ORIGINAL ARTICLE

Metacognitive Activities Performed by Pre-Service Science Teachers in Scientific Reasoning Skills Teaching with the POE Technique

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***Abstract**: The aim of this study was to investigate the pre-service teachers' metacognitive activities occurring in the teaching scientific reasoning skills with the POE technique. The participants of the research included six pre-service science teachers who were seniors in the science education department of at a university in the west of Turkey. The holistic single-case design was used as the research method in this study. The POE Activity Report, an Activity Journal and a Semi-structured Metacognition Observation Form were used to examine the participants' metacognitive activities. Inductive and comparative analysis was used to. It was found that (i) the pre-service teachers performed various monitoring activities (f = 13) and evaluating activities (f = 4) in the teaching of six different scientific reasoning skills (control of variables, proportional reasoning, correlation reasoning, probability reasoning, combinational reasoning, hypothetical-deductive reasoning) with the POE technique; (ii) there was more variety in metacognitive activities performed by pre-service teachers in teaching of control of variables (f = 15), there was least diversity in the teaching of hypothetical-deductive reasoning skill (f = 10). The results were discussed in line with the related literature, and suggestions were presented regarding the teaching of scientific reasoning skills.*

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Introduction

ONE of the main goals of science education is to develop students' scientific reasoning skills (SRS) (Glaze, 2018). Individuals need to be aware of and have control over their thinking processes in order to understand the SRS they use and to develop these skills through their activities. This requires the use of metacognitive skills (Ersözlü & Çoban, 2012). The importance of metacognition, which is one of most important skills needed in the 21st century for individuals (Sulaiman et al., 2021), in the teaching and learning process has become increasingly clear in recent years (Antonietti et al., 2015; Schraw et al., 2006). In addition, metacognition is one of the knowledge dimensions in Bloom's Taxonomy (Mahajan & Sarjit Singh, 2017), which is based on higher-order thinking skills (HOTS) (Garcia, 2015): these have recently been a focus of science education (Anderson & Krathwohl, 2001). The metacognition dimension defines the student's ability to connect various concepts, interpret, solve problems, explore, reason, and make decisions (Supeno et al., 2019). Metacognitive knowledge and metacognitive processes significantly affect students' performance in scientific reasoning and their subsequent learning achievements (Gillies et al., 2011; Mevarech & Fridkin, 2006; Mevarech & Kramarski, 2003; Zohar & David, 2008).

The SRS and metacognition are among the crucial competencies that pre-service science teachers should have in order to meet the requirements of a dynamically changing world. It is thus necessary to concentrate on these research areas (Chytrý et al., 2018). The importance of metacognition for scientific reasoning (SR) has been emphasized by various studies (Amsel et al., 2008; Andersen & Garcia-Mila, 2017; Magno, 2011; Pedaste et al., 2012). This study focuses on the metacognitive activities of pre-service teachers when they are teaching SRS, which is one of the principal purposes of science education. There are various classifications of the components of metacognition in the literature. This study focused on the regulation of cognition component in the classification of Schraw and Moshman (1995).

Conceptualizations of Scientific Reasoning (SR)

The SR, which include a range of cognitive and metacognitive skills, are considered to function through a cumulative and cyclical process that requires the coordination of theory and evidence (Kuhn, 2011; White et al., 2009). The purpose of this cyclical process is to obtain information or make changes to the existing knowledge (Kuhn, 2011). According to another view, "scientific reasoning involves skills related to inquiry, experimentation, evidence evaluation, and inference made to achieve conceptual change or scientific understanding" (Zimmerman, 2007, p. 172). Here, SR consists of the interplay of the nonlinear processes involved in formulating hypotheses, designing experiments to test hypotheses, and evaluating them (Dunbar & Klahr, 1989). Given these definitions of SR, control of variables, proportional reasoning, correlational reasoning and probability reasoning, combinational reasoning, and hypothetical-deductive reasoning skills emerge as the logical and mathematical skills that help the development of SRS (Lawson, 2004; Zimmerman, 2000). These skills are also considered necessary for scientific research (Braaten & Windschitl, 2011; Lawson, 2004).

Recent trends in SR research include investigating (i) descriptive, methodological, and conceptual issues of what is normative and authentic in the context of the science laboratory and science classroom; (ii) metacognitive and meta-strategic skills; and (iii) the different types of teaching and practice opportunities necessary to develop, reinforce, and transfer such skills (Zimmerman, 2005). Recent conceptual and empirical studies have indicated that successful SR should include metacognitive and meta-strategic knowledge (Kuhn, 2011). As a matter of fact, meta-analyses of this field have concluded that studies focusing on metacognitive strategies and other strategies that are thought to be important in SR have a substantial effect on the development of SRS (Engelmann et al., 2016).

The POE Technique

One of the instructional activities in which SRS can be developed is the Predict-Observe-Explain (POE) technique (Chang et al., 2013). This technique is a metacognitive teaching tool that improves students' conceptual understanding and problem-solving skills in science lessons (Rickey & Stacey, 2000). POE, developed by White and Gunstone, assumes that successful cognition will be properly structured through the activities of predicting, observing and explaining the results of observation, and it is therefore defined as a learning technique based on the constructivist learning theory (Kearney et al., 2001). This technique requires individuals to predict the outcome of an event, and the reasons for this outcome, without performing any activity, to then observe the event, and finally explain how and why their predictions were or were not consistent with the observations. In other words, this technique is based on the classical research model, in which a hypothesis is defined, relevant data are collected, and the results are discussed (White & Gunstone, 1992).

There is a limited number of studies in the literature on teaching SRS with the POE technique (Choowong & Worapun, 2021; Marušić –Sliško, 2012; Yüksel & Ateş, 2017). However, considering the operational definition and theoretical background of SRS, the POE technique is one of the predominant methods used in teaching these skills. In this study, the POE technique was used to improve the SRS of pre-service teachers.

Metacognition and Metacognitive Activities

The importance of metacognition and cognitive self-regulation for successful SR has been emphasized for many years (Schunk & Zimmerman, 1998; White & Frederiksen, 1998). Metacognition is the individual's ability to think about their own cognitive processes (Flavell, 1979). Although there is no single definition of metacognition, there are various classifications in the literature regarding the components of metacognition. For instance, Schraw (1998) presents a model in which metacognition includes two main components: "knowledge of cognition" and "regulation of cognition". Knowledge of cognition is what individuals know about their own cognition or cognition in general; regulation of cognition relates to a set of activities that help students control their learning. This study focused on the regulation of the cognition component. Various researchers have identified specific dimensions related to the regulation of cognition component: the orientation, planning, monitoring, regulating, controlling, evaluating, and debugging dimensions (e.g., Efklides, 2006; Meijer et al., 2006; Schraw & Moshman, 1995; Veenman, 2011). There are also three basic skills common to regulation of cognition: planning, which involves choosing appropriate strategies and allocating resources that affect performance; monitoring, which refers to one's awareness of one's own understanding and performance of the task; evaluating, which refers to assessing the results and effectiveness of one's learning (Hofstein et al., 2019).

Metacognition can help students look for the best way to develop and practice the knowledge they have learned so that they are able to both diagnose and solve problems (Chatzipanteli et al., 2013; Mevarech & Fan, 2018). Teachers thus need to be able to decide on the strategies that will enable students to use their metacognitive skills (Sulaiman et al., 2021). For this, it is first necessary to determine what metacognitive activities are performed by the students. Metacognitive activities are mental processes such as the individual's awareness, monitoring, and evaluating of their own mental activities while performing a task (Hennessey, 1999). They thus provide regulation and control of cognitive processes and are crucial in the strategic implementation of metacognitive knowledge to achieve cognitive goals (Alexander et al., 1995). In addition, metacognitive activities are guided by metacognitive strategies (Peña-Ayala & Cárdenas, 2015). Factors affecting metacognition include individual differences (personal characteristics such as an individual's prior knowledge, gender, age, cognitive style, and motivation level) (Efklides & Misailidi, 2010), the bond between family and learner (Kleitman & Moscrop, 2010), the teacher's strategic metacognitive knowledge about teaching techniques (Hartman, 2001), and the difficulty and context of the task (Bjorklund, 1990). Furthermore, according to a theory of settings developed by Garner (1990), contextual factors affect the use of metacognitive strategies. These factors include the application of strategies resulting from the learner's knowledge base, and the appropriateness of those strategies to the relevant domain; specific situations that enable learners to engage in cognitive monitoring; knowledge of the relationship between the use of strategy and the demands of the task; the existence of goals to support the use of strategies; learners' beliefs about the importance of strategies; and the applicability of these strategies to new and related situations. In addition, a number of mechanisms (i.e. cognitive, associative, emotional, psychological and sociological mechanisms) also affect the use of metacognitive strategies and thus metacognitive activities. These cognitive mechanisms include emphasizing, identifying, and regulating the importance of an individuals' use of strategy, and they are closely related to the concept of strategic competence (Phakiti, 2008). Associative mechanisms are defined on the assumption that the choice of strategy is determined by a set of learned correlations between tasks, actions, and outcomes (Crowley et al., 1997). The emotional mechanism explains how attention and processing capacity is diverted from a learning or performance goal to a goal that has already taken precedence in the individual's goal structure. For example, when students are faced with negative emotions, they motivate themselves by combining the available coping resources to overcome this situation (Boekaerts, 1995). The psychological mechanism is related to metacognitive knowledge (Richter & Schmid, 2010). In addition, metacognition also serves as a psychological mechanism that bridges the gap between prejudices embedded in individuals' cognitive mechanisms and the state of cognitive adjustment that facilitates functioning in a dynamic environment (Haynie et al., 2010). Sociological mechanisms also often encourage cooperation (Simpson & Willer, 2015).

SRS and Metacognitive Activities

In this study, we focused on the metacognitive activities performed by pre-service teachers in the teaching of SRS. Metacognition and SR often play an important role in the holistic development of students (Limueco & Prudente, 2018). Applying abductive, retrodictive, deductive, and inductive inferences cycles in scientific research consciously requires researchers to be more aware of their reasoning (Lawson, 2010). The concepts of consciousness and awareness evoke the concept of "metacognition" introduced by Flavell (1979). We can say that metacognition enables learners to take control of their learning, think reflectively, understand their tasks, and know what strategies are needed to complete their tasks successfully. Thus, learners can monitor, control and regulate their cognition and learning (Pintrich, 2002).

Sophisticated reasoning includes the use of various strategies for hypothesis-testing, induction, inference, and evaluation of evidence and a meta-level awareness of when, how, and why one should engage in these strategies (Morris et al., 2012). Metacognitive processes include the extent to which individuals monitor their own reasoning process, strive to maintain consistent reasoning, reflect on the progress of their reasoning and monitor the reasoning for inconsistencies (Klaczynski & Narasimham, 1998). Therefore, it can be said that we can engage in metacognitive activities while making scientific reasoning.

The Present Study

There has recently been increasing interest in the metacognitive processes accompanying SR (Ha et al., 2021). Some researchers have even emphasized the importance of metacognition for SR (Amsel et al., 2008; Andersen & Garcia-Mila, 2017; Magno, 2011; Pedaste et al., 2012). There is, though, only a limited number of studies in the literature investigating the relationship between SRS and metacognitive awareness (e.g., Haryani et al., 2018; Limueco & Prudente, 2018). Most of the current research in this domain examines cognitive processes related to learning, remembering, and understanding; less is known about metacognitive processes in complex procedures such as reasoning and problem-solving. However, recently there has been an increase in research in these domains (Ackerman & Thompson, 2017). Metacognition is significant in terms of choosing which SR strategies to use and when to apply them (Omarchevska et al., 2022a). Previous research has emphasized the importance of self-regulation during complex problem-solving activities (e.g., Azevedo et al., 2010; Bannert et al., 2015; Omarchevska et al., 2022b) such as SR (e.g., Manlove et al., 2009; Omarchevska et al., 2022a; Omarchevska et al., 2022b; White et al., 2009). However, a detailed analysis of the interaction between metacognitive skilss to self-regulate individuals' learning during inquiry and activities using SRS is still lacking (Omarchevska et al., 2022a). In addition, no studies have been found that examine the metacognitive activities occurring in the minds of individuals teaching SRS. In this study, we present a detailed analysis of pre-service teachers' metacognitive processes during the teaching of SRS with the POE technique.

It is expected that the findings in this study will contribute to (a) creating an analysing basis for the development of taxonomy of metacognitive activities that take place in the teaching of SRS and (b) give an idea about the possible strategies that can be used to develop these processes and how they can be included in the teaching.

Methodology

The holistic single-case design was used to examine the metacognitive activities of pre-service teacher while teaching the SRS with the POE technique. In this design, a single case is investigated in depth and from a holistic

Table 1. Participant Profile.

Participant codes	Gender	Age	GPA
PST1	Female	21	2.80
PST 2	Female	22	2.80
PST 3	Female	21	3.37
PST 4	Male	20	2.96
PST 5	Male	21	2.46
PST 6	Male	21	2.86

and real-world perspective (Yin, 2018). A seven-week implementation process was carried out in this study. Metacognitive activities occur during the teaching of the control of variables, proportional reasoning, correlation reasoning, probability reasoning, combinational reasoning, and hypothetical-deductive reasoning skills were examined holistically. A typical situation was thus focused on and this situation was examined holistically.

Participants

The study was carried out with six third-grade pre-service science teachers who were enrolled in the SRS course, which is a compulsory course, in the Faculty of Education of a university in the west of Türkiye. The convenient sampling method was used to choose the participants in the study, and six pre-service teachers enrolled in the course also participated in the study. Before the instruction, all the pre-service science teachers were informed about the purpose and the process of research, and their consent was obtained. Three of the participants were male and three were female. Information about the gender, age and grade points average (GPA) of the participants is given in **Table 1**. Participants were coded from PST1 to PST6 to represent each participant.

Data Collection Tools

The POE Activity Report, an Activity Journal, and a Semi-structured Metacognition Observation Form were used in this study. In developing these forms, the literature about metacognition was utilized (e.g., Chen, 2013; Flavell, 1979; Gunstone & Mitchell, 1998; O'Malley ve Chamot, 1990; Ozturk, 2017; Pearson & Cervetti, 2017; Schraw & Dennison, 1994; Vandergrift, 1997) and the forms were created to include metacognitive activities. The data collection tools were evaluated by an expert on metacognition in science education and the final version was created. The POE activity report consisted of three parts and a sample is included in Supplementary Material

1. In this form, a daily life scenario related to the scientific reasoning skill is presented to the students, and predictions about the problem given in the scenario are requested. In the observation phase a closed-ended experiment or an activity is carried out. In the explanation phase, questions about the similarities and differences between the predictions before the activity and the findings after the observation, the reasons for these findings, and the possible relations between the results and daily life are discussed.

The Activity Journal consisted of two parts and seven items including metacognitive activities. In the first part, there were two main questions and sub-questions about the theoretical information of the relevant skill. These questions were as below,

1 *Which scientific reasoning skill was taught in the lesson?*
- *What did you think when you first heard about the scientific reasoning skill, what came to mind, what words evoked in your mind? Why? Can you explain?*

2 *What did you learn theoretically about the relevant scientific reasoning skill? Can you express what you have learned using one of the concept teaching tools (V diagram, concept map, etc.)?*
- *Have you ever experienced a situation in which you did not understand or had difficulty in teaching this skill? Why? What did you do to overcome this problem? Why?*
- *The first part of the journal was completed by the pre-service science teachers after the theoretical information about each relevant scientific reasoning skill had been taught. The second part of the activity journal was about the teaching process for the related skill using the POE technique and consisted of five main questions and sub-questions. The questions were*

3 *We conducted a practice in the teaching of this skill. First, you were given a problem and asked to make predictions. In the second stage, you engaged in an activity to solve the problem. In the third stage, you made a statement about the solution of the problem. In this context,*
- *What did you do? What did you observe?*
- *Did you have any difficulties while performing the practice? Which part did you have difficulties with? Why?*
- *What did you do to overcome this challenge? Why?*
- *Have you always done this, or did you do this for the first time? Why?*

4 *What did you become aware of after teaching the relevant SR skill? Why?*

5 *Did your ideas about this skill change after teaching the relevant SR skill? Why and how?*

6 *How can you associate the relevant scientific reasoning skill to daily life? Why?*

7 *Have you ever had a situation where you said "I wish I had done that" in the teaching of the relevant SR skill? Why and how?*

The second part of the journal was completed by the pre-service teachers after they had practiced teaching each skill with the POE technique. The Metacognition Observation Form consisted of 18 items about metacognitive activities. These items were, “Monitoring whether you understand the theoretical information in the course”, “Monitoring the consistency of the theoretical information with your prior knowledge”, “Monitoring the change in your ideas about theoretical knowledge”, “Drawing attention to unfamiliar concepts/information”, “Choosing key points and supporting details”, “Monitoring when your prior knowledge is wrong”, “Evaluating the accuracy of your prior knowledge”, “Monitoring what you know and don’t know”, “Comparing the consistency of your own predictions with those of your friends’ predictions using the POE technique”, “Evaluating the reasons your friend’s predictions when they are different from your own when using the POE technique”, “Evaluating the elements your friends used to decide on their prediction”, “Monitoring whether they can explain their observations correctly”, “Comparing your observations with your experiences”, “Evaluating the consistency of your predictions and observations”, “Deciding which of your predictions and your observations are correct”, “Becoming aware that you have difficulties while doing the activities and then changing the strategies you use”, “Comparing the consistency of the activity with the theoretical knowledge of the relevant skill” and “Evaluating the strategies used for the lesson”. In addition, when one of the researchers encountered statements that were not included in the Metacognition Observation Form during teaching but that showed that pre-service teachers were engaging in metacognitive activities, she noted down these statements while she was observing them. As an example, the item “Being aware of what you know and what you do not know” was added in the teaching of the proportional reasoning skill, and the item “Being aware of encountering new situations” was added in the teaching of the combinational reasoning skill.

In order to ensure the content validity of the data collection tools, all the items in the data collection tools were created in order identify metacognitive activities. In addition, there were similar items in the Activity Journal, the Observation Form, and the POE Activity Report. Moreover, two experts were consulted to check the clarity and comprehensibility of the data collection tools. One of the experts specialized in metacognition in science education and the other was a linguist. After taking into account the experts’ views, the final version of the data collection tools was created with minor revisions.

Teaching Process

Hypothetical-deductive reasoning, control of variables, proportional reasoning, correlation reasoning, combinational reasoning and probability reasoning are important sub-skills for scientific reasoning (Lawson, 2004). In this study, these six skills were taught using the POE technique. The SRS teaching process in the study is shown in **Figure 1**.

As seen in **Figure 1**, the teaching of each skill lasted two weeks. In the first week, theoretical information about the scientific reasoning skill was given, and then a discussion was initiated about the problem scenario, prepared by the researchers, that required the use of this skill. Finally, students were asked their predictions about the problem (the "prediction" step of the POE technique). The following week, experiments or activities related to these predictions were performed, actual results were recorded (the "observation" step of the POE technique), and the teaching of the relevant skill was completed by explaining the differences between the predictions and the actual results (the "explanation" step of the POE). An example of the activity for the teaching of hypothetical-deductive reasoning skill is given in ***Appendix 1***.

Data Analysis

Inductive and comparative analysis was used to investigate in detail the participants' metacognitive activities occurring in the teaching of SRS with the POE technique. Since metacognitive activities occurring in the teaching process were being examined, the data collection tools focused on the monitoring and evaluating components of the regulation of cognition. First, the data were analysed back and forth in order to find statements by the participants that exemplified the metacognitive monitoring and metacognitive evaluating categories of the Activity Journal, the Metacognition Observation Form, and the POE Activity Report. The data were coded by considering the definitions of monitoring and evaluating activities in the literature. Thirteen activities for monitoring and four activities for evaluating were coded. After the coding, the operational definitions of the pre-service teacher's metacognitive activities that occurred in the SRS teaching were made: (a) Monitoring activity included being aware of what one knows and does not know, being aware of the challenge faced, being aware of encountering new situations, choosing key points and supporting details, drawing attention to unfamiliar concepts/information, monitoring the consistency of one's prior experiences with new information, monitoring the consistency of one's prior knowledge with information provided by different sources, monitoring the accuracy of the information provided by different sources, monitoring what one knows and does not know, monitoring the consistency of one's predictions with the observations, monitoring when one understands and does not understand an idea encountered, overcoming difficulties and monitoring the change in one's ideas; (b) Evaluating activity included evaluating one's learning, evaluating the accuracy of one's observations, evaluating the efficiency of practices and evaluating the efficacy of the strategies used. In making these

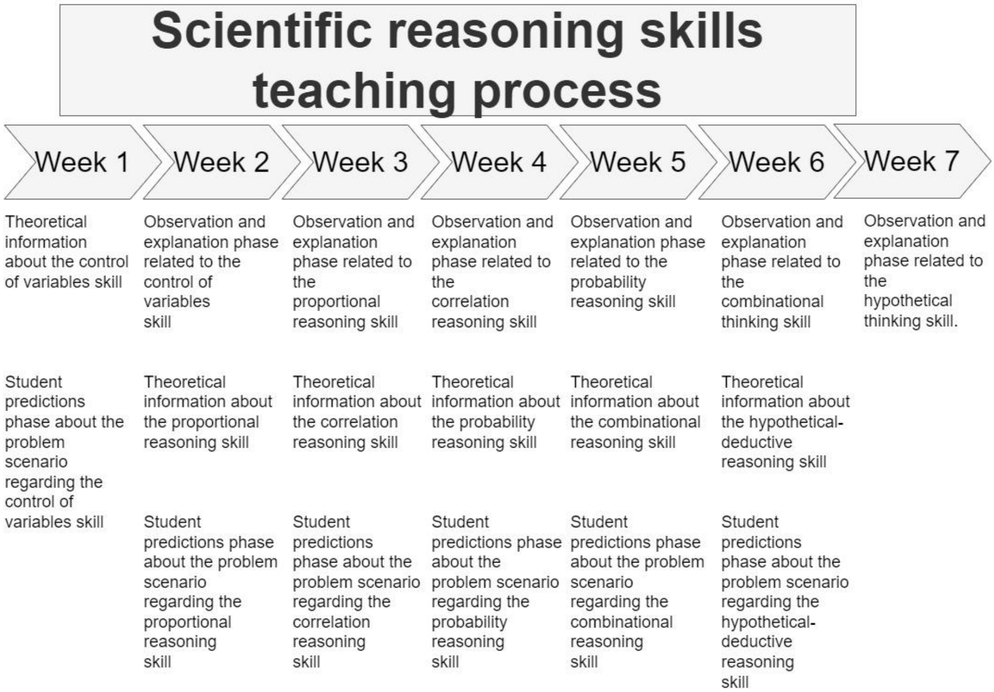

Figure 1. The SRS Teaching Process.

definitions, the studies by Berger and Karabenick (2016), Meijer et al. (2006), Meijer et al. (2012), Shraw & Dennison (1994), Schraw ve Moshman (1995), Veenman (2011) and Yürük (2005) were used.

Second, the subtypes of the metacognitive activities identified were defined according to the operational definitions of the pre-service teacher's metacognitive activities. For example, the monitoring activity was defined as the following sub-activity types: "Being aware of what one knows and does not know", "Drawing attention to unfamiliar concepts/information", "Choosing key points and supporting details", "Monitoring the consistency of one's predictions with the observations" and "Overcoming difficulties". The evaluating activity was defined with the following sub-activities: "Evaluating one's learning", "Evaluating the accuracy of one's observations", "Evaluating the efficiency of the practice", and "Evaluating the efficacy of the strategies used". Some of the sub-monitoring and sub-evaluation activities were compatible with the items in the Metacognition Observation Form (metacognitive observation items were included in the data collection tools section), and some of them were obtained as a result of coding the statements of the participants in the Activity Journal. For example, the sub-monitoring activities such as "Being aware of the challenge faced", "Being aware of encountering new situations", and "Overcoming difficulties" were categories

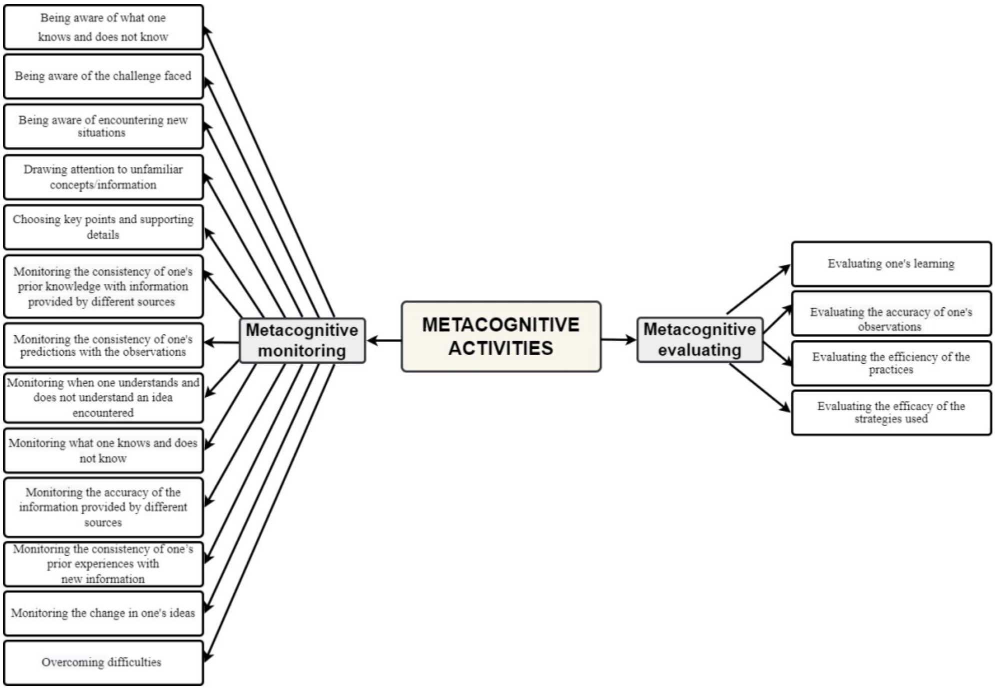

Figure 2. Categories and Sub-Categories Related to Metacognitive Activities.

derived from the Activity Journals. In addition, some items in the Metacognition Observation Form were revised and coded as categories to include both in the Activity Journal and the statements in the Activity Report. For example, the item “Comparing the consistency of your own predictions with those of your friends’ predictions using the POE technique” in the Metacognition Observation Form was revised to “Monitoring the accuracy of the information provided by different sources” sub-monitoring activity. The item “Monitoring whether they can explain their observations correctly” was revised to “Evaluating the accuracy of one’s observation” sub-evaluating activity. The subtypes of metacognitive activities are coded as sub-categories related to metacognitive activities. The categories and sub-categories obtained by examining the statements of the participants from the Metacognition Observation Form, the Activity Journal and the Activity Report, which are also related to metacognitive activities, are given in **Figure 2**.

While labelling the identified metacognitive activities and their types, one of the researchers considered the literature on metacognition and determined possible names for them. The labelling two researchers then discussed it together and decided on the final naming.

Some direct quotes from the Metacognition Observation Form and the POE Activity Report of PST3, one of the pre-service teachers and examples of how these were coded in terms of metacognitive activities are given below:

> PST3: *My observations are consistent with my predictions. I set up my first experimental setup, and then I established my second experimental setup. I concluded, "As the number of reels increases, the gain in force increases." The length of the first rope is 70 cm. In the second experimental setup it is 120 cm. In the second system, I should have pulled 140cm. I pulled 120cm, and my prediction was not exactly consistent with my observation. It may have been due to the weight of the reel. Also, I may not have measured correctly while pulling the rope.* (From the Metacognition Observation Form [Monitoring: Monitoring the consistency of one's predictions with the observations.])

> *PST3: There is inconsistency between my predictions and my observations. My predictions and my observations were almost the same. I predicted that there would be a gain in force when I added a movable pulley to the system. I also predicted that the length of the rope would be longer, and I observed better when I experimented. Since I wrote the data in the table wrong at first, my predictions and my observations were inconsistent. I have to correct my data. Also, if the weight of the moving pulley and friction force in the system are neglected, my result would be correct."* (From the POE Activity report [Monitoring: Monitoring the consistency of one's predictions with the observations.])

Tables are included in the Findings section to show which metacognitive activities occurred in the teaching of which scientific reasoning skill.

Validity and Reliability of the Study and Ethics

The study's validity and reliability were ensured through data triangulation, the researcher's position, appropriate and adequate engagement in data collection processes, an audit trail and the rich and dense descriptions technique (Merriam & Tisdell, 2016).

In data triangulation, data obtained from the Activity Journal, the Metacognition Observation Form, and the POE Activity Report related to teaching each scientific reasoning skill were examined. The consistency of the data coded from different data sources was compared, and similar categories emerged. Thus, reliable and common evidence was obtained. The coding set consisting of sample data sections for the categories created for each type of the metacognitive activities was coded by one of the researchers and an expert on metacognition in science education. Inconsistencies detected in the coding were discussed until a satisfactory agreement was reached. By reviewing the literature, the attempt was made to form taxonomy of the metacognitive activities performed by pre-service teachers in teaching SRS with POE.

The investigator's position or reflexivity, strategy was used in this study. One of the researchers is experienced in conducting qualitative studies and metacognition, and the other is experienced in SRS. In addition, they did not make any personal interventions that would affect the research process positively or negatively, and they did not make any prejudgements about the study results.

The adequate engagement in data collection strategy for data collection took the form of data collection over a specific period (seven weeks). Detailed information about the audit trail is included in the Data Collection Tools, Teaching Process, and Data Analysis sections. In addition, the data for the Activity Journal amounted to a 124-page document, while the data for the Metacognition Observation Form and the POE Activity Report resulted in documents that were 33 and 133 pages long respectively.

Regarding ethics, the necessary permissions were obtained from the Human Research Ethics Committee (letter dated 24.02.2021, numbered E-57452775-900-9101 and decision number 2021/39). In addition, the real names of the participants were kept confidential during the coding and reporting of the qualitative data to ensure their privacy. The participants were coded from PST1 to PST6 to represent each participant.

Results

Various metacognitive activities regarding monitoring and evaluating were found to have occurred in the pre-service teachers during the teaching of six different SRS with the POE technique. Information on the monitoring activities that occurred in each SRS teaching is given in **Table 2**.

When **Table 2** is examined, it is seen that there were 13 different monitoring activities performed by the pre-service teachers in the teaching of six different SRS. There was more variety in the monitoring activities of the pre-service teachers in teaching the control of variables and probability reasoning skills compared to the other skills. There was least diversity in teaching hypothetical-deductive reasoning skills. In addition, in **Table 2**, it is seen that the activities of being aware of what one knows and does not know, being aware of encountering new situations, monitoring the consistency of one's predictions with the observations, monitoring when one understands and does not understand an idea encountered, and overcoming difficulties occurred during the teaching of each scientific reasoning skill. The activities of pre-service teachers to monitor the accuracy of the information provided by different sources and to monitor the consistency of one's prior experiences with new information were found to be active only in teaching the correlational reasoning skill. Sample quotations regarding various monitoring activities performed by the pre-service science teachers in the teaching of SRS are given in **Table 3**.

Table 2. Monitoring Activities in the Teaching of Each Scientific Reasoning Skill.

Type of Monitoring Activities	Control of Variables	Proportional Reasoning	Correlation Reasoning	Probability Reasoning	Combinational Reasoning	Hypothetical-Deductive Reasoning
Being aware of what one knows and does not know	✓	✓	✓	✓	✓	✓
Being aware of the challenge faced	✓	✓	-	✓	-	-
Being aware of encountering new situations	✓	✓	✓	✓	✓	✓
Drawing attention to unfamiliar concepts/information	✓	✓	✓	✓	✓	-
Choosing key points and supporting details	✓	✓	-	✓	✓	✓
Monitoring the consistency of one's prior knowledge with information provided by different sources	✓	-	-	✓	✓	✓
Monitoring the consistency of one's predictions with the observations	✓	✓	✓	✓	✓	✓
Monitoring when one understands and does not understand an idea encountered	✓	✓	✓	✓	✓	✓
Monitoring what one knows and does not know	✓	-	✓	✓	✓	-
Monitoring the accuracy of the information provided by different sources	-	-	✓	-	-	-
Monitoring the consistency of one's prior experiences with new information	-	-	✓	-	-	-
Monitoring the change in one's ideas	✓	-	✓	✓	-	-
Overcoming difficulties	✓	✓	✓	✓	✓	✓

Information on evaluating the metacognitive activities of the pre-service science teachers that occur in the teaching of each SRS is given in **Table 4**.

When **Table 4** is examined, it is seen that four different evaluating activities occurred in the pre-service science teachers during the teaching of six different SRS. There was more variety in the evaluating activities in the teaching of the control of variables and proportional reasoning skills compared to the other skills. In addition, in **Table 4**, it is seen that evaluating

Table 3. Sample Quotes regarding the Kind of Monitoring Activities Performed by the Pre-Service Teachers in SRS Teaching.

Type of Monitoring Activities	SRS Teaching	Sample Quotes
Being aware of encountering new situations	Hypothetical-Deductive reasoning	PST4: *When I added pineapple to the milk, I noticed that there was some agglomeration. I did not expect that I would make such an observation*. (From the Observation Form.) PST4: *I knew that when lemon was added to milk, the milk would curdle, but I was not so sure that I would get that result for pineapple juice, and when I saw that the milk had curdled, I was very surprised.* (From the Activity Journal.)
Choosing key points and supporting details	Combinational reasoning	PST2: *By learning this skill, I realized the importance of systematically thinking about all the possibilities that could affect an event.* (From the Observation Form.)
Monitoring the consistency of one's prior knowledge with information provided by different sources	Control of variables	PST4: *PST3 gives a different explanation about the experimental data, did you notice, sir?* Researcher: *Yes.* PST4: *PST3 looked at the reaction time. So, he reached a different conclusion. I am looking at the end time of the reactions in different test tubes.* (From the Observation Form.)
Monitoring when one understands and does not understand an idea encountered	Probability reasoning	PST1: *I thought the probability thinking skill was hard. Because probability was a difficult subject for me. But when I listened to this lesson, I realized that it was not difficult at all. While listening to the lecture, I realized that I had difficulty because I did not like the subject. This time I listened to the lecture without any prejudices. For this reason, I realized that the subject is not difficult. Maybe I could have listened without prejudice because she was the lecturer of this course. I just realized that I need to be careful.* (From the Activity Journal)
Monitoring the change in one's ideas	Control of variables	PST2: *I'm confusing dependent and independent variables. I think theoretically at first and then I associate them with lots of examples.* (From the Observation Form.) PST2: *As someone who constantly confuses dependent and independent variables, I was happy to practice this reasoning skill in class. It helped me eliminate my misconception. The reason for my misconception is that I thought that the independent variable was a constant variable that is not affected by any situation and does not depend on any situation. The situation I had difficulty with was that I had the thought that I could not interfere with the independent variable, regardless of everything. But in the lesson, I understood that the dependent variable changes depending on the independent variable. In my mind, I replaced the wrong idea with the right idea. In this way, I overcame my problem by adopting the idea that the dependent variable changes depending on the independent.* (From the Activity Journal.)

one's learning, evaluating the efficiency of the practices, and evaluating the efficacy of the strategies used become active in the teaching of each scientific reasoning skill. The process of evaluating the accuracy of one's observations was found to be active only in the teaching of the control of variables and proportional reasoning skills. Sample quotes regarding the various evaluating activities performed by the pre-service teachers in the teaching of these skills are given in **Table 5**.

Table 4. Evaluating Activities in the Teaching of Each Scientific Reasoning Skill.

Type Of Metacognitive Evaluating Activities	Control of Variables	Proportional Reasoning	Correlation Reasoning	Probability Reasoning	Combinational Reasoning	Hypothetical-Deductive Reasoning
Evaluating one's learning	✓	✓	✓	✓	✓	✓
Evaluating the accuracy of one's observations	✓	✓	-	-	-	-
Evaluating the efficiency of the practices	✓	✓	✓	✓	✓	✓
Evaluating the strategies used	✓	✓	✓	✓	✓	✓

Table 5. Sample Quotes regarding the Types of Evaluating Activities Performed by the Pre-Service Teachers in Scientific Reasoning Skill Teaching.

Type of Evaluating Activities	SRS Teaching	Sample Quotes
Evaluating one's learning	Hypothetical-deductive reasoning	PST4: *I was aware that this skill actually includes most skills because we identify the variables, then we think about all the events. Actually, we need to think combinationally in part. I learned how to do this.* (From the Activity Journal.)
Evaluating the accuracy of one's observations	Proportional reasoning	*PST6: I set the angle as sin 90° and in this situation, I pulled the rope 12 cm. Then, when I widened the angle, I had to pull the rope 21 cm. As the angle widened, there was a gain in force and a loss in distance. However, I may have made a mistake in measuring the angle. The fact that I neglected the weights of reels may have caused the experimental error.* (From the Observation Form.)
Evaluating the efficiency of the practices	Combinational reasoning	PST6: *The practice we did was good in terms of explaining combinational thinking because it was an experiment that showed what kind of results could be obtained by setting different combinations.* (From the Activity Journal.)
Evaluating the efficacy of the strategies used	Probability reasoning	PST4: *If we take samples from certain parts of the whole field, then average these samples and interpret them as a whole, as I did in my own experiment, we will get a more accurate result*. (From the POE Activity Report)

General information on the frequency of the pre-service teachers' metacognitive activities occurring during teaching Scientific Reasoning Skill is given in **Figure 3**.

When **Figure 3** is examined, it can be seen that some metacognitive activities – being aware of what one knows and does not know, being aware of encountering new situations, monitoring the consistency of one's predict-

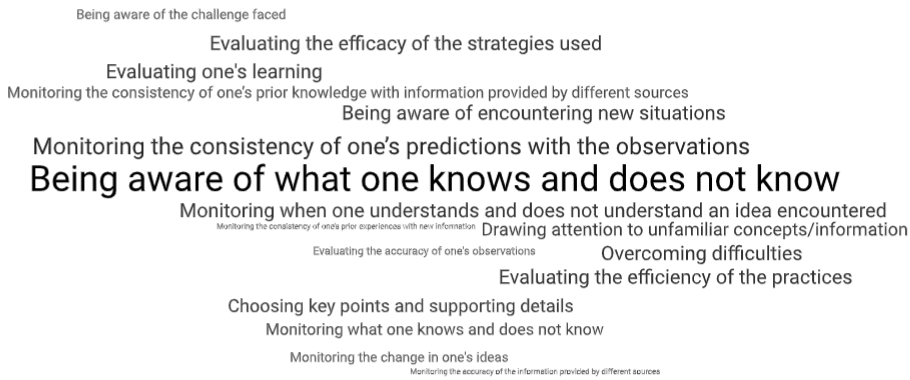

Figure 3. The Frequency of the Pre-Service Teachers' Metacognitive Activities Occurring during Teaching SRS.

tions with the observations, monitoring when one understands and does not understand an idea encountered, overcoming difficulties, evaluating one's learning, evaluating the efficiency of the practices and strategies used – occurred more frequently than others in teaching SRS with the POE technique. Activities to monitor the accuracy of the information provided by different sources, to monitor the consistency of one's prior experiences with new information, and to evaluate the accuracy of one's observations were among the least performed activities.

Discussion and Conclusion

This study determined the metacognitive activities occurring in pre-service science teachers in teaching various reasoning skills with the POE technique. Three conclusions were reached. The first result was that the types of metacognitive activity performed by pre-service teachers (e.g., being aware of what one knows and does not know, being aware of encountering new situations, monitoring the consistency of one's predictions with the observations, monitoring when one understands and does not understand an idea encountered, overcoming difficulties, evaluating one's learning, etc.) reflect the activities occurring in the steps of the POE technique. This can be explained by the fact that POE activities prompt students to make predictions and revise these predictions to monitor their learning (James et al., 2022). In addition, it is emphasized in the literature that this technique is a metacognitive teaching tool that improves students' conceptual understanding and problem-solving abilities (e.g., Bajar-Sales et al., 2015; Karadeniz et al., 2020; Rickey & Stacey, 2000; Thomas, 2015).

The second result was that there was more variety in the monitoring activities than in the evaluating activities. This can be explained by the fact that the POE technique used in teaching provides the opportunity to question students' prior knowledge and to play an active role in the learning process for each student (Acar-Şeşen & Mutlu, 2016). Thus, the learners have greater conscious awareness during teaching. In addition, it should not be forgotten that the use of monitoring and regulating skills is important for effective instruction during the interactive stage (Artzt & Armour-Thomas, 1998). In general, learners have difficulties monitoring their own cognitions. However, specific situations can be created in the learning environment in order to overcome these difficulties and promote the use of cognitive monitoring strategies (Garner, 1990). In this study, the learner's active monitoring skills were more diverse. This result shows the significance of including metacognition in teaching practices. In particular, students with weak metacognitive skills experienced difficulties in monitoring their learning. Thus, these students need well-designed teaching activities so that they can monitor their learning (Berardi-Coletta et al., 1995). We can achieve this by adding instructional supports (i.e., directives, prompting, and modelling) (Pieger & Bannert, 2018) when designing learning environments. Here, the teacher's knowledge of strategies that can be used to activate the metacognitive skills of the students, and the ability to use this knowledge in the learning environment, in other words, their strategic metacognitive knowledge about teaching techniques (Hartman, 2001), will also play a critical role.

We expect the POE technique to give rise not only to monitoring activities but also to evaluating activities, and that there would be a large variety of evaluating activities during teaching. However, in this study, there was less diversity in the evaluating activities than in the monitoring activities. In the literature on determining metacognitive awareness, there are also quantitative studies showing that teachers'/pre-service teachers' evaluation skills were at a low level (e.g., Fauzi & Sa'diyah, 2019). When learners do not fully understand how to evaluate their learning, they may not realize that they have failed (Garner, 1990). Thus, evaluation activities are very important. These activities also require the use of a variety of specific strategies. We can thus conclude that the participants in this study had limited knowledge about the strategy to use to perform evaluation activities (Zohar, 2012). This can be explained by personal characteristics such as the level of prior knowledge of strategy regarding this activity, their cognitive styles and their motivation levels (Efklides & Misailidi, 2010). In addition, during this process, the lecturer may not have been able to spare enough time to activate the evaluation activities.

Metacognitive strategies can be used to activate metacognitive activities in various teaching practices. For example, self-questioning is a common metacognitive monitoring strategy (Livingston, 2003) and can often be used in teaching practices. Incorporating various strategies into the content of the teaching is one of the ways to develop metacognitive skills (Veenman et al., 2006). To achieve this, instructional supports such as directives, prompting, and modelling can be used (Zepeda et al., 2019).

Being aware of when, how and which strategy to use in different contexts is crucial in performing metacognitive activities (Ku & Ho, 2010). The third result was that the variety and number of metacognitive activities performed by pre-service teachers in the teaching of SRS differ. For example, while there was large diversity in the metacognitive activities performed by pre-service teachers is high in teaching of control of variables skill; there was little diversity in the teaching of hypothetical-deductive reasoning skills. Another example is the finding that the activity of evaluating the accuracy of one's observations became active only in the teaching of control of variables and proportional reasoning skills. The reason for this is that the diversity of metacognitive activities varies depending on the nature of the task (Duncan & McKeachie, 2005) and the needs of the participants in completing the task (Alavi & Kaivanpanah, 2006), and the knowledge of strategy that learners need to fulfil the demands of the task (Garner, 1990). When a task is difficult, this provokes metacognitive activity (Meijer et al., 2006). We can associate to this with the Theory of Constructive Operators. According to this theory, "mental demand", which refers to the minimum number of schemas that must be used to solve a problem, is a measure of the complexity of the problem (Pascual-Leone, 1970), and a person cannot solve a problem whose mental demand is above the person's mental capacity (Pascual-Leone & Johnson, 2005). This is one of the main sources of cognitive load (Van Merrienboer & Sweller, 2005). When we consider the hypothetical-deductive reasoning skill, it is a difficult task that includes the skill of controlling variables and requires various cognitive processes, and the mental demand of the activities used in teaching this skill is higher than other activities. Studies on cognitive load showed that the strategies that need to be used in solving problems facilitate the solution of problems with high mental demands (e.g., Boujaoude et al., 2004; Tsaparlis & Angelopoulos, 2000). If students have a wide range of strategies, they can respond with greater variety and frequency to difficult tasks (Ikeda & Takeuchi, 2000). The hypothetical-deductive reasoning skill also requires the use of some experimental strategies in the process of control of variables (Tschirgi, 1980), and the use of monitoring strategies is crucial in this process (Taub et al., 2018). However, in this study, it was concluded that there was less variety and frequency in their metacognitive activities performed by pre-service teachers in the teaching of hypothetical-deductive reasoning skill than in the teaching of other SRS. This situation can be explained as arising from the lack of knowledge of pre-service teachers on the use of strategies to perform metacognitive activities. In the literature, there are studies showing that university students are deficient in the use of metacognitive strategies in their learning (e.g., Anthonysamy et al., 2020; Hashemyolia et al., 2015) and that they are not sufficiently interested in metacognition (Boser, 2018).

Limitations and Recommendations for Future Research

This study was limited to pre-service science teachers, teaching six SRS with the POE technique, the regulation of cognition component of metacognition, and qualitative research. Future studies can be conducted to determine the metacognitive activities performed by the learners in the teaching of SRS by using other techniques (argumentation, scientific inquiry, etc.), and to compare the metacognitive activities performed in the teaching of SRS by different techniques. In addition, the metacognitive knowledge and metacognitive experience components of metacognition can also be examined.

The study found that pre-service teachers engaged in fewer metacognitive activities in the teaching of the hypothetical-deductive reasoning less than in teaching other skills. Given that scientific reasoning can be supported by teachers through practices including prompts, scaffolds, didactic interventions, or metastrategic understanding (Kuhn & Dean, 2004), practices that can activate learners' metacognitive activities can be implemented in the teaching of hypothetical-deductive reasoning skill. The cognitive and metacognitive strategies used in teaching SRS can be taught.

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Appendix I

Scenario

Fatma reached this information while she was researching the structure of milk: "The reason why milk appears white is because of the casein micelles suspended in the milk. Casein is the most important protein component in milk. Casein proteins are hydrophobic, in other words they are insoluble in water. For this reason, the casein molecules are associated together in water and form small micelles. Since these micelles are very small, they are suspended in the milk. There are two factors that prevent the casein proteins from forming large micelles in the milk. First, the proteins on the surface of the casein micelles make it difficult for the different micelles to associate together. Second, while the pH of milk is between 6.7-6.9, the casein micelles are negatively charged. Therefore, there are electrical repulsive forces between the micelles.

Based on this information, Fatma wants to investigate the reasons for cessation of milk. What are your hypotheses about the cessation of milk? What would be the deductive reasoning cycle you would use when testing these hypotheses? Please explain.

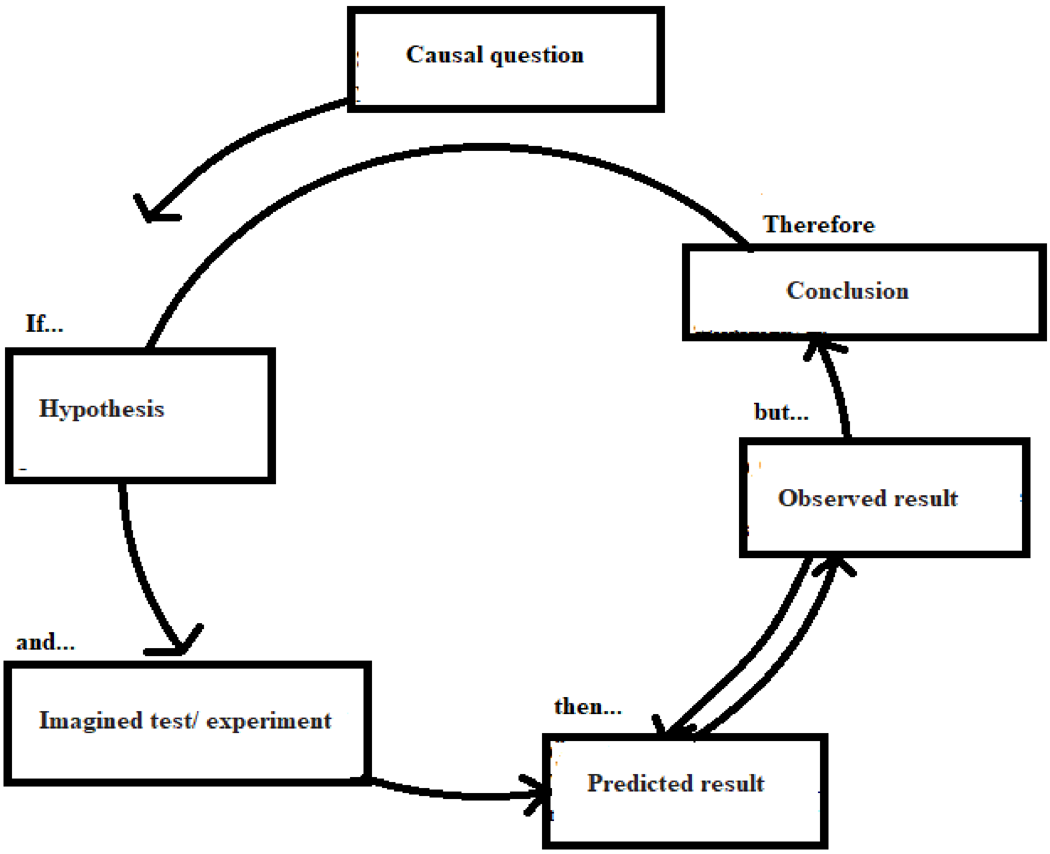
1-Prediction

Hypothesis 1...

Hypothesis 2...

Hypothesis 3...

Hypothetico-deductive reasoning cycle



2- Observation

Materials

• Milk
• Heater
• Heat-resistant container
• Adhesive
• Heat-resistant container
•Adhesive
• Teaspoon
• Paper
• Tablespoon
• Pen
• 6 cups
• Knife
• Lemon
• Plate
• Pineapple
• Strainer

Experimental Procedure

- Let's cut a peeled pineapple in half and cut one piece of into small cubes.
- Let's press the small cubes we cut with our hands or with a mortar until you get juice from pineapple.
- Let's drain the juice of the pineapple pieces with a strainer.
- Let's pour half of the pineapple juice into a cup. Let's heat the remaining half until the bubbles form.
- Let's pour the heated pineapple juice into a cup, and stick a label on it so that it does not confuse this cup with another cup.
- Let's label the first cup as "milk", the second cup as "milk and heated pineapple", the third cup as "milk and pineapple" and the fourth cup as "milk and lemon". Let's add 1 tablespoon of milk to each cup.
- Add a teaspoon of heated pineapple juice to the cup labeled milk and heated pineapple and mix.
- Add a teaspoon of fresh pineapple juice to the cup labeled milk and pineapple and mix.
- Add a teaspoon of lemon juice to the cup labeled milk and lemon and mix.

- Let's wait about 5 minutes. Let's observe the changes and the time of the changes in the mixtures and take note.

I. Experimental set up (Milk) ...

II. Experimental set up (Milk and heated pineapple) ...

III. Experimental set up (Milk and pineapple) ...

IV. Experimental set up (Milk and lemon) ...

3- Explanation Phase

- What conclusion did you reach as a result of your experiment? Did you reject your hypothesis? Did you accept? Why?
- What did you observe when we added lemon juice to milk? How did the change occur? What is the reason for this change?
- What did you observe when we added fresh pineapple juice to the milk? How did the change occur? What is the reason for this change?
- Comparing the mixture of lemon juice and milk and the mixture of fresh pineapple juice and milk, what did you observe? Does the change occur immediately or after a while?
- Pineapple juice (pH between 2.5-3.5) is not as acidic as lemon juice. However, when we add pineapple juice to the milk, micelles still form. Why?
- What did you observe when we added heated pineapple juice to the milk? Why?