education sciences

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Elementary Preservice Teachers' Understandings and Task Values of the Science Practices Advocated in the NGSS in the US

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Abstract: K-12 science education in America has long been criticized for not preparing scientifically literate students who are prepared to engage in science-as-practice. Bearing this in mind, the Next Generation Science Standards (NGSS) recommend engaging students in eight science practices to build their knowledge of and proficiency in science. Engaging students in science-as-practice instruction depends on building preservice teachers' understanding of, proficiency with, and value for the science practices. Through this mixed methods study, we investigated the effects of an elementary science teaching methods course on 109 preservice teachers' epistemic understanding of the practices, their perceived importance of each practice, and the value that they ascribe to each practice. The results of our analysis indicate that: (1) the course initiated changes in preservice teachers' epistemic understanding of the practices; (2) these preservice teachers viewed Asking questions as the most important science practice; and (3) they most frequently attached Attainment value to the science practices. Based on these findings, we recommend that courses for preservice teachers purposefully include significant opportunities for them to engage in the doing of science; place emphasis on crosscutting concepts and disciplinary core ideas in science; and provide preservice teachers with viable strategies for engaging students in each of the science practices in actual classrooms.

Keywords: NGSS science practices; task values; elementary preservice teachers; science teaching methods course

Citation: Seung, E.; Park, S.; Kite, V.; Choi, A. Elementary Preservice Teachers' Understandings and Task Values of the Science Practices Advocated in the NGSS in the US. *Educ. Sci.* **2023**, *13*, 371. https://doi.org/10.3390/educsci13040371

Academic Editors: Yew-Jin Lee and Yann Shiou Ong

Received: 31 January 2023
Revised: 29 March 2023
Accepted: 29 March 2023
Published: 4 April 2023

1. Introduction

K-12 science education in the US has been criticized for not providing students with engaging opportunities to experience how science is actually carried out [1]. This assertion underpins the design of the Next Generation Science Standards (NGSS), which emphasize engaging students in learning experiences crafted around asking fundamental questions about the world and learning about how scientists have pursued answers to those questions [2]. To guide the creation of these learning experiences, the NGSS outlines eight essential science practices through which students should learn disciplinary core ideas and crosscutting concepts as well as the nature of science: (1) Asking questions, (2) Developing and using models, (3) Planning and carrying out investigations, (4) Analyzing and interpreting data, (5) Using mathematics and computational thinking, (6) Constructing explanations, (7) Engaging in argument from evidence, and (8) Obtaining, evaluating, and communicating information [2]. The NGSS explicitly states that "students in grades K-12 should engage in all eight practices over each grade band" [2] (p. 2), and suggests these practices should be interwoven into instruction in a coherent learning progression.

To attain the goals of the NGSS, the fundamental paradigm of science education needs to shift from presenting final-form science to students as facts toward emphasizing science as an ongoing process and practice. However, this paradigm shift places significant demands on teachers [3], as they should understand how to engage students in science practices through which students not only develop a conceptual understanding of scientific knowledge but also learn how scientific knowledge is constructed, communicated, and validated. Given the centrality of teachers in educational processes and student learning [4,5], the extent to which students are engaged in these science practices depends on teachers providing rich learning opportunities to their students. That is, science teachers are required to provide guidance on how to effectively participate in the practice, how to use them to make sense of the world, and how to apprentice into the scientific community [6,7]. This new emphasis necessitates science teachers' deep understanding of the epistemic nature of science practices [8]. In short, teachers should know "for what purposes and to what ends each science practice is engaged in" [8] (p. 393). Only when teachers are confident that they know what the epistemic nature and goals of the eight practices are and understand them as interdependent epistemic procedures for building knowledge can they create learning environments to engage their students in the essential practices of science proposed by the NGSS [6,9,10].

In this regard, examining teachers' epistemic understanding of the eight NGSS practices can be a stepping stone for supporting science teachers' implementation of reform-oriented science teaching. Kite and his colleagues [11] conducted a qualitative study to examine the characteristics of secondary science teachers' understanding of the epistemic nature of the eight science practices. The researchers highlight the need for teacher education initiatives that explicitly target teachers' epistemic understandings that promote effective implementation of the science practices that are critical to student learning of cognitive, epistemic, and social aspects of science. However, few studies have been conducted to examine pre-service teachers' understanding of the science practices. Preservice teacher education programs or professional development programs for in-service teachers should be the places where teachers can improve their understanding of the NGSS science practices. Considering that, this study aimed to examine elementary preservice teachers' understanding of the NGSS science practices and the impact of science teaching methods courses on their understanding. A number of studies have repeatedly reported that elementary teachers do not provide the desired level of science lessons in an inquiry-based, science practice-centered way [12,13]. Findings from this study will provide significant insights into how to better prepare future elementary teachers to promote student science learning through science practices.

In addition to teacher knowledge, research has shown that teachers' beliefs and values affect their instructional choices and efforts to change their pedagogical practice [14–16]. Although teacher beliefs are difficult to define clearly and the relationship between beliefs and practices is not always apparent, many researchers have highlighted that teacher beliefs play a critical role in implementing reform initiatives in the science classroom [17–19]. In particular, task value beliefs that individuals place on an activity, along with their expectations for success, affect their choice and persistence to engage in as well as performance in the activity [20,21]. In their expectancy-value theory, Wigfield and Eccles [21,22] identify four major task value beliefs: Attainment value or Importance, Intrinsic value or Interest, Utility value or Usefulness, and Cost. Bearing this in mind, we expect that when preservice elementary teachers value the eight science practices outlined by the NGSS, they are more likely to implement them in their future classrooms. Stated differently, students may not be exposed to the practices that their teachers do not value or that they deem to be less important. Thus, it is imperative to understand the value preservice elementary teachers place on each of the science practices and their underlying reasoning for their valuation. From this understanding, science educators could gain implications for potential interventions to change preservice teachers' beliefs about science practices in a way that will promote their effective implementation of the science practices. To respond to this need, this study aimed to identify science practices that elementary preservice teachers identify as the most important and task values they ascribe to those practices, using the expectancy-value theory [22]. Taken together, this study was guided by the following research questions.

1. What is the impact of a science teaching methods course on elementary preservice teachers' understanding of the epistemic nature of the eight NGSS science practices?
2. What are elementary preservice teachers' beliefs about the eight NGSS science practices?

2. Theoretical Background

2.1. NGSS Science Practices

A major change from the National Science Education Standards [23] to the Next Generation Science Standards [2] is the shift from teaching science as inquiry to teaching science as practices. This shift was driven by the criticism that the concept of teaching science through inquiry creates "a confusion of the goal of science—to discover new knowledge about the material world—with the goal of learning science—to build an understanding of the existing ideas that contemporary culture has built about the natural and living world that surround us" [24] (p. 178). That is, there is a conflation of the two activities, doing science and learning science, which are characterized by their different goals [24,25]. Anderson [26] also identified three variations of inquiry: scientific inquiry (the various ways in which scientists investigate the natural world), inquiry learning (a process by which students acquire scientific knowledge), and inquiry teaching (the pedagogical approach by which teachers engage students in inquiry). In addition, there has been a lack of agreement on what it means to teach science through inquiry [24]. For example, many teachers and students interpret that inquiry equates to using hands-on activities. In this case, scientific inquiry is seen as a means of verifying the scientific explanation offered by the teacher [3,27]. Simply using science process skills with no testable questions or target scientific concepts is also counted as inquiry-based teaching.

Considering that the idea of teaching science as inquiry is inadequately articulated and communicated, NGSS replaces the term inquiry with engaging students in eight science practices, emphasizing that students should understand science as a set of ongoing practices that build upon a body of scientific knowledge [2]. With the launch of the NGSS, science education communities have sought to move US science education away from teaching isolated concepts and processes toward student engagement in science practices [11]. By engaging in essential science practices, students can understand not only science concepts but also improve critical thinking skills that empower them to become lifelong learners of science [3,28]. Students can also develop their understanding of how science works and how scientific knowledge is developed as well as the epistemic basis of science [6,29].

2.2. Teachers' Epistemic Understanding of Science Practices

The epistemology of science is a complex and multi-faceted construct that describes how scientific knowledge is developed, validated, and communicated as well as the practices engaged by the scientific community to continually build and refine the body of scientific knowledge [9,30]. Teachers' epistemic understanding of science requires that the educator understands "for what purposes and to what ends the practices are" [8] (p. 2). For example, science educators should not only understand that scientists analyze and interpret data, but also that scientists using the same procedures might get different results; that analytic procedures can influence conclusions; and that data produced by investigations must be analyzed to derive meaning [31]. As another example, consider that the NGSS practice of engaging in argument from evidence makes clear that teachers should understand that scientific data are different from scientific evidence [31]. By emphasizing the integration of practices, disciplinary core ideas, and crosscutting concepts, the NGSS requires significant epistemological and pedagogical shifts on the part of teachers [11]. Particularly, teachers' understanding of both how to perform science practices appropriately and why they are doing what they are doing is critical to the successful engagement of students in science practices as a means to learn disciplinary core ideas and crosscutting concepts [6]. Park et al. [31] demonstrate that secondary science teachers' understanding of the epistemic nature of the science practices as well as their epistemic orientations predict their implementation of science practices. Hence, in order to create learning environments for their students to develop both scientific knowledge and scientific processes concurrently, teachers need a deep understanding of the epistemic nature of the science practices in addition to strong conceptual and procedural knowledge of the sciences [3,10]. The importance of incorporating epistemic knowledge of science into science curricula has been widely advocated by many science educators in the form of explicit instruction on the nature of science, ideas about science, etc. [32–34]. However, few studies have investigated teachers' epistemic understanding of science practices specifically, especially with pre-service teachers.

2.3. Task Value Beliefs and Teaching Practice

Achievement motivation theorists have attempted to explain how motivation influences individuals' choice, persistence, and performance of achievement tasks [35,36]. Motivation predicts academic achievement beyond cognitive ability [37]. A widely accepted approach to motivation is the expectancy-value theory [22,38]. In this theory, expectations of success and subjective task value are identified as the two major components that influence individuals' effort, choices, and achievement in a variety of contexts, including academic achievement on different educational levels [38–41]. In other words, individuals' choice of achievement tasks, persistence in those tasks, and performance in them can be explained by their beliefs about how well they will do on the activity and the extent to which they value the activity [20,21,42].

According to the expectancy-value model, expectations for success and personal efficacy is the main factor that influences individuals' task, activity, or behavior choices [35,43,44]. Subjective task value is the second major component of the expectancy-value model of achievement-related choices. Eccles et al. [20] explain that life-defining choices are influenced by the subjective task value individuals attach to the various achievement-related options. In the longitudinal study with approximately 1000 high school seniors, Eccles [38] examined the relationship among personal expectation/efficacy for success, subjective task values, and occupational choice. They report that students' expectations for success and personal efficacy predict their occupational choice, but they are not the only factor. Students' decisions to enter particular occupations appear to depend on the value they attach to various occupational characteristics.

The defined components of the subjective task value beliefs are Attainment value or Importance, Intrinsic value or Interest, Utility value or Usefulness, and Cost [20–22,38,45]. According to Eccles et al. [20], Attainment value is defined as the personal importance ascribed to succeeding in a given task. Attainment value can be related to personal or collective identities individuals develop as they grow up by performing well in a task [38]. Intrinsic value is defined as the enjoyment an individual experiences when engaging in a task or the subjective interest in a task. When individuals perform tasks that are intrinsically valued, positive psychological consequences are the reward [22]. Utility value describes the perceived personal usefulness of engaging in a task or how a task fits into an individual's future plans. For example, taking a math class to fulfill a requirement for a science degree. While Intrinsic value is similar to intrinsic motivation, Utility value can be viewed as extrinsic motivation as described in the self-determination theory [38,45–47]. Cost refers to the cost of participating in the activity, which is influenced by many factors such as anticipated anxiety, fear of failure, fear of the social consequences of success, and the loss of time and energy, etc. [38]. Cost also includes the amount of perceived effort that has to be utilized in order to succeed [20]. It is important to note that our participants are preservice teachers who have not engaged in the activity of teaching yet. In this regard, preservice teachers' subjective task values discovered from this study should be interpreted as their "envisioned" task values of eight science practices. Considering that preservice teachers' subjective task value of science practices would affect their implementation of science practices in their future classrooms, we aimed to examine what value preservice teachers ascribe to the science practices that they choose as most important.

3. Methods

3.1. Participants

The participants of this study were elementary preservice teachers who enrolled in a 3-credit elementary science teaching methods course during their junior or senior year at a state university in the US. Due to the small size of each preservice teacher cohort, this study was conducted over eight consecutive semesters, including summer, with the same instructor. A total of 120 elementary education majors registered for the course, but 109 preservice teachers participated in both pre- and post-surveys. Among 109 participants, 94 are female and 15 are male; 98 are Caucasian, 6 are African American, 3 are Hispanic, 2 are Asian; 98 are between the ages of 20 and 25, 7 are between 25 and 30, and 4 are between 30 and 35. All of the participants had completed a 3 or 4-credit science foundation course prior to taking the elementary science teaching methods course. The science methods course was the only course that the participants learned about NGSS science practices. Specifically, the methods course aimed to prepare elementary preservice teachers to create effective science learning environments for elementary students and to increase their understanding of NGSS science practices to help them teach science as practice. The course covered the eight science practices implicitly and explicitly in various contexts including lectures, group discussions, hands-on activities, practicum, etc. Participants discussed the meaning of each practice using the NGSS documents and analyzed elementary science teaching videos in terms of the eight science practices. Participants also engaged in science practice themselves during the methods course. For example, in the lesson focused on "Models in science teaching", participants carried out various experiments and hands-on activities that required using scientific models and modeling. In addition, they had opportunities to discuss why scientists use models and why using models is important in science teaching as well as strategies to incorporate scientific models and modeling in their future classrooms connecting them to the NGSS. All names used throughout the manuscript are pseudonyms. Most of the class time was spent on group discussions and hands-on activities followed by a short lecture related to the topic of the day. Throughout the semester, preservice teachers engaged in short research activities such as determining the best paper towel, but due to time constraints, they were not able to participate in an authentic science research experience. Additionally, the course included a three-week practicum during which preservice teachers taught three lessons to local elementary students.

3.2. Data Collection

To measure the changes in elementary preservice teachers' understanding of the NGSS science practices, we administered an open-ended survey called the "Epistemic Nature of Science Practices (ENSP)" at the beginning and end of each semester. This survey was developed and adopted in our previous study, which aimed to explore secondary science teachers' understanding of the epistemic nature of science practices [11]. The ENSP survey consists of eight open-ended questions corresponding to each of the eight science practices. The eight survey questions and target science practices are shown in Appendix A. In addition to the eight questions, the post-survey included two additional questions that asked participants to rank the eight practices by their perceived importance of each practice from most important (1) to least important (8) and to describe why they felt that their top three practices are important for students' science learning. The survey was conducted during class and took approximately 15–20 min to complete. Their participation and performance on the survey did not impact their grades.

3.3. Data Analysis

Participants' written responses to the eight questions about the epistemic nature of science practices were scored using a rubric that was modified from the original rubric used in the previous study [11] to improve clarity and to fit preservice teachers. Two researchers scored participants' written responses from the first three semesters separately. Any discrepancies were discussed until they reached an agreement and the scoring rubric was refined accordingly. The initial inter-rater agreement was 84.0%. Then, the same two researchers separately scored the remaining data with the refined rubric, regularly discussing any discrepancies found in their scores to reach an agreement. A paired samples *t*-test was conducted to compare the pre-and post-survey scores in order to measure the changes in preservice teachers' understanding of the epistemic nature of science practices. Both the total score and the sub-scores for each science practice were compared between the pre- and post-survey.

Preservice teachers' perceptions of the importance of science practices were analyzed through average ranking scores and the number of participants who chose each practice as their top three. Preservice teachers' justifications for their top three were analyzed using qualitative content analysis. The four main concept-driven categories were derived from the components of the expectancy-value theory: (1) Attainment—achievement of immediate instructional goals or helping students achieve proficiency in science practices, (2) Utility—building skills for future application outside the classroom, (3) Interest—enhancing student motivation, and (4) Cost—barriers to implementation of science practices in the classroom. Within each of the main categories, data-driven subcategories were identified with specifications from the coding scheme used in the previous study and through open coding of the data for this present study. The definition of each sub-category is presented in Appendix B. Once the categories and subcategories of the coding scheme were finalized, we analyzed all participants' responses to the justification question and counted the frequency of each subcategory and category.

4. Results

4.1. Understanding of the Epistemic Nature of Science Practices

The paired samples *t*-test of the pre- and post-survey with 109 participants shows that the total mean score of ENSP increased significantly ($p < 0.05$) between the beginning ($M = 9.00$, $SD = 3.18$) and end of the methods course ($M = 10.96$, $SD = 4.51$), as reported in Table 1. The mean scores of all eight science practices increased, but the increment for four practices (Practices 1, 2, 5, and 6) was statistically significant ($p < 0.05$). This indicates that the elementary preservice teachers' understanding of the epistemic nature of the NGSS science practices improved over the methods course overall, but this improvement was more notable for certain practices than others.

Table 1. *t*-test results of survey scores in each practice ($N = 109$).

Science Practices	Survey Question	Pre-Mean (*SD*)	Post-Mean (*SD*)	*t* (Sig. 2-Tailed)
1. Asking questions	Q6	0.57 (1.15)	1.00 (1.51)	2.30 * (0.024)
2. Developing and using models	Q5	1.12 (0.73)	1.43 (0.75)	3.19 * (0.003)
3. Planning and carrying out investigations	Q7	1.80 (1.30)	2.05 (1.32)	1.43 (0.160)
4. Analyzing and interpreting data	Q3	1.45 (0.78)	1.54 (0.80)	0.90 (0.361)

Table 1. *Cont.*

Science Practices	Survey Question	Pre-Mean (*SD*)	Post-Mean (*SD*)	*t* (Sig. 2-Tailed)
5. Using mathematics and computational thinking	Q4	0.68 (0.73)	1.21 (0.99)	4.69 * (<0.001)
6. Constructing explanations	Q2	0.83 (0.75)	1.06 (0.80)	2.47 * (0.021)
7. Engaging in argument from evidence	Q8	1.21 (0.81)	1.32 (0.88)	1.10 (0.272)
8. Obtaining, evaluating, and communicating information	Q1	1.34 (0.64)	1.36 (0.63)	0.25 (0.821)
Overall Score		9.00 (3.18)	10.96 (4.51)	4.15 * (<0.001)

$N = 109$ $p < 0.05$ * Note: maximum score for each practice: 4, total score: 32.

4.2. Perceived Importance of Science Practices

Table 2 presents the relative significance of the eight science practices, measured by ranking scores and the number of participants who chose each practice as their top three. Analysis of preservice teachers' average ranking scores reveals that preservice teachers ranked Asking questions, Planning and carrying out investigations, and Analyzing and interpreting data as the most important science practices to support student science learning. Using mathematics and computational thinking and Engaging in argument from evidence were ranked as least important.

Table 2. Ranking scores of the science practices in the post-survey (*N* = 109).

Science Practices	Average Ranking Score (Frequency)
Asking questions	1.57 (73)
Planning and carrying out investigations	3.65 (41)
Analyzing and interpreting data	4.15 (45)
Developing and using models	4.32 (24)
Constructing explanations	4.94 (20)
Obtaining, evaluating, and communicating information	5.05 (10)
Using mathematics and computational thinking	6.07 (35)
Engaging in argument from evidence	6.25 (25)

Note: Science practices with lower average ranking scores are perceived as more important than higher scores because we asked participants to rank the practice from most important (1) to least important (8).

4.3. Values Attributed to Science Practices Identified As Important

Based on participants' justifications for their top three practices, Tables 3 and 4 show the values they ascribed to the practices of their choice. Preservice teachers most frequently attached the Attainment value to science practices they chose to be most important for student science learning, making up 71.7% of the total quotations (175 of 244 quotations). Only 44 (18.0%) quotations were attached to the Utility value while 25 (10.2%) quotations were attached to the Interest value. The category of Cost did not appear in our preservice teachers' responses.

Table 3. Values attributed to important science practices (N = 244).

Attainment Value	*n*	Utility Value	*n*	Interest Value	*n*
A—Building science practices	86	U—Building transferable skills	35	I—Stimulating student curiosity	12
A—Enhancing learning	35	U—Developing student thinking	9	I—Engaging students	4
A—Understanding the nature of science	45			I—Providing hands-on learning	2
A—Students demonstrate understanding	9			I—Student-centered learning	7
Total frequency	175 (71.7%)		44 (18.0%)		25 (10.2%)

Table 4. Categories and sub-categories of task values.

Category: Attainment Value			
Sub-Category	Specification		
A1. Building science practices (*n* = 86)	A1.1. Communicating/sharing findings (20) A1.2. Developing/discovering new ideas/theories/knowledge (8) A1.3. Constructing explanations (27) A1.4. Finding/using evidence to support claims (4) A1.5. Supporting/guiding investigations (19) A1.6. Evaluating ideas (8)		
A2. Enhancing learning (*n* = 35)	A2.1. Increasing depth of understanding (17) A2.2. Building conceptual understanding (13) A2.3. Forming links with the prior knowledge (5)		
A3. Understanding the nature of science (*n* = 45)	A3.2. Questions are fundamental to science (23) A3.3. Science practices are the foundation of science (22)		
A4. Students demonstrate understanding (*n* = 9)	A4.1. Students demonstrate understanding (6) A4.2. Students reflect on their learning (3)		
Category: Utility value			
Sub-category	Specification		
U1. Building transferable skills (*n* = 35)	U1.1. Transferable skills for everyday life (23) U1.2. Develop scientific literacy (5) U1.3. Transferable skills for other subjects (7)		
U2. Developing student thinking (*n* = 9)	U2.1. Developing critical thinking (7) U2.3. Thinking outside the box (2)		
Category: Interest value			
Sub-category			
I1. Stimulating student curiosity *n* = 12	I2. Engaging students *n* = 4	I.3. Providing hands-on learning *n* = 2	I.5. Student-centered teaching *n* = 7

Within the Attainment value category, preservice teachers identified Building science practices (86/175) as a primary justification for their ranking. As presented in Table 4, preservice teachers expressed that the practices they chose were most valuable because they are essential procedures for constructing explanations (27/86), communicating findings (20/86), supporting investigations (19/86), evaluating ideas (8/86), discovering new knowledge (8/86), and using evidence to support claims (4/86). As an example, a preservice teacher perceived that Practice 8 (Obtaining, evaluating, and communicating information) is important because it is necessary to construct an explanation during an investigation and communicate it with others, saying,

> The last practice that I believe is very important is practice eight, obtaining, evaluating, and communicating information. Once someone has a question, they should be able to obtain and evaluate information to construct their explanation. Then, they should be able to communicate those thoughts with others. (Summer 2020, Katie)

Understanding the nature of science (45/175) was the second most frequent subcategory under the Attainment value category with a number of quotations indicating that questions are fundamental to science (23/45) and science practices are the foundation of science (22/45). For example, as demonstrated in the quotation below, a student explained that Practice 1 (Asking questions) is important because asking questions is a foundation of science, and thus, without questions, an investigation itself cannot exist.

> The reason why I believe that practice 1 is important is because questions are the root and essence of science and engineering. Without questions, there would not be investigations, and there would not be solutions. Questions are the foundation to science and engineering, and it is important that students develop the ability to ask questions and define problems. (Spring 2021, Shelby)

This implies that some of the preservice teachers viewed scientific methods as a linear sequence, perceiving that science always begins with scientists' questions. This perspective appeared mostly in relation to Practice 1.

Enhancing learning (35/175) through increasing the depth of students' understanding (17/35), building conceptual understanding (13/35), and forming links with prior knowledge (5/35) was the third most frequent justification for the importance of practices that were ascribed to Attainment value. Responses assigned to this subcategory were frequently mentioned regarding Practice 2 (Developing and using models). The following quotation exemplifies the idea that science practices (Developing and using models, in this example) can enhance student learning by increasing the depth of students' understanding of science.

> I think models are very important because it allows deeper and more accurate learning to happen. Many times, science topics are not easily able to be observed or may even be close to impossible to observe. This practice will help students to visualize and understand concepts that are not easy to observe. It can help students understand better and help them develop less misconceptions. (Fall 2020, Abbi)

The Utility and Interest values received 44 (18.0%) and 25 (10.2%) quotations, respectively. Justifications classified under Utility value focused on Building transferable skills (35/44) and Developing student thinking (9/44). Some preservice teachers described that science practices are important because they develop transferable skills for everyday life (23/35) and other subjects (7/35) as well as develop scientific literacy (5/35). Building transferable skills was connected more frequently to Practices 1 (Asking questions), 3 (Planning and carrying out investigations), and 8 (Obtaining, evaluating, and communicating information). Only 9 quotations among 244 described that science practices develop student thinking: developing critical thinking (7/9) and thinking outside the box (2/9). This type of response was mostly connected to Practice 1 (Asking questions) and Practice 6 (Constructing explanation). As an illustration, in the following quotation, a preservice teacher connects Practice 3 and transferable skills for everyday life.

> They can take the practices they learn from their investigations and apply them at home and in real life. It is important for students to know how to carry out investigations so they can answer their own questions in their lives outside of school. (Fall 2020, Andy)

Preservice teachers who referred to Interest value focused heavily on the ideas of Stimulating student curiosity (12/25) and Encouraging student-centered learning (7/25). Stimulating student curiosity was mostly connected to Practice 1 (Asking questions) while Encouraging student-centered learning was mostly connected to Practice 3 (Planning and carrying out investigations) as shown in Taylor's quotation and Sam's, respectively, as follows.

> Questions also spark curiosity in students. If the students know they can ask questions and they can get answers, they are more likely to enjoy science. (Fall 2020, Taylor)

> I chose Planning and carrying out investigations, this is important because it allows students to engage and explore their own findings from top to bottom or start to finish instead of just evaluating work that has already been done. (Spring 2022, Sam)

5. Discussion and Implications

The findings of this study reveal that preservice teachers' epistemic understanding of the practices improved over the methods course. Regarding the relative significance of the eight science practices, preservice teachers ranked Asking questions, Planning and carrying out investigations, and Analyzing and interpreting data as the most important science practices to support student science learning. Preservice teachers most frequently associated Attainment value with the science practices they considered to be most important for student science learning.

With respect to the first research question, there was an improvement between pre- and post-survey scores on the understanding of the epistemic nature of the NGSS science practices. Among eight practices, the scores of Practices 1 (Asking questions), 2 (Developing and using models), 5 (Using mathematics and computational thinking), and 6 (Constructing explanations) increased significantly. Interestingly, these four practices had lower scores than the others on the pre-survey. This finding is consistent with the assertion from previous studies that teachers often have an insufficient understanding of these four practices. Specifically, many teachers explain scientific methods as a linear procedure and that the procedure must start with a question [11]. Teachers also exhibit a limited understanding of models and their utility for promoting scientific inquiry [48–50]. Many teachers consider models as teaching tools to explain science concepts to students but rarely perceive models as learning tools for making sense of natural phenomena [11,49]. They identify the role of models as representing or explaining ideas, rarely including predicting phenomena, generating hypotheses, testing ideas, or communicating scientific knowledge [11]. Using mathematics and computational thinking is an unfamiliar practice to most teachers, so they have difficulties connecting it to their curriculum [51]. Teachers usually provide explanations to their students, not requesting students to construct explanations themselves [52]. Our findings indicate that the preservice teachers' initial understanding of the four practices in terms of their epistemic nature was very limited, but their understanding improved throughout the science teaching methods course.

The overall post-survey score (i.e., 10.96) increased compared to the pre-survey score (i.e., 9.00), and it is close to the one from our previous study with 128 in-service teachers using the same survey (i.e., 10.67) [31]. This finding indicates that various class activities focusing on the eight science practices in the science methods course contributed to preservice teachers' better understanding of the epistemic nature of science practices. However, the score is still low considering that the maximum score is 32. This implies that, in order to improve preservice teachers' understanding, they need more purposeful learning experiences through which they actually engage in the practices themselves such as authentic research experiences [3,11].

With respect to the second research question, the preservice teachers in this study perceive that Asking questions is the most important science practice. While some participants perceive that asking questions supports student science learning by stimulating curiosity and engaging students, a majority of participants describe that asking questions is the necessary initial step for scientific investigation because science always begins with scientists' questions. Among 73 participants who chose Asking questions as one of their top three practices, 23 participants described that Asking questions is a foundation of science and that investigation itself cannot exist without questions. This implies that a great number of preservice teachers view the scientific method as a step-by-step linear process, which shows their limited understanding of the nature of science. This lack of understanding prevents preservice teachers from viewing asking questions as a part of the intertwined yet coherent process of scientific investigation [11,53]. Developing an understanding of the crosscutting concepts and disciplinary ideas of science is another critical objective of engaging students in science practices [1]. By engaging in the practice of Asking questions, students activate their prior knowledge and elaborate on current knowledge [54,55]. However, preservice teachers rarely connected Asking questions with student learning of science content.

Another interesting finding is that the preservice teachers view Engaging in argument from evidence as the least important. This finding is consistent with the findings of many previous studies that teachers often lack an understanding of argumentation and rarely or inappropriately incorporate it in their science lessons [56–58]. All claims in science require justification based on a body of accumulated data and warrants [24]. A growing number of studies have reported that students improve their conceptual learning, meta-knowledge of science, and use of verbal and non-verbal reasoning when they engage in argumentation [24,59,60]. Thus, engaging in scientific argumentation is critical to students' development of epistemological perspectives of science and their learning of scientific knowledge [61]. Teachers' beliefs about argument can act as a crucial factor influencing whether or not and how they design and implement argumentation in their science classrooms [62,63]. In this respect, science teacher education programs should support preservice teachers to understand the significance of argumentation in science as well as how to include argumentation as a core activity of science teaching and learning.

The three most selected practices as important for student science learning (i.e., Asking questions, Planning and carrying out investigations, and Analyzing and interpreting data) imply that the preservice teachers perceive the primary practice of science as "doing experiments" [24] (p.188). The model of science activity presented in the NGSS consists of three areas: investigating, evaluating, and developing explanations and solutions [2]. Among these three areas, the preservice teachers seem to place the highest value on investigating. As planning and carrying out a systematic investigation including observing, experimenting, measuring, and testing has been asserted as a major practice of scientists [64], teachers should also understand the importance of evaluating and developing explanations and solutions. Contrary to the popular image of science such as "doing experiments" or "doing investigating", scientists and engineers spend more than 50% of their time engaged in reading and writing science [65]. Preservice teachers need to relate the importance of evaluation and communication practices to scientific literacy [66], which includes individuals' ability to construct meaning through interactions with the multiple forms of semiotic communication used in the discipline of science [67]. Writing and arguing are core activities of doing science and preservice teachers should understand them as such [68]. Mathematics and computational thinking are also central to science because they support "the description of the material world enabling systematic representation that is the foundation of all scientific modeling and the clear communication of meaning" [24] (p. 187).

An important finding regarding values the preservice teachers ascribe to their top three important practices is that they most frequently refer to the Attainment value, perceiving each practice as a means for building other science practices rather than for enhancing student learning. The most frequent quotations usually mention that practices are the essential procedures to construct explanations, communicate findings, and support investigations. Only a few responses focus on student learning in terms of science concepts and the nature of science. This implies that the preservice teachers do not have a sophisticated understanding of the principles underpinning the NGSS that intertwine science content learning and science practices under the umbrella of crosscutting concepts and the epistemic nature of science [2,69]. Engaging in practices is meaningful only "if it helps students to develop a deeper and broader understanding of what we know, how we know and the epistemic and procedural constructs that guide the practice of science" [24] (p. 183).

Regarding the Utility value, some preservice teachers mention that the practices can both build transferable skills for students' everyday lives or other subjects and develop students' thinking skills. These responses are meaningful considering that a primary goal of science education is to help students develop transferable skills and habits of mind that will allow them to thrive in modern society as critical thinkers and scientifically literate citizens [1,70]. Thus, efforts should be made to support preservice teachers to develop abilities to identify concrete links between the practices in which students engage in their future classrooms and their everyday lives. It should be noted that despite a heavy emphasis on Attainment values, some quotations addressed Interest values, highlighting the importance of intrinsic motivational factors on student science learning. This finding indicates that the preservice teachers recognized the critical roles of affect and motivation in science learning that have been supported by a growing number of research [71,72].

No responses related to Cost were found in our preservice teachers' responses. The Cost can include any barriers to the implementation of science practices in the classroom [22]. Further research is needed to better understand preservice teachers' perceived barriers to the implementation of the NGSS science practices in their classroom, which will provide implications for interventions and strategies to support their teaching of science as practices. Taken together, this work demonstrates that further efforts are needed to develop meaningful learning experiences for preservice science teachers that allow them to experience science as practices, help them develop an appropriate and nuanced understanding of the process of science, diversify the value that they attach to scientific practices and provide them with concrete methods for engaging their students in each of the practices.

Author Contributions: Conceptualization, E.S., S.P. and V.K.; Methodology, E.S., S.P. and V.K.; Data analysis, E.S. and S.P.; Writing—original draft preparation, E.S.; Writing—review and editing, S.P., V.K. and A.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This research project was exempt from IRB review according to federal regulations (45 CFR 46).

Informed Consent Statement: Participant consent was waived because this project was exempt from IRB review as a commonly accepted educational practice.

Data Availability Statement: We are unable to share the data due to privacy and anonymity concerns.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Epistemic Nature of Science Practices survey questions.

Survey Question	Target Science Practice
1. For what purposes do you think scientists strive to obtain information from multiple authoritative sources such as scientific literature or media reports?	8. Obtaining, evaluating, and communicating information
2. How do scientists develop explanations of natural phenomena from scientific investigations?	6. Constructing explanations
3. If several scientists ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not.	4. Analyzing and interpreting data

Survey Question	Target Science Practice
4. In what ways do you think mathematical and computational thinking contributes to scientific investigation?	5. Using mathematics and computational thinking
5. In what ways do you think models can be used to facilitate students' science learning in your classroom?	2. Developing and using models
6. Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no". Whom do you agree with and why?	1. Asking questions
7. Two teams of scientists are walking to their lab one day and see a car pulled over with a flat tire. They all wondered, "Are certain brands of tires more likely to get a flat?" Team A went back to the lab and tested various tires' performance on one type of road surface. Team B went back to the lab and tested one tire brand on three types of road surfaces. Explain why one team's procedure is better than the other one.	3. Planning and carrying out investigations
8. What do you think is the main role of argumentation in doing science? Why do you think so?	7. Engaging in argument from evidence

Two additional questions
9. Please rank the practices below to indicate how important you feel they are in helping students fully understand science core ideas from most important (1) to least important (8).
(1) Analyzing and interpreting data
(2) Asking questions
(3) Constructing explanations
(4) Developing and using models
(5) Engaging in argument from evidence
(6) Obtaining, evaluating, and communicating information
(7) Planning and carrying out investigations
(8) Using mathematics and computational thinking
10. Please describe why you feel that each of the practices you identified as a member of the top three is important.

Appendix B. (Modified from McCance et al. [73])

Definition of each sub-category.

Attainment Value	
Sub-Category	Definition
Building science practices	Engaging students in these science practices is valuable for building students' understanding of and proficiency with any of the eight NGSS science practices.

Enhancing learning	The practices are valuable for enhancing students' learning by building their conceptual understanding, increasing the depth of their understanding, and forming links with their prior knowledge.
Understanding the nature of science	Engaging students in these science practices helps students to understand the nature of science that questions are fundamental to science and individual science practices form the foundation of scientific inquiry
Students demonstrate understanding	Engaging students in these practices is a useful outlet for students to demonstrate and reflect on their understanding of scientific concepts.
Utility value	
Sub-category	Definition
Building transferable skills	Engaging students in these practices allows students to build skills and scientific literacy that they can transfer or use in other subjects or their lives.
Developing student thinking	Engaging students in these practices builds their critical thinking skills and helps them to think "outside the box"
Interest value	
Sub-category	Definition
Stimulating student curiosity	Engaging students in these practices builds or engages students' curiosity
Engaging students	Involving students in these science practices enhances student engagement.
Providing hands-on learning	Engaging students in these science practices is a practical way to provide students with opportunities for "hands-on" learning.
Student-centered teaching	Engaging students in these practices is a useful tool for building a student-centered classroom.

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