning in the classroom. Therefore, further studies that examine teachers' incorporation of SI and SPs in their classroom and the impact of their implementation on student engagement and understanding seem to be necessary. The study presented here provides answers that require further research in PSSTs' understanding of SI and SPs. Considering the COVID-19 pandemic and its impact on society and education for an extended period (Erduran, 2020) as well as the unclarity of understandings of SI and SPs, further investigations exploring students' understanding of SI and SPs in virtual labs and online educational settings are needed.

Lastly, this study mainly focused on SI and SPs in a laboratory application course. Najami et al. (2020) found that conducting open-ended experiments resulted higher number of student claims and higher level of argumentation along with discourse, compared to confirmatory experiments. On the other hand, they found no significant difference between two types of experiments regarding the level of argumentation in pre-service teachers' lab reports. The current study did not explore PSSTs' argumentation levels. Further research exploring pre-service teachers' argumentation level along with discourse and investigating the lab reports in a laboratory application course may bring new light to this issue.

Appendix 1

Table 8 VASI assessment rubric generated from the PSSTs' responses

SI aspect	Naïve	Mixed	Informed
SI 1	1a: "No, the data he collected must be shown as scientific documents such as essays, thesis, etc. the data must be collected from as many species as high amounts. The thesis must be published in a scientific book, or he must present it into a specific meeting." 1b: "No, there is only observation. 2: "No, it can be inductive."	1a: "No, because he needs to write an academic paper and this paper needs to be published in some "accepted" scientific journals or in the scientific meetings." 1b: "No, I don't think that this is an experiment. For a process to be an experiment, it needs to have dependent, independent, and controlled groups, so that the conductor can observe." 2: "No, since one can make observations then he may ask a question that leads to scientific papers".	1a: "Yes because some observation was done. He doesn't conduct an experiment on the birds, he just observes." 1b: "No because there is an observation. And referring to what we've done in our lab classes with acid-bases, we've just made observations. Same here, he only makes observations on birds." 2: "Scientific investigations begin with identifying a research question or problem. So yes. Referring to our lab classes, we always started with a question. That is a little bit different from research, but it made me think about our lab classes. It is like we are leading children to do something, something like inquiry. Then I realized, after our lab classes, we do not let children ask many questions. Yet, it should start with a question."
SI 2	1b: "Yes, because he/she used the scientific steps and found the proof of his/her theory." 1c: "Yes. For example, the investigation of lifting force by Archimedes is made just by observation."	1b: No because experiment needs some variables which are dependent, independent and controlled." 1c: "Yes, for example investigations can also include some experiments."	1b: "In order to be an experiment, there must be dependent, independent and controlled variables. This person does not change or control any variables. Therefore, this his/her investigation is not an experiment." 1c: "Yes, there could be more than one method to make a conclusion. Observation, looking at beak shapes and food types they eat. Then it might be an experiment while manipulating the types of food they eat."

Table 8 (continued)

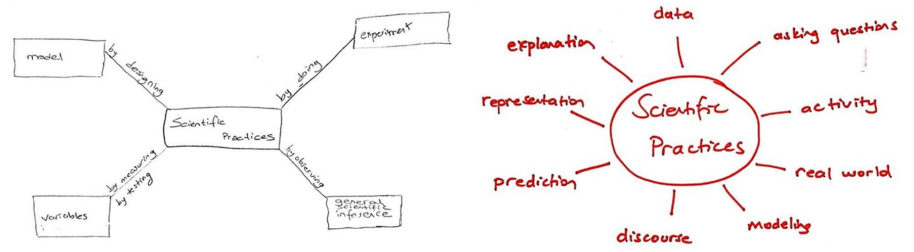
SI aspect	Naïve	Mixed	Informed
SI 3	“Team B is better because while some brands are better in one type of road surface, the other can be better in a different road. So, the more variables there are, the better the procedure is.”	“Team B is better. Because team B did this experiment on different types of road surfaces.”	“Team A because we investigate whether certain brands of tires are more likely to get a flat. Therefore, we changed the brands of tires and controlled the road surface.”
SI 4	3a: “Yes, if there is a scientific question, conclusions are the same. The method of a scientific investigation is universal.”	3a: “No, because the same questions can have different endings after investigations.”	3a: “No, because scientific questions can be too comprehensive and different results can occur with the same procedures. Besides, observations and collecting data can be different depending on different ways of collecting data or different people who observe.”
SI 5	3b: “Yes, if there is one correct answer then it’s okay to use different ways and end up with the same conclusion.”	3b: “Yes, they can. Different points of views, different methodologies may lead to the same thing. I mean, one could have a perspective, the other person could have a different perspective.”	3b: “No, but some of them may get the same results. Every scientist can look from different perspectives.”
SI 6	“Section A. Without any sunlight the plant grows 25 cm. So, we can come up with the conclusion that this plant does not like sunlight. We can also see the decrease in the growth with the increase of sunlight.”	“Section C. Because even as the minute of sunlight increased, plant growth changed disproportionally. For example, from 5 minutes to 10 minutes’ light plant growth decreased, but from 15 to 20 minutes the plant growth increased.”	“Section B. There is a big difference between 15-20 minutes of light each day. When the time of light increases, plant growth-height decreases. However, looking at the 15th and 20th minutes, there is an increase. So, I think other environmental conditions are important to test plant growth-height.”
SI 7	“Data and evidence should be the same. Then the hypothesis cannot be true. In such a case, there should be some mistake.”	“Data is known information; it is acceptable for everyone. Evidence requires proof to support an outcome.”	“Data is factual information such as numbers, percentages. Evidence is derived from data leading to a conclusion.”

Table 8 (continued)

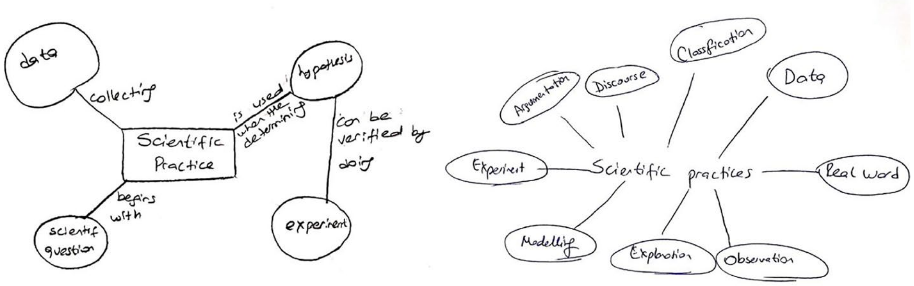
SI aspect	Naïve	Mixed	Informed
SI 8	7a: "Dinosaur Fig. 2, because its physical appearance is much better than Fig. 1." 7b: "The correlation between bonds and strong."	7a: "Because it has stronger back legs that it can stand in balance. It can collect things more easily, because it can use its arms not to stand but to eat. Also, natural selection chooses the strong ones and Dinosaur Fig. 1 is stronger and it is easier for Fig. 1 to live/survive. It can stand in a balanced way on its back legs and collect its food with its forefeet. Dinosaur Fig. 2 must stand with its forefeet so it can feed itself. It is hard for it to eat its food or fight other dinosaurs. Its' survival chance is less than Dinosaur Fig. 1." 7b: "The information about their morphological development can help scientists to conclude with this statement"	7a: "Because it's legs are strong. It can stand still and can use its forefeet to catch its prey. Dinosaur Fig. 2 uses its front legs to stand but it cannot catch its food efficiently. In Dinosaur Fig. 2 considering position and structure, how could legs be functional? In terms of body control Fig. 2 is more adequately evolved and efficient." 7b: "Scientists could observe such things while looking at functions, arrangement, morphological features of the bones and they can investigate physiologically as well as the formation of bones, information about morphology."

Appendix 2

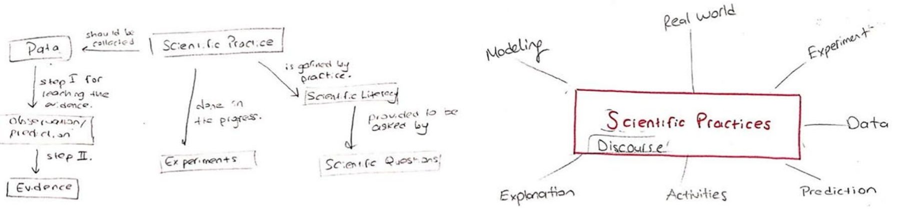
Fig. 3 Pre- and post-concept maps of PSSTs


Section 1: Group 3 Pre-concept map

Section 1: Group 3 Post-concept map


Section 2: Group 1 Pre-concept map

Section 2: Group 1 Post-concept map


Section 2: Group 2 Pre-concept map

Section 2: Group 2 Post-concept map

Appendix 3

Fig. 4 Dinosaur figures in the VASI instrument item #7. Dinosaur Fig. 1, Dinosaur Fig. 2

Dinosaur Figure 1 **Dinosaur Figure 2**

Declarations

Conflict of Interest The authors declare no competing interests.

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