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The Scientific Curiosity of Preservice Elementary Teachers and Confidence for Teaching Specific Science Topics

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ABSTRACT
This study explored whether, and how, preservice elementary teachers' scientific curiosity related to their confidence for science teaching. A group of 29 preservice, elementary teachers in the U.S. engaged in a curiosity journaling strategy across a 16-week scientific inquiry course. Their expressions of curiosity were coded using Luce and Hsi's framework of curiosity. Whether expressions of curiosity related to their confidence for teaching associated science topics was examined statistically. In addition, the categories of their curiosity were coded and are described across eight journal entries. The nature of the relationship between scientific curiosity and science teaching confidence, as well as the nature of the curiosity they expressed, are described. Generally, curiosity about specific scientific phenomena and changes in confidence for teaching those topics did not relate to one another. Relationships did emerge, however, among categories of curiosity and participants' confidence for teaching seven specific science topics.

KEYWORDS
Initial teacher education (pre service); nature of science; science journals; teacher thinking

Introduction

Promoting scientific literacy and professional pathways into science is a perennial goal among policymakers, researchers, and educators. Decades of scholarship positions the personal relevance of science concepts and contexts as well as higher order thinking as key to promoting scientific interest and identity among students (for example, Ampartzaki et al., 2021; Kapon et al., 2018; Sharples et al., 2015; Tytler, 2014). Recent research in education, the philosophy of science, and developmental psychology have begun to converge around the juxtaposition of children's thinking and the personal relevance of science. Specifically, work around leveraging children's scientific curiosity, wonder, and creativity to improve access to, and engagement in, science and STEM as well as to later career pathways (Engel, 2011; Gilbert & Byers, 2017; Luce & Hsi, 2015; Valdesolo et al., 2017). From a developmental psychology perspective, curiosity, wonder, and creativity underlie knowledge transformation and development as complementary cognitive processes (Bazhydai & Westermann, 2020) that have consequences for access to science and STEMFor example, a positive relationship between students' curiosity and their academic performance and self-regulation has been observed in children as young as five (Sansone et al., 2010; Shah et al.,

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2018; von Stumm et al., 2011). Hadzigeorgiou and Schulz (2014) assert that "a sense of wonder about the natural world can help students become alert that natural phenomena and natural objects or entities are involved, in some way, in our own existence (p. 1994). Bazhydai and Westermann (2020) distinguish between these types of thinking where "curiosity drives information seeking, wonder expands and enriches the quest for knowledge to new dimensions, and creativity enables transformation of existing knowledge and generation of new, original knowledge about the world" (p. 1). Teachers' can influence these types of scientific thinking in their classrooms among their students (Antink-Meyer & Lederman, 2015; Bevan, 2017; Engel, 2011; Gilbert & Byers, 2017; Wilujeng & Lestari, 2022), but teachers' own thinking, the influence of that thinking on their teaching, and the implications for science teacher education are not well understood.

Researchers' understanding about teachers' cognition, metacognition, and relationships to their science teaching practices (e.g., subject matter knowledge (SMK), affective variables like confidence, and teaching practice) have shifted dramatically over the last two decades (Abell, 2007; van Driel et al., 2014). We now understand that teachers' subject matter knowledge improves their confidence for teaching science, and as that confidence improves, so does their willingness to embed more novel learning experiences for students (van Driel et al., 2014). Our study sought to explore how teachers' thinking, specifically their curiosity, might fit within this dynamic. If curiosity drives information seeking (Bazhydai & Westermann, 2020), might curiosity be a means to promote confidence? The implications are consequential because if confidence predicts more novel teaching practice there may be a cascading effect that ultimately gives students' more opportunities to engage in curiosity, wonder, and creativity in the science classroom. We focused this investigation on scientific curiosity, which has been described as a naïve, or folk, descriptor for reward-learning within autonomous knowledge acquisition (Murayama et al., 2019) and a realization that there are gaps in our understanding (Schinkel, 2017). If teachers' growth in subject matter knowledge relates to confidence, and curiosity relates to growth in subject matter knowledge we reasoned that investigating whether changes in confidence may relate to the curiosity expressed by teachers may provide insights for teacher education. Hadzigeorgiou and Schulz (2014) describe that "what curiosity does, namely, [is] to take things apart, in order to investigate them closely" (p. 1994). This conception of curiosity and Murayama's description of curiosity as a means of closing gaps in understanding has been problematized by scholars who distinguish between curiosity about the natural universe, and wonder. While the two words are sometimes used interchangeably, Schinkel (2017) and others frame curiosity as a distinct process of becoming aware of a gap in understanding. Wonder and creativity are ultimately goals for science classrooms because they embody both the personal relevance and higher order thinking important to developing science identities. Curiosity, while being a more simple act of cognitive engagement that implies noticing, is also a key aspect of the pathway between a teachers' awareness of a gap in understanding and the acquisition of SMK.

The journaling strategy that was employed in this study is reflective of the types of journals often used by science teachers in K-16 settings and sought to provoke participants' noticing about familiar objects and phenomena from their daily lives and to recognize gaps in their understanding about them. This noticing was intended to promote curiosity and was a means to investigate whether that curiosity would influence their confidence for teaching about those phenomena.

Conceptual framework

Teacher thinking and growth

Teachers' beliefs about the subjects they teach, as well as their beliefs about their own abilities for teaching those subjects, influence their instruction (Bleicher & Lindgren, 2005; Menon & Sadler, 2016; Velthuis et al., 2014). Preservice teachers' elementary school experience with science, as well as their informal, secondary, and college experiences are predictive of their initial interest in science as teachers (Bulunuz et al., 2012; Norris et al., 2018; Palmer, 2004). The number of college science courses they have taken as well as their completion of a scientific inquiry course predicts confidence for teaching both science (Banilower et al., 2018; Jarrett, 1999) and engineering (Antink-Meyer & Parker, 2021). In addition to these factors, elementary teachers' self-efficacy relates to the type of science *learner* they embody (Norris et al., 2018). Their science learner type is influenced by the science learning experiences they have been afforded and Bleicher (2009) describes four typologies: fearful, disinterested, successful, and enthusiastic. Typologies are not mutually exclusive (Norris et al., 2018), however. Norris et al. (2018) observed that not all teachers are characterized by a singular typology and can demonstrate orientations toward science learning that are, for example, sometimes enthusiastic and sometimes fearful.

Decades of intervention studies illustrate how engaging elementary teachers as learners about scientific phenomena can support their pedagogical content knowledge (PCK) and ultimate inclusion of those scientific phenomena in their classrooms. Interventions have taken a multitude of forms, not exclusive to, but including: pre-service coursework (e.g., Foley et al., 2017; Nilsson & Loughran, 2012), short- and long-term professional development (e.g., Sandholtz et al., 2019; Stewart et al., 2015), research experiences for teachers (Dixon & Wilke, 2007), engagement in informal science learning settings (Holliday et al., 2014), among others. As is the case in the present study, pre-service coursework has emerged as a valuable context for learning about the science that elementary teachers will ultimately teach.

Nilsson and Loughran (2012) describe the importance of engaging pre-service elementary teachers with science learning in ways that help them unpack their subject matter knowledge as it is situated within their knowledge about pedagogy. In their study of pre-service elementary teachers' PCK development, participants in a science methods course reflected on their own conceptions about air alongside their knowledge about teaching the concept. Through their use of the CoRe tool (Loughran et al., 2006), which positions teachers' conceptions of the big ideas of a topic against pedagogical constructs (e.g., *why is it important for students to learn these concepts*), Nilsson and Loughran found that through "articulating what they came to learn, they saw that they needed to learn more about each big idea" (p. 718). Reflecting on their own understandings promoted their belief that they needed to continue growing.

Reflecting on content knowledge is not simply a matter of considering what one knows against their perceptions of what could be known, however.

Self-efficacy and confidence

Elementary science teachers hold both positive and negative views about teaching and learning science and their self-concepts of their abilities are observed to relate to their learning goal orientations (Cavallo et al., 2002). Where a teacher holds intrinsic value of science learning, their interest and effort mediate engagement and growth (Ramey-Gassert et al., 1996). That engagement promotes self-efficacy and Yeung et al. (2014) assert that teachers with stronger self-concepts as learners and teachers imbue their students with greater learning potential. Teachers with lower self-concepts are more likely to create more teaching-centered classrooms and perceive students' capacity for growth as more limited.

Preservice teachers were the focus of the present study, in part, because they were in the last phase of their career where an emphasis on professional development around teaching science was sustained. Support for U.S. elementary teachers' development as scientists and teachers of science is inconsistent across their careers and less emphasized compared to mathematics (Banilower et al., 2018). Norris et al. (2018) describe that PSTs self-efficacy for teaching in one learning domain can differ from their self-efficacy in another domain. Teacher education has a crucial role in developing self-efficacy, as it is an environmental determinant" (p. 2295). This implies that self-efficacy for teaching in different disciplinary domains may differ, but that different topics within domains may as well. Bandura (1997) described *perceived self-efficacy* as individuals' beliefs in their capacity to induce outcomes. Confidence is also well represented in the literature (e.g., Banilower et al., 2018) around the development STEM teachers' subject matter expertise. For example, Stankov et al. (2012, 2014) defined confidence as "a state of being certain about the success of a particular behavioral act" (2012, p. 747) and in their studies of mathematics learning found it to be highly correlated with self-efficacy but also a better predictor of achievement (2012) and explanation of variance (2014). We focused on confidence in this study Scientific Curiosity.

Teachers' orientation toward science learning (e.g., disinterested) relates to their self-efficacy for teaching (Bleicher, 2009; Norris et al., 2018), but Norris et al. observed that those orientations are not always rigid. As learners of science, teachers can change and classroom environments can contribute to both perceived orientation (Bandura, 2012; Bergman & Morphew, 2015) and actualized orientation. A mechanism for that change may relate to what Berlyne described in 1954; we learn better about things that we are curious about. Teacher curiosity, wonder, and creativity have broad relevance for understanding teachers' engagement in endeavors as localized as teaching specific topics in their classrooms (Gulten et al., 2011) to their engagement in global education issues and opportunities (Mikulec, 2014).

Jirout and Klahr (2012) describe scientific curiosity as "desired uncertainty in an environment which leads to exploratory behavior" (p. 26), but distinctions between curiosity and wonder suggest that curiosity may be a starting point that leads to exploratory behavior and wondering about a phenomenon. Curiosity is distinguished from wonder as "the drive to investigate or study something, and wonder, as a state of mind or feeling—that also includes some kind of awareness" (Hadzigeorgiou & Schulz, 2014, p. 1993). Luce and Hsi (2015) described the expression of curiosity "as fleeting observations of wonderment and noticing inconsistencies or finding novelty in an object or through activity" (p. 73). This definition of curiosity

> implies the realisation that there is some particular thing one does not yet know, but it doesn't foreground the question of the general extent of one's current knowledge (or ignorance) the way wonder does. Moreover, wonder has greater psychological depth; it 'engages the whole person' (Opdal, 2001, p. 332) in a way that curiosity does not. (Schinkel, 2017, p. 544)

These descriptions of curiosity and wonder are consistent with Murayama et al.'s (2019) suggestion that curiosity is a folk concept that actually describes reward-learning, but where curiosity is the launching point and the reward seeking is more consistent with wonder. Reward-learning implies self-driven knowledge acquisition where "the expected feeling of reward is the key modulator of our information-seeking behavior" (p. 878). The reward is intrinsic and Murayama et al. demonstrated in a 2010 study that the introduction of extrinsic rewards (monetary in the case of their study) can actually break down the self-rewarding cycle. Students and teachers both have the "capacity to self-sustain their task engagement" (Murayama et al., 2019, p. 890). We leveraged this asset by incorporating a curiosity journal where participants were required to notice, observe, ask, and explain their ideas about natural and technological phenomena over short periods (journal directions are included in the methodology section). knowledge gaps.

The type of curiosity that participants expressed was of interest in this study as *how* they demonstrated curiosity. In their examination of early adolescents' expressions of scientific curiosity, Luce and Hsi (2015) observed six categories of curiosity that related to both what children were curious about and how they expressed it. These categories were employed in this study and are mechanistic, teleological, inconsistency, cause and effect, engineering or medicine, and general knowledge types of curiosity. *Mechanistic* curiosity is defined by Luce and Hsi as causal in nature while *cause and effect* type curiosity does not relate to the mechanism but in the relationship and a desire to investigate *what would happen if* type curiosity. *Teleological* curiosity relates to explanations and curiosity about *inconsistencies* relates to surprise or unexpectedness in observations. The final two categories of curiosity include *engineering or medicine*, which relates to how things are made and in which we include engineering design, and *general knowledge*, which were fact-based curiosities about science like *what kind of clouds precede rain*. Luce and Hsi (2015) developed these categories in a study of 19 middle grades learners through photo journals and interviews in order to investigate the nature of student interest in science. They have been used in other studies of university level students (Laherto et al., 2017), as well as studies of afterschool and informal science education settings (Toprani et al., 2017).

Based on the operationalized distinction between self-efficacy and confidence proposed by Stankov and colleagues, we examined the science confidence and curiosity of a group of 29 preservice, elementary teachers across a semester of a scientific inquiry course where they engaged in curiosity journaling. We use the term *curiosity journaling* to describe the strategy for writing reflections on natural and technological phenomena that an observer notices and perceives a knowledge gap. Journaling is a well-established strategy for bridging reflection on science phenomena, curiosity, and growth in conceptual understanding. Evidence of the efficacy of journaling as a strategy that promotes science learning has emerged across a multitude of contexts including early childhood settings (e.g., Brenneman & Louro, 2008), elementary science learning settings (e.g., Shepardson & Britsch, 2001), with middle grades English learners (e.g., Huerta et al., 2016), and within science teacher professional development (e.g., Monet & Etkina, 2008), among others.

Learning *about* science phenomena that they will one day teach, and learning to teach that science, are happening in tandem in teacher education programs. Pre-service teachers' goals for their future students must align with their own goals. "[F]uture science teachers also generate new ideas . . . in the context of making sense of how science is and could be taught" (Russell & Martin, 2014, p. 886). Teachers' own scientific curiosity is therefore a contributor to their development of science teaching practice. The nature of that contribution, however, has not been examined and its correspondence to other key factors in the development of practice (e.g., confidence) has not been explored. Two research questions framed this study.

Research questions

(1) How do changes in pre-service elementary teachers' confidence for science teaching, and the scientific curiosity they express when journaling, relate to one another?
(2) What is the nature of the scientific curiosity expressed among a group of pre-service elementary teachers?

Research design

Participants and context

Twenty-nine PSTs who were enrolled in a scientific inquiry course during their third year in a program leading to elementary teaching licensure (grades 1–6; ages 6–12) participated in this study. PST demographics consisted of a predominantly female (3 identified as male) and White (1 Black, 2 Latinx, and 1 Asian American participants) group. Their average age was 21 years old. The course included learning about the nature of science (NOS), the science and engineering practices in the Next-Generation Science Standards (NGSS), the nature of engineering knowledge, and it included a student-directed inquiry project around a scientific question of their choice. As part of the course they also engaged in curiosity journaling, a term we are using to describe a science journal intended to support reflection on science and engineering phenomena that the PSTs encountered in their lives that they were curious about. We distinguish between curiosity and wonder using Bazhydai and Westermann's (2020) framing. Curiosity is a more cursory noticing and information seeking experience, while wonder implies new dimensions of understanding are driven by exploration and expansion of that initial information seeking. Eight entries were made throughout the 16-week study, one approximately every two weeks, and were between one and four pages of written or digital text. The participants were asked to notice and reflect on phenomena, outside of class time, that they encountered in their everyday life and that they felt would be classified as *science* or *engineering*. They were required to include written observations, questions, connections, drawings, and models. All journals were gathered at the end of the semester of the study. The directions for journaling as they were presented to students were

> We will use an observational notebook to develop our abilities to observe and make inferences about the natural and human created world Each entry should be at least 2–3 pages and should include your observations and inferences about something you are curious about, and that you can see, hear, touch, etc. Include an image that you have drawn that helps you explain or share your observations. Connect them with things you already know or other things you have observed. Generate a question related to your observations that you think you could collect data to answer (you don't actually have to collect any data). You can incorporate entries about the natural world as well as about the human made world.

Course description

This study was conducted in a scientific inquiry and engineering design course completed by PSTs in their third year of study and one year prior to their full-time student teaching experience. The class was intended to bridge the science concepts they had studied in discipline-oriented classes (e.g., Introductory Chemistry) to the reform-oriented, three-dimensional structure of science learning advocated for by the Framework for the Next-Generation Science Standards (NGSS) (National Research Council, 2012). The goals of the course emphasized the nature of scientific knowledge (Lederman & Lederman, 2014), the nature of scientific inquiry (Lederman & Lederman, 2014), the nature of engineering knowledge (Antink-Meyer & Brown, 2019; Deniz et al., 2019) and engineering design (Farmer et al., 2014), and the science and engineering practices described in the Framework.

Eight total entries in the curiosity journal were a required component of the course. Participants were allowed to reflect on any natural or technological phenomena that they were curious about. The course itself was shaped around four themes: 1) science of foods and cooking, 2) microorganisms and biomedical engineering, 3) the universe and space technologies, and 4) independent scientific inquiry projects. The course was comprised of 30 class sessions and sessions were grouped around an investigation and explicit, reflective instruction (Khishfe & Abd-El-Khalick, 2002). For example, the first class session was anchored by the science of foods and cooking theme and it consisted of beginning a fermentation investigation framed empirically by temperature, pH, and CO_2 evidence gathering. Disciplinary core ideas around the conservation of matter and properties of substances were explicit and the nature of science and scientific inquiry concepts and skills of causal, correlational, and descriptive investigations were introduced alongside making observations. It was not required that journal entries connected to course themes or class session content.

Research design

This two-phase study explored relationships among preservice teachers' (PST) curiosity about scientific phenomena and their confidence for teaching, as well as the nature of the curiosity that they expressed though journaling. We utilized an explanatory, sequential mixed methods design (Creamer, 2018; Creswell & Clark, 2017; Creswell et al., 2003) to inform an understanding of whether, and how, the extent and nature of a teachers' scientific curiosity related to their confidence for teaching the topics they were curious about.

Phase I: relationships between preservice teachers' curiosity and teaching confidence

A survey of participants' confidence for teaching 22 science topics (e.g., structures and functions of organisms) adapted from the Horizon Science Teacher Survey, Preparedness to Teach, (Banilower et al., 2018) was used at the start and end of the 16-week class. Items were Likert scale (not adequately prepared, somewhat prepared, fairly well prepared, and very well prepared). Internal consistency was reestablished because only a portion of the full survey was used in this study. A Cronbach alpha coefficient of .953 for the initial administration of the adapted survey and of .962 on the final administration indicates satisfactory internal consistency.

In addition to the survey, each participants' journal entries were coded using the 22 science topics by reading each utterance (i.e. questions, bullet pointed observations, explanations, etc) and identifying which (if any) of the topics from the survey were the topics of focus. This integration of these approaches supported mixing the quantitative and qualitative results which drives the later discussion of the study's findings and implications (Ivankova et al., 2006). It was possible for none, or more than one science topic to be included in a single entry and all topics that arose were coded. This was the case whether it was an explanation or question contained within many lines or whether it was a single question or observation. In addition, coding did not differentiate between accurate and problematic conceptions. For example, the entry that included this statement "Is milk's freezing point/boiling point the same as water? I know water boils/ evaporates/ freezes/condensates. Does milk? Milk seems to get chunky white when heated and that happens with almond milk as well" suggests the participant understood milk as a homogeneous solution. That they expressed curiosity about the properties of that solution in comparison to water was coded as *properties of solutions* but evidence of problematic conceptions were not coded because the nature of their understanding was not relevant to whether they expressed curiosity and perceived their own confidence for teaching.

For the first research question, the analyses began with all three authors using the 22 topics from the survey as *a priori* codes and analyzing nine journals first. Results were discussed, examples of each code agreed upon, and points of disagreement addressed until all codes were consistent across the three coders. The first author then coded the remaining journals using the code definitions from Luce and Hsi's (2015) framework and the examples developed as a group. In order to inform the first research question, a Chi-square test of association was utilized to assess whether curiosity journaling related to teaching confidence for the 22 topics in the survey. These data were categorized by scientific topic and occurrence in the journals (0 entries, >1 entry). Data were then compared to changes in self-reported confidence (Decline or No Change, or Improved) to teaching the related scientific topic.

Phase II: expressions of curiosity about science phenomena

The second phase of this study consisted of second cycle coding of journal entries using Luce and Hsi's (2015) six categories of curiosity expression. These describe different ways that participants demonstrated curiosity about science phenomena and relate to the nature of scientific inquiry. The nature of the PSTs curiosity was coded using Luce and Hsi's framework as: mechanistic, teleological, inconsistency, cause and effect, engineering or medicine, or general knowledge. Each author coded a set of four participants' journals and discussed coding to support common definitions and exemplars. Each entry in the remaining journals were then coded by the first two authors and any inconsistent codes were discussed. One hundred percent agreement was achieved.

Findings

RQ1: how do changes in pre-service elementary teachers' confidence for science teaching and the scientific curiosity they express when journaling, relate to one another?

Topic of curiosity and confidence for teaching

We explored the first research question through mixing of different quantitative and qualitative lenses. These were as a matter of 1) specific science topics and 2) frequency of journaling about those topics. We discuss the findings around each of these separately.

Table 1. Structures and functions contingency table.

	PSTs with journal entries expressing curiosity about structures and functions of organisms		
Confidence for teaching structures and functions of organisms	No journal entries	At least one journal entry	Total
No change/declining confidence	3	5	8
Improved confidence	16	5	21
Total	19	10	29

Generally, the results of our analysis show limited evidence of an association between expressions of curiosity about a topic in journal entries and changes in the PSTs' confidence to teach related topics. Chi-square tests of independence only demonstrated that improving confidence for teaching structures and functions was not independent of expressions of curiosity about this topic in journals ($c^2 = 3.839$, $df = 1$, $p = .050$, Contingency Coefficient = 0.342). However, changes in confidence for teaching the remaining 21 topics were independent of the curiosity that participants expressed in their journals. The contingency table for structures and functions is shown in Table 1 but illustrates that 21 of the participants' confidence improved for teaching about structures and functions but only 10 journaled at least once about the topic. While statistically significant, the practical significance of this relationship is limited.

This finding suggests that the extent of reflection on a topic that a PST was curious about did not meaningfully relate to whether they gained or lost confidence for teaching the topic. Or, it suggests that expressions of curiosity must be more persistent than were observed in this study. This may relate to the findings of Turner (2012) who observed that the relationship between reflection on content and the development of content knowledge is not direct. The relationship between reflection on a phenomenon of interest to a PST and changes in their confidence for teaching it is either not direct, or was not supported with the nature of the journal utilized.

Frequency of journaling about a topic and confidence for teaching

While opportunities to reflect on scientific curiosity may promote motivation and interest, they may not imbue pedagogical confidence around related topics. Table 2 illustrates the average number of journal entries where PSTs expressed curiosity related to that topic. Biology and engineering were the only topics where more than one entry was common among the 29 participants. Journal entries consisted of one to three pages of questions, models, and observations around a variety of topics. Journal entries coded as biology were most often characterized by entries related to microorganisms and disease. This study took place prior to the COVID-19 pandemic, but many participants demonstrated curiosity about things like "how CO^2 affects microbial growth" and "how come some germs have such a wide range of transfer methods from one body to another to cause an illness." Those entries coded as engineering were also common. Among them, for example, one participant's entry included that "the last thing that makes me think relating to cars is how did they discover that they run on gas? How did they distinguish between regular unleaded or diesel? How did engineers even test this."

The mean change in teaching confidence for each topic similarly illustrates that while the general trend was one of improved confidence, engineering was the topic of greatest

Table 2. Curiosity in journal entries and changes in confidence (mean of means for each PST, n = 29).

TOPIC	Mean # topic entries/PST (s)	Mean change in teaching confidence (s)
Biology	1.34 (.72)	0.62 (.62)
Earth and Space	0.14 (.35)	0.86 (.44)
Physics	0.07 (.26)	0.52 (.63)
Earth Science features and physical processes	0.03 (0.19)	0.62 (.62)
Climate and weather	0.21 (.49)	0.31 (.89)
Cell biology	0.38 (.62)	0.69 (.71)
Structures and functions of organisms	0.38 (56)	0.69 (.66)
Ecology	0.24 (.51)	0.55 (.57)
Genetics	0.17 (.38)	0.45 (.74)
Evolution	0.10 (.31)	0.52 (.69)
Chemical bonding,equations,nomenclature, and reactions	0.41 (.73)	0.38 (.62)
Elements, compounds, and mixtures	0.17 (.54)	0.31 (.81)
The periodic Table	0.07 (.37)	0.24 (.83)
Properties of solutions	0.10 (.41)	0.34 (.77)
States, classes, and properties of matter	0.79 (.77)	0.41 (.63)
Forces and motion	0.38 (.56)	0.59 (.63)
Energy transfer, transformations, and conservation	0.97 (.78)	0.34 (.72)
Properties and behaviors of waves	0.28 (.45)	0.55 (.74)
Electricity and magnetism	0.21 (.41)	0.45 (.78)
Modern physics (for example: special relativity)	0.07 (.26)	0.48 (.57)
Engineering	1.10 (.82)	1.00 (.27)
Environmental	0.14 (.35)	0.69 (.60)

improvement. The course was the first in which engineering concepts and epistemology was taught, which likely explains this finding. One participant, Charity's entries illustrate how their reflection on engineering developed across this first course where engagement with engineering was sustained. Her first entry related to paper towels and her three-page entry included questions like "What is the best paper towel design?" and "Why are paper towels absorbent?" Her second entry, illustrated a little more depth but still focused on the relationship between design and function. That entry included questions like "How does the design of a winter coat keep us warm?," but it also demonstrated that she was thinking more deeply about how design and phenomena interact in solving a problem. For example, at one point she poses the question "Why do some very thin, light jackets keep people warm?" In a later entry, that was also coded as an engineering entry, Charity illustrated fans of different designs and asked "how does the design of a fan produce cool air?"

Evidence of relationships between topic-specific curiosity and confidence were lacking. A more general examination of the 1) total number of instances of coded expressions of curiosity across all journal entries and 2) total change in science teaching confidence across all 22 topics on the survey demonstrated a similar disconnect. The simple product-moment correlation between the total expressions of scientific curiosity and the total change in science teaching confidence was not statistically significant ($r = 0.193$, $p = .198$).

Type of curiosity and confidence for teaching specific science topics

Interestingly, positive correlations between expressions of specific types of scientific curiosity and changes in their confidence for teaching specific topics did emerge. Mechanistic curiosity and improved confidence for teaching modern physics ($r = .392$, $p < .05$, 95% confidence interval 1.0.091) and energy transfers/transformation/conservation ($r = .364$,

$p < .05$, 95% confidence interval 1.0.059) were each positively correlated. Similarly, teleological curiosity (i.e. why/explanation-type curiosity) and improved confidence for teaching about atomic structure (r = .374, $p < .05$, 95% confidence interval 1.0.071) and chemical bonding and reactions (r = .395, $p < .05$, 95% confidence interval 1.0.095) were also positively correlated.

The number of journal entries with *inconsistency*-coded curiosity was positively correlated with changes in participants' confidence for teaching about evolution (r = .403, $p < .05$, 95% confidence interval 1.0.105). Similarly, only one topic where a change in confidence was positively correlated with the type of curiosity was found for *engineering or medicine* and that was biology (r = .388, $p < .05$, 95% confidence interval 1.0.013). Lastly, changes in confidence for teaching climate and weather were positively correlated with the number of expressions of curiosity about general knowledge r = .313, $p < .05$, 95% confidence interval 1.0.001). Cause and effect type curiosity did not correlate with any changes in confidence for topic-specific teaching.

These findings may indicate that the *nature* of curiosity may be a factor in changes in confidence for teaching specific topics. The nature of those topics, the PSTs understandings about those topics, or the representations of those domains of science practice and understanding may be consequential.

RQ2: what is the nature of the scientific curiosity expressed among a group of pre-service elementary teachers?

The six categories of curiosity in participants' journals are taken from Luce and Hsi's (2015) scientific curiosity framework. That framework extends beyond science as a way of knowing and includes fields of designed technologies; specifically engineering and medicine. Research question two was addressed from two perspectives. First, the total number of each category of curiosity across all journal entries, and all participants, were identified. The mean frequency across participants for each category is described along the left side axis in Figure 1. Second, the distribution of categories across journal entries over the course of the semester is also described. The six categories from Luce and Hsi's framework are shown in Figure 1.

Across all journal entries the predominance of categories from most to least frequent was mechanistic, cause and effect, engineering and medicine, teleological, inconsistency, and general knowledge. Table 3 shows the percentage of each journal entry across the study based on the extent of representation of each type of scientific curiosity. That data includes instances where some PSTs demonstrated more than one type in a single journal entry. However, more than three types in one entry did not arise. Between 38 and 28% of each entry were coded as including at least two types of curiosity and between zero and four percent included at least three types (again, more than 3 types did not arise).

The most often coded types of scientific curiosity were *mechanistic* and *cause and effect*. Luce and Hsi define mechanistic curiosity as "curiosity about how something works or how a process occurs. Wanting to understand underlying mechanisms for processes or observations. Wanting to know how the entities in a causal relationship interact" (p. 79). This was the most frequent category of curiosity. For example, in an entry related to microorganisms and illness, Leslie asked. "*How does ecoli spread? Does it stick to you? What is the process?*" The same entry also precipitated the *cause and effect* code which is defined as *what-if* type

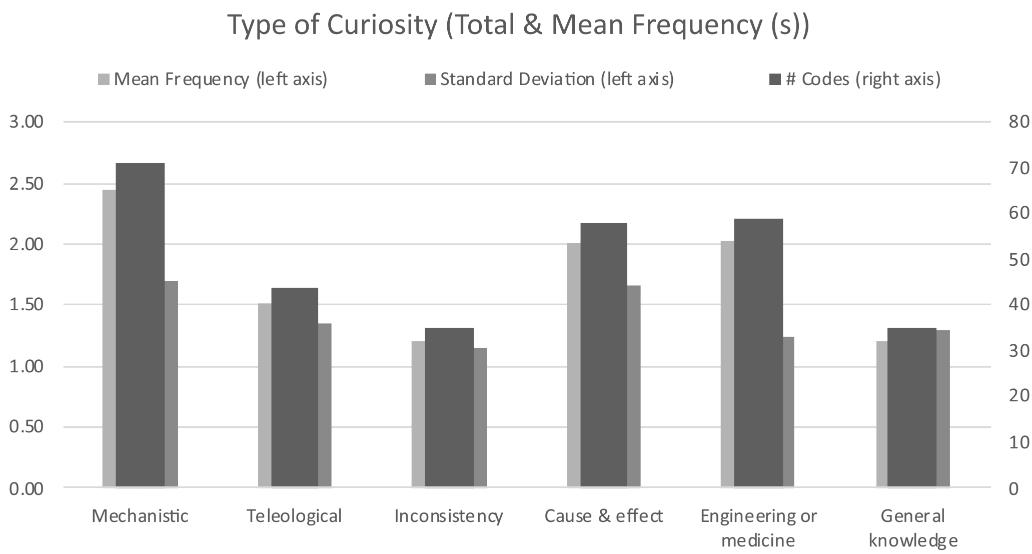

Figure 1. Description of curiosity distribution across participants' journals.

Table 3. Percentage of journal entries with each curiosity type (29 participants).

	Journal 1	Journal 2	Journal 3	Journal 4	Journal 5	Journal 6	Journal 7	Journal 8
Mechanistic	25.00%	34.04%	20.00%	24.44%	23.26%	17.65%	12.50%	24.40%
Teleological	27.27%	14.89%	15.56%	15.56%	6.98%	8.82%	4.17%	19.25%
Inconsistency	20.45%	12.77%	4.44%	11.11%	11.63%	5.88%	12.50%	14.88%
Cause and Effect	4.55%	8.51%	26.67%	20.00%	16.28%	26.47%	41.67%	25.79%
Engineering and Medicine	15.91%	23.40%	2.22%	11.11%	37.21%	35.29%	20.83%	10.52%
General Knowledge	6.82%	6.38%	31.11%	17.78%	2.33%	5.88%	8.33%	9.92%

curiosity or "curiosity about whether something does affect or will affect something else . . . wanting to know the entities in a causal relationship" (p. 79). Leslie's fourth entry transitioned from mechanistic type curiosity to cause and effect, "[h]ow did ecoli get on the vending machines buttons in the first place? Is it from feces particles in the air?"

The *engineering and medicine* code was the third most common type of curiosity expressed in the journals and Figure 2 illustrates how this type peaked around journal entry 5 in week nine of the semester, which coincided with the introduction of engineering design and emphasis on engineering design experiences.

Luce and Hsi define the *engineering and medicine* type of curiosity as related to "how things are built, constructed, or made" (p. 79) and this study considered the process of engineering design as part of that definition because we interpreted *how* as implying a process. Journal entries coded as *engineering or medicine* were most often technologically focused in ways that reflected their lives. For example, Tina, a student who was parenting a young child at the time of the study, reflected in journal entry six on "how to design a device that would allow an infant to safely breastfeed while strapped in a car seat, how to get it to stay on without constant suction?" This entry included drawings of a series of designs that reflected the problem as she experienced it.

Teleological, inconsistency, and general knowledge were the three least common types of curiosity. These are, respectively, curiosity about "the purpose of things, why things exist, or

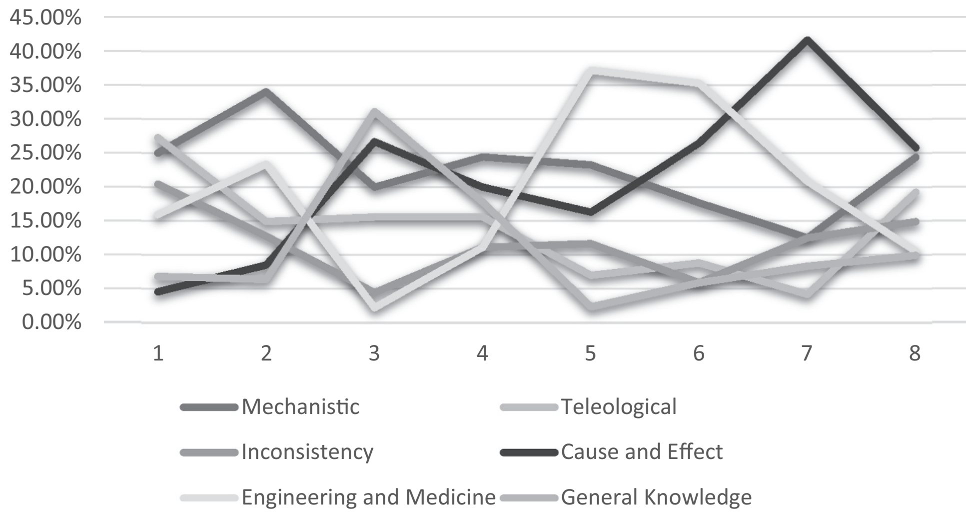

Figure 2. Distribution of curiosity codes by journal entry.

why processes occur"; "an observation that is surprising or inconsistent with prior knowledge"; and "facts, terms, classifications, or general information" (p. 79). Examples of teleological curiosity are *why does water not wash away germs* (Hermione, Journal Entry 6) and *why does the outside of food not burn when the inside is being cooked* (Zoe, Journal Entry 1). The demonstration of curiosity about inconsistencies peaked in the first journal entry which was collected in the first week of the course. That timing may have been a factor since this was their first inquiry-centered course. Liam's fourth journal entry provides an example of the inconsistency category of curiosity where he expressed that "I was surprised that simply drinking from a plastic bowl can dry a dogs (sic) nose out."

The final and least frequent type of curiosity was *general knowledge*. For example, Bridget's third journal entry included the question "what type of bacteria is good bacteria?" These types of questions were almost always embedded within, or adjacent to, other types of curiosity including in Bridget's second journal where she asked whether "different foods require different temperatures to cook, why? Different foods require different amounts of times to completely cook. Do foods have different size molecules that cook differently?" This last statement is curiosity about general knowledge but embedded within curiosity of a teleological nature. *Why* do foods cook differently and how does that relate to differently sized molecules is focused on why a process occurs, but embedded with that questioning was also a curiosity about general information; *does* the size of molecules within foods vary.

Discussion

Yesilyurt et al. (2021) observed that self-efficacy for teaching novel content, like engineering, is predicted by cognitive content and pedagogical mastery. We were interested in whether teachers' curiosity about content may also play a role. Lindholm (2018) has described scientific curiosity as "a driving force for societal and scientific growth, and to maintain its development and wellbeing throughout childhood in science education is an urgent task" (p. 998). The implications of curiosity about scientific phenomena are no less relevant to teachers of science, whom are integral to the societal and scientific growth to which Lindholm alludes. Teachers have the capacity to promote scientific curiosity and creativity among their students (Antink-Meyer & Lederman, 2015; Engel, 2011; Luce & Hsi, 2015), but their own scientific curiosity also relates to skills necessary for teaching including problem solving (Aldan Karademir, 2019) and inquiry skills (Aldan Karademir et al., 2019).

Teachers' curiosity about phenomena and their confidence around the conceptual mastery needed for teaching about those phenomena can be viewed through a metacognitive lens. Metcalfe et al. (2020) assert that curiosity is ultimately metacognitive. "When people are in the state of curiosity, they seek out information, and when they do come upon the answer, they hyper encode it—resulting in enhanced learning and memory, as well as enhanced reward in learning" (p. 45). Positioning curiosity as a motivator that has both an emotive and cognitive dimension that simultaneously act within the learning process, may be the key to understanding the lack of relationship between curiosity and confidence observed in this study. If we situate the curiosity journaling strategy that was used in an empirically grounded instructional model like Keller's ARCS-V (attention, relevance, confidence, satisfaction, and volition; Li & Keller, 2018) motivational model, we can view the strategy we used as a means of gaining learners' attention. However, if, as Metcalfe et al. assert, satisfying that curiosity is key to learning, and confidence in professional learning aligns in part with confidence in teaching, as suggested by Nolan and Molla (2017), then the use of the curiosity journaling strategy employed in this study was an incomplete opportunity. As Bazhydai and Westermann (2020) assert, curiosity, wonder, and creativity underlie knowledge transformation and development as complementary cognitive processes and this study illustrates that curiosity is a starting point.

> [C]uriosity always concerns a new fact about the familiar object, it needs to tread new territory ... That being said, it is easier to experience wonder at something unfamiliar ... Fisher (1998, p. 19) even says that 'wonder has its elemental existence in surprise'. And it is commonly observed that (the ability to) wonder wears off with increasing familiarity.

The premise of the journals was to notice the familiar in ways that would promote novel ideas and questions. The basis of the directions given to students as to notice what surrounds you everyday and that you don't think about often. Murayama et al. (2019) framework of reward learning is inclusive of surprise, the generation of new questions, perceived costs, environmental structure, and expectancy beliefs. Acquiring knowledge as a rewarding experience is more aligned with wonder and, according to Murayama et al., is driven and arises within autonomous knowledge acquisition. Our evidence suggests that this was not supported by the typical science journal we used, that commonly used in classrooms. The implications of this work support Metcalfe et al.'s (2020) findings about curiosity as an anchor that stimulates the emotive and cognitive processes that support learning. Reflections on phenomena that teachers are curious about, without sustained engagement, did not support that process, which also meant that changes in confidence were not observed. Luce and Hsi (2015) investigated the nature of curiosity among early adolescents and found that general knowledge was the most common category. In this study, this was the least commonly expressed type of curiosity in the journals. The age and education of the participants likely played a role in that difference, but the scientific inquiry course in which the study took place may have as well.

High-school-aged students have been observed to pursue inquiry models that produce less certainty when they were curious about the project (Zion & Sadeh, 2007). Future studies that examine sustained curiosity journaling strategies that connect to inquiry engagement are suggested because learner engagement in scientific inquiry is a mediator of the relationship between curiosity and inquiry abilities (Wu et al., 2018). This investigation was conducted within a course where participants were consistently engaged in inquiry and engineering design experiences. The fact that they expressed curiosity about a topic did not relate to changes in their confidence for teaching that topic. But the inquiry experiences they were having in the course were not necessarily connected to the topics they were expressing curiosity about. This may partially explain why curiosity, generally, was not found to be related to confidence for teaching. However, the nature of the curiosity they expressed (e.g., teleological) was found to relate to some topical areas of confidence.

Conclusions

The use of *a priori* coding imposes some limitations on the findings of this study. Both the categories of curiosity and the science topics from the Preparedness to Teach survey potentially constrained the outcomes of this study because they constrained our lens. In addition to examining journaling strategies that sustain connectedness to inquiry and engineering design experiences, future studies are needed that examine whether disciplinary domains imbue associations between types of curiosity and types of epistemic engagement.

How science journals can be structured to promote curiosity within PSTs everyday experiences and extend to wonderment, also needs to be upacked. The notion of personal relevance as a factor in science learning is under-developed (Stuckey et al., 2013), but Kapon et al. (2018) posit that there is a tension between science learning and personal relevance that is essential to the development of science identities. Personal relevance was observed in their work as something that could be supported, or *nurtured* through developing their conceptual, epistemic, and creative competencies. They are lifelong learners of science, therefore it is important to nurture the significance of science for teachers by bridging their conceptual and epistemic learning with their curiosity, wonder, and creativity. Further understanding of how, and whether, promoting wonder through journaling is also needed. Gilbert and Byers (2017) position wonder as a support along the pathway into professional practice among new teachers and this study suggests that it may be the bridge between curiosity and the development of understanding and confidence for science teaching.

This study asked how changes in pre-service elementary teachers' confidence for science teaching, and the scientific curiosity they expressed when journaling, related to one another. Our findings question the use of science journaling in teacher education settings (at least in the way it was used in this study) because its efficacy as a tool to bridge their scientific curiosity, learning, and confidence for science teaching is lacking. The structure and duration of the use of the science journal in this study were factors in this finding and future studies are needed to investigate the frequency, structure, and content of journal entries in terms of their influence on novice teachers' confidence.

This study also asked what is the nature of the scientific curiosity expressed among PSTs and the implications of these findings can inform the science teacher education curricula. Future studies that use curiosity (or wonder or creativity) to explore the differences between what teachers express scientific curiosity about and what their student's express curiosity about may provide an interesting lens for explorations of teaching and learning motivation, interest, and identity. The personal relevance of science includes what an individual finds worth questioning. When differences in the personal relevance of science exist between teachers and students, as evidenced by what they are curious about or what they wonder, what are the implications for learners?

Disclosure statement

No potential conflict of interest was reported by the authors.

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