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What are They Good For? The Importance and Value of NGSS Science Practices

Gary W. Wright
University of Missouri

Vance Kite
Kenan Fellows Program for Teacher Leadership

Soonhye Park
North Carolina State University

ABSTRACT

This study aimed to identify the Next Generation Science Standards (NGSS) science practices secondary science teachers considered as most important, to determine what type of value teachers ascribed to those practices, and to examine any correlations between teachers' perceived importance of the practices and their self-reported implementation. An electronic survey was used to collect multiple forms of data from 128 secondary science teachers. Quantitative data was analyzed using descriptive statistics, average ranking scores, and Spearman's rank correlation coefficient. Qualitative data was analyzed through qualitative content analysis using Wigfield and Eccles' (2000) Expectancy-Value Theory (EVT) as an analytic framework. Our findings indicate that: (1) teachers ranked asking questions as the most important science practice, and mathematics and computational thinking as least important; (2) teachers most frequently attached attainment value to the usefulness of the practices; and (3) the correlations between teachers' rankings of the practices and their self-reported implementation were mixed. The rank-implementation mismatches can be interpreted as an outcome of teachers' misconceptions about some of the science practices. This study highlights the need for teacher education initiatives that promote teachers' implementation of and long-term utility value of proficiency with all eight of the science practices.

Keywords: NGSS science practices, Expectancy Value Theory, teachers' values, science practice implementation, teacher education

Introduction

Science education in the United States (US) has been criticized for focusing on unidirectional transmission of science content from teacher to student and rote memorization of scientific facts (Osborne, 2014; Richmond et al., 2016). Alternatively, there has been a growing consensus in science education literature that science consists of a series of practices, and thus, science practices should be placed at the center of science teaching and learning (Aleixandre & Crujeiras, 2017; Duschl, 2008; Osborne, 2014). The emphasis on science-as-practice was translated into policy documents such as the Framework for K-12 science education (National Research Council [NRC], 2012) and the Next Generation Science Standards ([NGSS], NGSS Lead States, 2013a) in the US. The term "practice" is specifically used to highlight that for students to engage in authentic science investigations, they need not only skills but also knowledge specific to each science practice (NRC, 2012). Prioritizing science practices represents the significance of involving students in core science practices as a means to achieve cognitive, epistemic, and social learning goals in science (Duschl, 2008; NGSS Lead States, 2013a).

To address these concerns, the introduction of the NGSS aimed to transform approaches to science education by emphasizing science as an ongoing process rather than presenting it as static facts. The NGSS put forth eight key science practices that students should learn to grasp Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and the epistemology of science (NGSS Lead States, 2013a). These practices include: (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 (NGSS Lead States, 2013a). Acknowledging that helping students develop knowledge of, and proficiency with, these practices will take time and purposeful instruction. In fact, the NGSS explicitly states that "students in grades K-12 should engage in all eight practices over each grade band" (NGSS Lead States, 2013a, p. 2), and suggests these practices should be interwoven into instruction in a coherent learning progression.

While research shows that engaging students in science practices enhances their understanding of science content, processes, and epistemic knowledge, doing so imposes profound demands on teachers (Crawford & Capps, 2016; Nollmeyer & Bangert, 2017) and teachers often struggle to implement the practices (e.g., McNeill et al., 2017). There must be a shift in science teachers' epistemological, procedural, and conceptual understanding of science (Crawford & Capps, 2016; Kite et al., 2021). Hence, there is an imperative need for research that provides insight into how to support science teachers' implementation of science practices. The present study responds to this call by focusing on the value, a critical component of teachers' beliefs, that science teachers attribute to the science practices. This is because science teachers' implementation of the science practices requires a considerable shift in their beliefs, professional knowledge, and skills (Park et al., 2022).

Researchers have highlighted the role of science teachers' values in mediating their implementation of reformed science teaching practices (e.g., Herrington et al., 2016). Values have been conceptualized as highly personal and relatively durable drivers of an individuals' overarching worldview and behaviors (Schwartz, 1994; Wallace & Priestley, 2017). Herrington et al. (2016) noted that values are "a central driver for action" (p. 186) and demonstrated through their research that teachers with stronger values towards implementation of reformed teaching practices were more motivated to implement reformed teaching in their science classrooms. Likewise, Wigfield and Eccles (2000) posited that individuals' motivations to engage in a particular task depends on the value that they place on the task, as well as their expectancy for success. Consequently, we infer that there may be a relationship between the value that teachers place on each of the science practices and the likelihood of them implementing those practices in their classrooms. The logical consequence of this inference is that teachers may not expose their students to practices that they believe to be less valuable for learning.

Despite increased attention to the importance of engaging students with the NGSS science practices and the critical role of teachers' beliefs in their instructional practice, little effort has been directed towards examining secondary science teachers' perceived task value - a critical component of teacher beliefs - and the importance of each of the eight science practices. Although there is a notable body of literature on the relationship between teacher beliefs and practices in general (e.g., Martin et al., 2019; van Aalderen-Smeets & van der Molen, 2015; Wallace, 2014), research paying specific attention to task values is scarce (e.g., Herman et al., 2017; Herrington et al., 2016) despite its important role in teacher belief systems (Eccles & Wigfield, 2020). This study aimed to fill this gap.

In this study, we employed Expectancy-Value Theory (EVT) (Wigfield & Eccles, 2000) as a theoretical framework to qualitatively examine the science practices that secondary science teachers perceive as most important for students' science learning, with no relation to individual teachers' overall values for the practices, the value they ascribe to those practices, and the relationship between the practices they value and the practices they implement. This study was guided by the following questions:

> (1) Which of the eight NGSS science practices do secondary science teachers consider most important and what value do they ascribe to those practices?
> (2) What is the relationship between secondary science teachers' ascribed importance of each of the science practices and their self-reported implementation of each of the practices?

Findings from this study contribute to a better understanding of the relationships between teachers' values and their instruction -- especially with respect to the science practices that have received significant attention in the broader science education community beyond the US (Stroupe, 2015). In addition, this study will provide insights to inform strategies to promote teachers' implementation of the science-as-practice approach to teaching science from the perspective of teacher task value as an important motivational factor influencing instructional decisions.

Theoretical Frameworks

Science Practices as Both Process and Product of Students' Science Learning

Promoting students' scientific literacy has been an ongoing goal of science education reform and has informed national science standards in many countries including the US (e.g., NRC, 2012; Organization for Economic Co-operation and Development [OECD], 2019; Roberts & Bybee, 2014). Scientific literacy is defined as the ability to scientifically explain phenomena, engage in scientific inquiry, and interpret data and evidence through the integration of content, procedural, and epistemic knowledge (OECD, 2019). To facilitate this goal, the NGSS outline eight science practices to support students and teachers in navigating the larger cognitive, epistemic, and social learning goals of authentic scientific inquiry (Duschl, 2008). Through engaging in science practices, students can develop an understanding of how scientific knowledge is constructed and applied (Berland et al., 2016), internalizing "what we know, how we know, and the epistemic and procedural constructs that guide the practice of science" (Osborne, 2014, p. 183).

As conceptualized in the NGSS, these science practices represent both instructional strategies and learning outcomes. Rather than existing as discrete skills of scientific inquiry that can be mastered by students, teachers are to engage students in these eight practices on a regular basis as a means of building students' proficiency with each and to help students internalize the process and practice of contemporary science. The NGSS envisioned science classrooms where students build knowledge, skill, and epistemic understanding by "practicing" science (Bybee, 2011). Building classrooms rooted in rich scientific practice, however, depends on teachers understanding each of the practices and valuing the practices as both a process and product of student learning.

Teacher Beliefs, Values, and Practice

Teachers' beliefs and values about the nature of teaching and learning act as filters that guide their instructional decisions. A number of studies have suggested a positive association between teachers' beliefs and their decisions about both curriculum and pedagogy (Biesta et al., 2015; Suh &

Park, 2017; van Aalderen-Smeets & van der Molen, 2015; Wallace, 2014), and demonstrated that teachers' beliefs strongly influence their science teaching and the implementation of alternative forms of practice (Lotter et al., 2016; Lumpe et al., 2012; Martin et al., 2019). Particularly, teachers resist implementing innovative teaching approaches or curriculum materials that contradict their beliefs about either the purpose of teaching science or how science should be taught (Bryan, 2012; Wallace, 2014). Hence, for any reform movement that requires changes in teachers' practices to be successful should carefully consider teachers' beliefs.

Eccles (2009) provides some explanation of the relationship between teachers' beliefs, their values, and their instructional practice. Specifically, Eccles (2009) has pointed out that the likelihood of an individual engaging in an activity is driven by a combination of their beliefs about who they are, what they are good at, and the subjective value they place on an activity. If a teacher believes that an instructional approach is valuable for their students, and if they feel confident that they can adequately implement the strategy, then they are likely to pursue enactment. Herrington et al. (2016) highlighted the importance of science teachers' values in their work, demonstrating that teachers whose science teaching values shifted towards prioritizing long term student growth (utility value described below) during professional development were more likely to implement inquiry-based teaching with their students and to encourage their colleagues to do so as well. Further, Herman et al. (2017) showed that teachers with high utility value for teaching the nature of science (NOS) (i.e., they thought teaching NOS would prepare students to be scientifically literate, lifelong learners) demonstrated stronger implementation of NOS in their classrooms. Therefore, to support teachers to engage students in the science practices, it is necessary for science teachers to value the practices as critical to students' long-term success and believe them to be aligned with their own goals of science teaching. Understanding teachers' current individual values regarding the science practices is a critical first step towards this goal.

Expectancy-Value Theory (EVT)

EVT of achievement (Wigfield & Eccles, 2000) served as both a theoretical and analytic framework for our investigation of the value that secondary science teachers place on the science practices outlined in the NGSS. According to EVT, an individual's choice to engage in achievement-related activities is governed by both their expectancy for success and the value that they place on the activity or outcome (Wigfield & Eccles, 2000). EVT has been used in previous research as a model to understand science teachers' implementation of innovative pedagogies, but has yet to be applied to the context of the NGSS science practices (e.g., Lee & Blanchard, 2019). EVT identifies four key factors that shape an individual's decision to engage in an activity: intrinsic value or interest, attainment value or importance, utility value or usefulness, and cost (Eccles et al., 1983; Wigfield & Eccles, 2000). Eccles et al. (1983) defined intrinsic value as the enjoyment an individual experiences when engaging in a task. Attainment value is the importance of doing well on the given task, while utility value refers to how the task will affect an individual's future plans. Cost value has received minimal attention in research but is broadly concerned with how engaging in the task will affect participation in other activities, the effort required to complete the task, and the emotional costs (Wigfield & Eccles, 2000). In this study EVT served dual purposes. First, it was used to guide the development of our coding frame for qualitative content analysis. Specifically, EVT informed our four categories of values: interest - enhancing student motivation; attainment - achievement of immediate instructional goals or helping students achieve proficiency in scientific practices; utility - building students' skills for future application outside the classroom; cost - barriers to implementation of scientific practices in the classroom. Second, we interpreted the results of our analysis through EVT as a theoretical framework to draw conclusions regarding secondary science teachers' values of science practices in relation to their self-reported implementation of those practices.

Methods

Study Design

This study used an open-ended online survey administered to secondary science teachers in a Southeastern State in the U.S. Given the exploratory nature of this study and our goal of providing evidence of patterns among a large teacher population, we decided to use an open-ended survey instead of individual interviews (Kendall, 2008). Further, an open-ended survey allowed for data collection from a large and geographically dispersed population and gives anonymity to respondents that may encourage them to provide more honest responses (Bloch et al., 2011; Erickson & Kaplan, 2000). The design of and data collection for this work was approved by the [University] Institutional Review Board for the Use of Human Subjects in Research (Protocol #9432).

Participants

A Qualtrics survey link was distributed via email to 895 secondary science teachers. Participants consented to participate in the study by opening the survey and were offered a gift card upon completion of the survey and 128 teachers fully completed the survey. As shown in Table 1, our sample is fairly representative of the demographic characteristics of teachers in the state for the time period in which the data was collected (Department of Public Instruction, 2020).

Table 1

Demographic Characteristics of Teachers in the State and Study Participants (N = 128)

Characteristic	Sample	State
Gender		
Female	78%	80%
Male	22%	20%
Ethnicity		
European American/White	85%	81%
African American	10%	14%
Hispanic/Latino	2%	3%
Other	2%	1%
Native American	1%	1%
Educational Attainment		
Master's Degree	45%	
Bachelor's Degree	37%	
Some graduate level credit	18%	
School Level		
High School	63%	
Middle School	33%	

Each teacher was assigned an ID number (e.g., T1, T2, … T128) that will be used as an identifier throughout the manuscript. For context, the data for this study was collected prior to the COVID-19 pandemic in a State that has not adopted the NGSS.

Although the targeted state has not adopted the NGSS, our findings can still inform the literature about the gaps in teachers' values related to the science practices. First, the state in focus was one of the leading states for developing the NGSS but chose not to adopt them. Instead, it opted for newly introduced science standards that closely aligned with the NGSS (NGSS Lead States, n.d.). Therefore, it is reasonable to expect that science teachers in the state had experience with the science practices whether it was explicitly mandated or not. Second, the targeted state recently adopted the performance expectations of the NGSS for the state science learning standards, with science practices embedded in the standards (North Carolina Department of Public Instruction, 2023). Accordingly, these findings are useful to understand how science teachers in this state value the practices prior to implementation, to support professional development that considers their existing beliefs, knowledge, and skills about the science practices. The results of our work will also be most informative in locations that are also transitioning their science standards to align with the NGSS science practices.

Data Sources

Data analyzed for this study is drawn from the final section of a larger survey that consisted of three sections: (a) teachers' epistemic orientations to science teaching, (b) their epistemic understanding of the science practices, and (c) their self-reported implementation of the practices (Park et al., 2022). The section relevant to this study included the 18 questions presented in Appendices A and B. The first 16 questions were five-point Likert-scale questions (Never, Sometimes, About half the time, Frequently, or Always) asking how often teachers implement aspects of each of the eight science practices (two questions for each practice). The next two questions focused on teachers' perceived importance of the science practices: one drag-and-drop question asked teachers to rank the eight science practices from most important (1) to least important (8), and one open-ended question asked them to describe why they thought their top three practices were most important for students' science learning. Analysis of the construct validity of the 16 Likert scale items about science practice implementation revealed that one item (Imp05) about the practice of conducting scientific investigations was misfitting (Park et al., 2022). Consequently, we removed that item from our analysis. Appendix B shows that the Cronbach's Alpha value for the 15 items used in our analysis was $\alpha = 0.928$.

Data Analysis

Analysis of Likert Scale and Ranked Items

Teacher responses to the 15 Likert-style implementation questions were converted to 5-point scale scores from Never = 1 to Always = 5. Implementation scores from the two Likert-style questions associated with each practice were averaged and descriptive statistics were calculated to identify trends in teachers' self-reported implementation of each practice. Next, teacher responses to the drag-and-drop ranking question were analyzed using descriptive statistics, average ranking scores were calculated for each practice, and the frequency with which each practice was selected as one of the teachers' top three was determined. Finally, Spearman rank-order correlations were calculated to identify any significant relationships between responding teachers' rankings of the science practices and their reported implementation of individual practices; the assumption being that a higher ranking for a practice should correlate with more frequent implementation.

Analysis of Open-ended Responses

Teacher responses to the open-ended question were analyzed using qualitative content analysis (Schreier, 2014) with Atlas.ti as an aid. First, a coding frame was developed that consisted of both concept-driven and data-driven categories (Mayring, 2015). The four main concept-driven categories were derived from the EVT as described above (i.e., interest, attainment value, utility value, cost). Next, data-driven subcategories under each main category were developed through open-coding and defined in a way to ensure mutual exclusiveness between sub-categories (Schreier, 2014). The coding frame was revised and finalized through a pilot phase of an iterative process involving two researchers. First, the two researchers independently coded the same 10% of the responses, compared and discussed the codes until they reached agreement, then revised and refined the initial coding frame. Next, the same two researchers independently coded another 20% of the responses using the revised coding frame and, again, compared and revised the codes to finalize the coding frame. Following the finalization of the coding frame, Atlas.ti was used to calculate Krippendorff's alpha of 0.989 (Krippendorff, 2011). Finally, analysis moved to the main phase in which each researcher coded 50% of the remaining data independently using the final coding frame (Schreier, 2014). See Table 3 and Appendix C for this information.

Results

Through our analysis we investigated which of the eight NGSS science practices teachers believed were most valuable, the type of value that they believed inclusion of the science practices would have in their instruction, and correlations between teachers' rankings of the practices and their self-reported implementation of the practices. The results of our analysis are presented below, organized by research questions.

RQ 1: Teachers' Prioritized Science Practices and Ascribed Value

Analysis of teachers' rankings of the eight practices revealed that teachers believed that the practice of asking questions was most important. Content analysis of their justifications for their rankings showed that teachers thought that questioning was most useful as a means of monitoring student learning. Regarding the EVT categories, teachers primarily focused on the attainment value of the practices. A full reporting of our findings follows.

Teachers Prioritized Asking Questions

Data analysis revealed that teachers in this study prioritized asking questions ($M = 1.93$, $SD = 1.70$) as the most important practice for student science learning, followed by analyzing and interpreting data, and constructing explanations. Table 2 presents participants' mean ranking score, the standard deviation, and number of times a practice was identified as a "top three" for each of the science practices (i.e., Frequency).

Table 2

Average Importance Ranking Scores of the Science Practices (N=128)

Science Practice	M	SD	95% CI	Frequency
Asking Questions	1.93	1.70	[1.635, 2.225]	106
Analyzing and Interpreting Data	3.51	1.49	[3.252, 3.768]	65
Constructing Explanations	4.28	1.62	[3.999, 4.561]	42
Developing and Using Models	4.73	2.10	[4.366, 5.094]	43
Planning and Carrying out Investigations	4.73	2.33	[4.326, 5.134]	51
Obtaining, Evaluating, and Communicating Information	4.95	2.04	[4.597, 5.303]	37
Engaging in Argument from Evidence	5.43	2.17	[5.054, 5.806]	30
Using Mathematics and Computational Thinking	6.44	1.79	[6.130, 6.750]	10

Mean scores closer to 1 indicate that a practice was frequently given first rank and mean scores closer to 8 denote a practice that was frequently ranked last.

It is worth noting that some of the practices were more frequently listed as one of the "top three" practices, but did not have a top three average. For example, planning and carrying out investigations was the third most frequent response (*n* = 51) but was fifth in terms of mean ranking (*M* = 4.73, *SD* = 2.33). We conducted a one-way ANOVA to compare the means and confidence intervals of the three mid-ranked practices (explanations, models, and investigations). The test revealed that there was not a significant difference between the mean rankings, *F*(2, 381) = 2.11, *p* = .122, and the confidence intervals mostly overlap. This could explain why some of the practices have a higher frequency but lower ranking.

Teachers selected asking questions as the most important practice for two primary reasons: (a) many viewed questioning as a fundamental component of science (*n* =19) and (b) a majority saw questioning as a means of monitoring students' engagement and learning (*n* =63). Most teachers viewed questioning as a fundamental component of science because asking questions is the start of inquiry (*n* = 12) and is the foundation of science (*n* = 6). As one teacher (T5) stated, "Asking questions is what science is all about." Though teachers often wrote about questioning as being an important component of science, they more frequently described the practice as an important tool for monitoring students' engagement and learning (*n* = 63). Specifically, several teachers (*n* = 31) stated that asking questions shows [engagement, curiosity, critical thinking, metacognition]. This view is well reflected in T9's response: "Students must be engaged or interested in topics to really digest the information and asking questions shows interest" (T9). Additionally, some teachers indicated that asking questions is the basis for understanding as shown in T8's response: "In order for students to understand they need to ask questions." Notably absent from teachers' responses were any mentions of scientific questions as a tool for critique.

Teachers' Predominantly Ascribed Attainment Value to the Practices

Our content analysis indicated that the teachers primarily attributed attainment value to their prioritized science practices. See Table 3 for this information.

Table 3

EVT (Wigfield & Eccles, 2000) Coding Frame with Quotation Frequencies (N = 285)

Categories (*n*)	**Sub-category**	**Frequency**	**Percent**
Attainment		198	69.47
	Enhancing Conceptual Understanding	73	25.61
	Engaging in practices of science	54	18.94
	Developing student thinking skills	39	13.68
	Building students' understanding of the nature of science	32	11.23
Interest		57	20.00
	Enhancing student interest	36	12.63
	Building student motivation	21	7.37
Utility		18	6.32
	Building transferable skills	18	6.32
Cost/Barriers		12	4.21
	Teachers' negative perceptions of students	8	2.81
	Standards and testing	4	1.40

That is, they viewed the science practices as a means of accomplishing instructional goals like enhancing student conceptual understanding, engaging students in the practices of science, developing student thinking skills, and building students' understanding of the nature of science. Capturing the ideas of enhancing conceptual understanding and engaging in the practices of science, T74 highlighted both their belief about what science education should be and the role of the science practices in enhancing science learning in their statement that, "students need to be able to investigate, ask questions, and develop/use models to foster their understanding of science. This is what science is and should be rather than learning facts from a textbook." Another common thread under the theme of enhancing conceptual understanding was the idea of deep learning (*n* = 24). In other words, the science practices are an avenue through which students will develop deeper understandings of disciplinary content. Characteristic of this idea was T57 who mentioned that "coming up with and conducting your own experiment is crucial to students' true understanding of the subject."

The second most prominent value that teachers ascribed to the science practices was Interest. Common ideas under interest indicate that teachers felt that the science practices were useful for engaging students, giving students ownership, and piquing student curiosity. Speaking collectively of their three top science practices, T124 noted that "They [the science practices] help to create a classroom of student engagement." Similarly, T54 stated that "Asking questions is critical to engaging students in the learning process." Regarding the idea of giving students ownership, T38 asserted that "If they [students] construct their own explanations rather than being spoon-fed everything from a teacher, they take ownership of their learning and achieve higher results."

Interestingly, only 18 teachers ascribed utility value to the science practices. All of these quotations indicated that the teachers view the science practice as useful for helping students Build transferable skills that will support students in their future endeavors. Referring to the practice of constructing arguments, T72 said that "Making informed arguments is what our students need to do even if they do not follow a STEM path. It will help them make their own decisions in life." Similarly, T114 stated that "If they [students] can engage in this type of discourse and investigation in class with me, then those skills are transferable to their lives outside of the classroom."

Though teachers were not asked to identify barriers to implementing the eight science practices in their classrooms, 12 teachers described challenges that they believed might prevent them from including the practices in their instruction. As shown in Table 3, the noted barriers included teachers' negative perceptions of their students and standards and testing. T100 noted that "I work with mostly standard-level students, so asking questions is my biggest challenge." Speaking to multiple practices, T60 explained the following

> I have seen students struggle the most within the scientific method in the analysis of data (what the heck is it telling you), how to then use the data to develop an explanation of the results, and the idea that math can and should be used to help interpret experimental results.

Finally, in a disheartening depiction of the influence of standardized testing on science education, T86 concludes that

> Teachers are judged and scored on a Multiple Choice test!!!!! The top three [science practices] give the best results for test taking skills, I would love to spend more time doing science versus preparing students for a test, the test is pressure on students, and results are used against teachers, some of our best scientists and minds would fail such tests.

Notably, all the science practices that were attached to barriers to implementation in the classroom received middle to low rankings on both value and reported implementation, and include: planning and carrying out investigations, developing and using models, analyzing and interpreting data, and using mathematics and computational thinking.

RQ 2: Relationships Between Teachers' Practice Rankings and their Reported Implementation

Teachers' average reported frequency of implementation for all eight of the science practices was 2.69 (*SD* = 0.95, 95% CI [2.52, 2.85]), which translates to less than half the time. As shown in Table 4, we found mismatches between the practices that were ranked as most important and the practices that were reported as most-frequently implemented.

Table 4

Correlations Between Teachers' Ranking for Each Science Practice and Reported Frequency of Implementation (N = 128).

Practice	Importance Ranking	Average Importance	Average Implementation	Correlation Coefficient	*p*
Developing and using models	4	4.73	2.543	-0.315	0.001***
Planning and carrying out investigations	5	4.73	2.328	-0.272	0.002**
Using mathematics and computational thinking	8	6.44	2.555	-0.206	0.020*
Engaging in argument from evidence	7	5.43	2.613	-0.162	0.067
Constructing explanations	3	4.28	3.160	0.154	0.083
Analyzing and interpreting data	2	3.51	2.816	-0.079	0.373
Obtaining, evaluating, and communicating information	6	4.95	2.828	-0.056	0.527
Asking questions	1	1.93	2.641	0.023	0.792

Note. Negative correlation coefficients are to be expected because higher ranking scores move closer to 1 while higher implementation scores move further from 1; meaning the values are moving in opposite directions.***$p < 0.001$, ** $p < 0.01$, *$p < 0.05$

For example, while asking questions was the highest ranked of all practices, it was the fifth most implemented practice (less than half the time). Likewise, constructing explanations was the only practice that teachers reported implementing about half the time but was ranked as third most important.

Conversely, there were significant correlations found between teachers' importance rankings and reported implementations for three of the science practices: modeling, $r_s(126) = -0.31$, $p = .001$; investigations, $r_s(126) = -0.27$, $p = .002$; and computational thinking, $r_s(126) = -0.20$, $p = .020$, as seen in Table 4. Overall, the correlations fell roughly into two categories. There was significant alignment between teachers' low levels of implementation and their low rankings for three practices (modeling, investigations, and computational thinking).

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Notable mismatches emerged between teachers' relatively high ranking and average implementation of analyzing and interpreting data; their relatively low ranking and average implementation of obtaining and evaluating information; and their high rank and average implementation of questioning. We urge a cautious interpretation of these results as teachers' frequency of implementation was self-reported and the average implementation scores for the majority of the practices (except investigations and explanations) fall within the same confidence interval.

Limitations

We urge a cautious interpretation of our findings for three reasons. First, our findings are based on responses from only 14% (*N* = 128) of our target sample. Consequently, the findings of this study may be most applicable to the teachers who provided data. We note, however, that our sample of teachers are demographically similar to teachers in the state where the data was collected. Second, the study uses self-reported implementation data without corroborating observational data. Although large scale self-reported survey data can match observational data (Gibbons et al., 2018), research has noted that teachers' self-reported data can elicit socially desirable and biased responses (e.g., Cross Francis et al., 2015; Desimone, 2009). These biased responses could explain the observed mismatches between teachers' reported implementation and perceived importance of the science practices. As such, the findings should be interpreted cautiously, and further research should consider combining short-term and longitudinal self-report and observational data (Desimone, 2009). Third, our data comes from a single state in the US that has not adopted the NGSS, and we did not collect data about teachers' prior exposure to the NGSS. Thus, teachers' prior exposure to the NGSS could have influenced their responses in a manner that we were not able to account for. These limitations provide opportunities for future research. Future studies that involve a larger sample of secondary science teachers in different settings and with different levels of NGSS professional development experience would expand our understanding of the value and importance that teachers place on the NGSS science practices. Research in this vein could investigate differences in value and importance between teachers from states that have, and have not, adopted the NGSS as well as teachers with different NGSS professional development opportunities.

Discussion and Implications

This study explored science teachers' perceived value and importance of the eight science practices, and the relationship between the practices they value and self-reported implementation of each of the practices. Our findings provide useful insights to inform efforts to better support secondary science teachers' implementations of the NGSS science practices.

Perceived Importance and Value

In response to our first research question, we found that teachers considered asking questions as the most important science practice because they believed that it supports student science learning through enhancing student engagement and giving students ownership of their learning. While provoking student interest and motivation is an important outcome of participation in the science practices, the NGSS model of three-dimensional (3D) learning stresses that students should engage in all eight practices as epistemically coherent practices that build students' understanding of crosscutting concepts, disciplinary core ideas, and the epistemology of science (NRC, 2012). Participants' value of scientific questioning primarily to monitor student progress indicates that they may not fully understand both the ways in which scientific questions are interwoven with other practices, and the role of questioning in scientific critique. This limited view could prevent teachers from supporting their students in understanding questioning as a part of the intertwined yet coherent process of scientific inquiry (Berland et al., 2016; Capps & Crawford, 2013; Kite et al., 2021). Thus, science teacher professional development initiatives should provide learning opportunities that engage the teachers in a range of activities that require developing scientific questions for further investigation and using questioning to critique models and investigative designs.

Despite an increased focus on supporting teachers to effectively implement computational thinking (CT) in their classrooms (Li et al., 2021; Yadav et al., 2017), the teachers did not see this practice as being applicable beyond the classroom and did not value this practice as a means of either motivating students or building their scientific competency. The low level of both priority and value that teachers placed on this practice may be an artifact of their uninformed understanding of CT (Kite & Park, 2023). Research has identified several factors hindering science teachers' understanding and implementation of CT: very few examples of CT-integrated science curriculum, minimal exposure to CT in their teacher preparation program, and prevalent beliefs that CT is simply using mathematics and computers (Sands et al., 2018; Yadav et al., 2017). In this respect, science teacher professional development initiatives will need to make the role of CT in contemporary science clear to their teachers and engage them in both programming-based and technology-free activities that demonstrate how CT can be infused into science curriculum (Kite & Park, 2023; Peel et al., 2020).

It is interesting that teachers value the scientific practices most as a means of meeting immediate instructional goals (i.e. attainment value) and less as a means of either enhancing student motivation (i.e. interest value), or providing students with skills for the future (i.e. utility value). Considering Herman et al.'s (2017) findings that high utility value of teaching the NOS corresponded with higher quality implementation of NOS teaching, the high attainment value that teachers in our study placed on the science practices could be problematic. This is because teachers may prioritize providing their students with superficial science practice experiences to solidify content understanding, rather than engaging them deeply in the science practices as a means of developing critical thinkers who can operate as scientifically literate citizens (OECD, 2019).

Keeping the above in mind, more attention must be devoted to both identifying and shifting the value that teachers place on the practices to promote their effective implementation of the practices. Research has shown that collaboration with other teachers and participation in content-related tasks and activities that model the NGSS science practices can improve teachers' self-reported knowledge, implementation, and epistemic values related to the science practices (Christian et al., 2021). Initiating a shift in teachers' values may be challenging, but not impossible. A growing number of studies have also indicated that experiences with systematic teacher education programs play a critical role in facilitating meaningful changes in teachers' beliefs, values, and practices (Herrington et al., 2016; Lotter et al., 2016: Luft, 2001; Lumpe et al., 2012). Thus, teacher preparation programs also have an important role in helping teachers understand the utility value of the NGSS science practices.

Teachers' reference of barriers (i.e., Costs) to implementing the science practices bears mentioning because the question prompt did not ask teachers to identify barriers to implementation. Nonetheless, participants cited low-level students and accountability regimes as significant barriers to implementing the practices in their classrooms. These results are concerning because research has shown that teachers' beliefs about both their students' abilities and contextual constraints can prevent teachers from attempting to engage their students in more rigorous, practice-based work (Abrami et al., 2004; Day, 2020; Savasci & Berlin, 2012). Any interventions to support the science-as-practice approach (Osborne, 2014) should also aim at increasing teachers' awareness that NGSS-aligned instruction can support science learning for *ALL* students. In addition, efforts must be made to align high-stakes standardized exams with the NGSS emphasis on conceptual understanding of disciplinary core ideas and cross-cutting concepts, rather than memorization of factual knowledge. Given that cost value has not been operationalized and studied as much as other task values (Eccles & Wigfield, 2020; Flake et al., 2015; Perez et al., 2019), additional research is needed to explore teachers' perceived barriers more deeply to implementing the science practices. Specifically, we recommend further investigation into the science practices that were associated with barriers and corresponded with low to medium levels of implementation (e.g., developing and using models).

Relationship Between Perceived Importance and Implementation

Regarding our second research question, we identified mixed findings pertaining to alignments between importance ranking and reported implementation. These findings do not align with our expectations based on the EVT, which suggests that if science teachers place higher value on certain practices, they will be more likely to implement them (Eccles, 2009). Specifically, our study showed that although the teachers valued the science practices mostly in terms of attainment value, there was not a significant relationship between the importance ranking of the top three science practices and teachers' self-reported implementation. This is not entirely surprising given that prior research has argued that science teachers' implementation of the science practices requires a sophisticated change in understanding of procedural, conceptual, and epistemic knowledge in science (Kite et al., 2021). Given this, our findings reinforce the notion that science teachers' implementation of the science practices depends not only on their value of the practices but also their knowledge and skills (Kite & Park, 2023).

These findings could be explained by the responding teachers' similarly infrequent implementation of all science practices. Stated differently, on average, teachers in this study implemented the science practices less than half of the time. Due to this, the practices that they gave lower ranks could have been correlated with their low frequency of implementation for those practices. However, practices with relatively high rankings may not have correlated with the implementation scores because teachers' reported implementations were not high enough to be distinguishable from the implementation scores of lower ranked practices. Moreover, the mismatches could be an artifact of the teachers not fully understanding the practices (Kite et al., 2021) and, thus, being unable to accurately report their implementation. Considering this, we suggest that future research combine individual or focus group interviews with survey data to further understand how factors other than teachers' perceived value, including teachers' knowledge and skills, influence their instructional decisions and implementations of the NGSS science practices in their classrooms.

As an example, contrary to previous research suggesting teachers' infrequently implement explanations (Hayes et al., 2016), teachers in our study reported implementing explanations most frequently. A plausible reason for the higher frequency of reported explanation implementation could be that teachers think of explanations in narrow terms, such as explaining a concept or describing data from a lab. In this vein, Kang et al. (2018) found that teachers accurately described students' observations as the beginning of explanation construction, but did not have a clear idea of how to move students from the initial observation to the construction of a full evidence-based explanation. If teachers in our study understood explanation construction as intrinsically integrated with other practices (NRC, 2012), we would expect that adjacent practices (e.g., data analysis or obtaining information) should have similar levels of reported implementation. This, however, was not the case.

In conclusion, teachers' values directly impact their instructional decisions. Through this study we have demonstrated that teachers' attach high attainment value to the eight NGSS science practices and that their perceived importance of a practice rarely corresponds with the frequency of their implementation of this practice. Consequently, we recommend that science teacher PD initiatives work to help teachers' develop strong utility value for each of the science practices.

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Gary W. Wright (gwwright@missouri.edu) is an Assistant Professor of Science Education at the University of Missouri in the Department of Learning, Teaching, and Curriculum. His research and teaching focuses on justice-oriented science teaching, gender and sexual diversity (GSD)-inclusive STEM education, and pre-service science teacher education. He draws on a variety of frameworks in his research, including queer and critical trans theory, teacher attitudes and beliefs, and identity, as well as his own experiences teaching high school science in rural communities.

Vance Kite (vkite@ncsu.edu) is the Director of the Kenan Fellows Program for Teacher Leadership, a nationally recognized program dedicated to investing in educators to elevate K-12 education and build the future workforce. As a 2012-13 Kenan Fellow and the first alumnus to hold this prominent role, he forges statewide connections to bolster the program's reputation. Dr. Kite's educational journey includes achieving National Board Certification, prolific research in science education and teacher development, and over 30 international conference presentations.

Soonhye Park (spark26@ncsu.edu) is a Professor of Science Education in the Department of STEM Education at NC State University. Her research centers on teacher Pedagogical Content Knowledge and teacher professional development. She has led various federal, state, and internally funded grant

projects on teachers' knowledge, skills, and practices that promote students' engagement in scientific practices, critical thinking skills, and science achievement, especially in the context of rural and low SES schools.

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Appendix A: Science Practice Implementation (SPI) Survey Items

Table A1

Likert-Scale Survey on How Often Teachers Implement the Eight Science Practices (Park et al., 2022)

How often do students in your classroom typically...

	Never	Sometimes	About half the time	Most of the time	Always
1. develop scientific questions which guide experimental design?	☐	☐	☐	☐	☐
2. use questions to critique experimental design or scientific models?	☐	☐	☐	☐	☐
3. develop models and use them to explain scientific concepts?	☐	☐	☐	☐	☐
4. develop and revise models based on evidence to make predictions about scientific phenomena?	☐	☐	☐	☐	☐
5. use the same set of steps to reach a conclusion in a project or experiment?	☐	☐	☐	☐	☐
6. plan and conduct their own investigations to answer their own questions?	☐	☐	☐	☐	☐
7. engage in analysis (statistical processing, graphing, etc.) to make sense of data?	☐	☐	☐	☐	☐
8. consider the limitations of data collection and analysis?	☐	☐	☐	☐	☐
9. use mathematical and/or computational models to identify relationships in data?	☐	☐	☐	☐	☐
10. use mathematical and/or computational models to make and test predictions?	☐	☐	☐	☐	☐
11. make explanations based on data and current scientific understanding?	☐	☐	☐	☐	☐
12. employ a claim, supporting evidence, and connecting reasoning when constructing explanations of their findings?	☐	☐	☐	☐	☐
13. construct written and/or oral arguments based on data and evidence?	☐	☐	☐	☐	☐
14. engage in critiquing one another's scientific arguments based on evidence?	☐	☐	☐	☐	☐
15. engage in reading and evaluating scientific information from multiple authoritative sources?	☐	☐	☐	☐	☐
16. communicate scientific ideas using multiple representations (oral, graphic, textual, mathematical)?	☐	☐	☐	☐	☐

Table A2

Alignment Between Science Practices and SPI Items (Park et al., 2022)

Science Practices	Definition/SPI Items
Asking questions	Develop scientific questions which guide experimental design Lederman et al., 2014; NGSS Lead States, 2013b)
	Use questions to critique experimental design or scientific models (NGSS Lead States, 2013b)
Developing and using models	Develop models and use them to explain scientific concepts (NGSS Lead States, 2013b; Windschitl et al., 2008)
	Develop and revise models based on evidence to make predictions about scientific phenomena (NGSS Lead States, 2013b; Windschitl et al., 2008)
Planning and carrying out investigations	Use the same set of steps to reach a conclusion in a project or experiment (Abd-El-Khalick et al., 2008; NGSS Lead States, 2013b)
	Plan and conduct their own investigations to answer their own questions (NGSS Lead States, 2013b)
Analyzing and interpreting data	Engage in analysis (statistical processing, Graphing, etc.) to make sense of data (Leonelli, 2015; NGSS Lead States, 2013b)
	Consider the limitations of data collection and analysis (NGSS Lead States, 2013b)
Using mathematics and computational thinking	Use mathematical or computational models to identify relationships in data (NGSS Lead States, 2013b; Weintrop et al., 2016)
	Use mathematical or computational models to make and test predictions (NGSS Lead States, 2013b; Weintrop et al., 2016)
Constructing explanations	Make explanations based on data and current scientific understanding (NGSS Lead States, 2013b; Osborne et al., 2003)
	Employ a claim, supporting evidence, and connected reasoning when constructing explanations of their findings (NGSS Lead States, 2013b)
Engaging in argument from evidence	Construct written and/or oral arguments based on data and evidence (NGSS Lead States, 2013b; Sandoval & Millwood, 2007)
	Engage in critiquing one another's scientific arguments based on evidence (NGSS Lead States, 2013b)
Obtaining, evaluating, and communicating information	Engage in reading and evaluating scientific information from multiple authoritative sources (NGSS Lead States, 2013b; Osborne et al., 2003)
	Communicate scientific ideas using multiple representations (NGSS Lead States, 2013b; Osborne et al., 2003)

Appendix B: SPI Construct Validity

IRT Model: Rating Scale Model

Item	16 Items				15 Items			
	Estimate	Unweighted MNSQ	Weighted MNSQ	Alpha if Item Deleted	Estimate	Unweighted MNSQ	Weighted MNSQ	Alpha if Item Deleted
Imp01	0.255	0.84	0.90	0.922	0.248	0.93	0.97	0.926
Imp02	-0.024	0.88	0.88	0.920	-0.039	0.95	0.92	0.923
Imp03	-0.135	1.10	1.10	0.922	-0.153	1.17	1.15	0.925
Imp04	0.735	1.23	1.22	0.920	0.747	1.26	1.23	0.923
Imp05	-0.220	1.57	1.35	0.928				
Imp06	0.684	0.93	0.96	0.922	0.695	0.93	0.96	0.925
Imp07	-0.560	0.85	0.86	0.920	-0.592	0.91	0.91	0.924
Imp08	0.186	0.95	1.02	0.918	0.178	0.92	1.01	0.922
Imp09	0.012	0.97	1.01	0.919	-0.002	1.00	1.04	0.922
Imp10	0.530	1.03	1.04	0.919	0.531	1.07	1.09	0.922
Imp11	-0.977	0.83	0.80	0.919	-1.027	0.89	0.84	0.923
Imp12	-0.492	0.97	0.96	0.919	-0.525	0.94	0.96	0.922
Imp13	-0.210	0.94	0.99	0.918	-0.234	0.91	0.94	0.921
Imp14	0.587	1.07	1.05	0.920	0.589	1.06	1.05	0.923
Imp15	0.219	1.05	1.12	0.922	0.209	1.09	1.16	0.926
Imp16	-0.590	0.92	0.86	0.918	-0.627	0.91	0.86	0.921
Separation Reliability	0.945				0.950			
EAP/PV RELIABILITY	0.912				0.924			
Cronbach’s alpha	0.925				0.928			
Chi-square test of parameter equality	251.050				255.03			
df	15				14			
p	0.000				0.000			
Final Deviance	4740.37207				4394.08532			
Akaike Information Criterion (AIC)	4780.37207				4432.08532			
Akaike Information Criterion Corrected (AICc)	4775.202				4427.40039			
Bayesian Information Criterion (BIC)	4837.41267				4486.2739			
Parameter Estimated	20				19			

Appendix C: EVT (Wigfield & Eccles; 2000) Coding Frame

Categories (*n*)	**Sub-Category (*n*)**	**Codes**	**Frequency**	**Percent**
Attainment (198)	Enhancing conceptual understanding (73)	Building understanding	31	10.88
		Increasing depth of understanding	24	8.42
		Connecting concepts	7	2.46
		Personalized instruction	6	2.11
		Make student thinking visible	5	1.75
	Engaging in practices of science (54)	Communicating findings	15	5.26
		Using evidence to support claims	12	4.21
		Forming conclusions	9	3.16
		Analyzing data	5	1.75
		Evaluating ideas	5	1.75
		Learning to conduct investigations	5	1.75
		Constructing explanations	3	1.05
	Developing student thinking skills (39)	Developing critical thinking	21	7.37
		Promoting creativity/Thinking outside the box	7	2.46
		Benefiting from multiple perspectives	7	2.46
		Metacognition	4	1.40
	Understanding the nature of science (32)	Questions are fundamental to science	18	6.32
		Understanding the scientific method	8	2.81
		Science practices are the foundation of science	6	2.11
Interest (57)	Enhancing student interest (36)	Engaging students	17	5.96
		Piquing student curiosity	11	3.86
		Providing hands-on learning	8	2.81
	Building student motivation (21)	Giving students ownership	13	4.56
		Student-centered teaching	8	2.81
Utility (18)	Building transferable skills (18)	Transferable skills	18	6.32
Cost/Barriers (12)	Teachers' perceptions of students (8)	Low-level students	5	1.75
		Perceived area of struggle	3	1.05
	Standards and testing (4)	Standards and testing	4	1.40