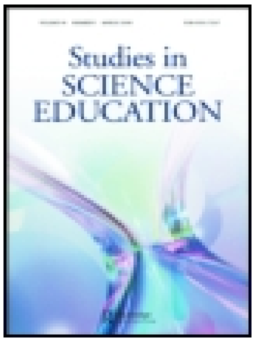

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Unpacking readiness for elementary science teaching: what preservice teachers bring and how that can be shaped through teacher education

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ABSTRACT
The work of elementary science teaching is challenging given the wide array of subject matter most teachers are expected to teach and a systematic de-prioritisation of science at these grades. In this literature review (63 papers; 2010–2020), we use a framework of readiness for science teaching. Using this framework allows us to illustrate foundational characteristics and abilities that preservice teachers may start with and develop as they become well-started beginners for elementary teaching in the face of systemic challenges. To this end, we identify what is known from the research literature about the strengths that preservice elementary teachers bring to this difficult work with regard to their characteristics and abilities in addition to the challenges they face, describing a foundation on which preservice teachers can build. We also highlight additional studies that show how teacher education can build on preservice teachers' strengths and support them in areas that are challenging. We identify themes around novices' identities, dispositions, emotions, beliefs, attitudes, self-efficacy, knowledge, engagement in and with science practices, lesson planning, and lesson enactment. Finally, we highlight four implications for science teacher educators, noting focal areas that may compensate for challenges preservice elementary teachers face while building on their strengths.

KEYWORDS
Elementary science; teacher education; preservice teachers; assets; readiness

Introduction

The work of teaching is terribly difficult (Lampert, 2001). It requires being responsive to the academic and socio-emotional needs of large groups of students with varying degrees of interest, knowledge, and skills in any given topic while being held accountable to delivering on rigorous academic achievement outcomes. Elementary[1] or primary teaching is peculiarly challenging as elementary teachers typically teach all academic subject areas – reading, writing, mathematics, social studies, and all disciplines of science, including life science, earth and space science, physics, and chemistry, as well as engineering – without specialising in most or any of them. For novices learning to do this work, it can be daunting. Though elementary teachers typically do not enter the

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profession because of a strong affinity with science, they do have strengths that they bring to this work (National Academies of Sciences, Engineering, and Mathematics; NASEM, 2022). This review is intended to help to identify preservice elementary teachers', or novices',[2] initial and early strengths (with regard to beliefs, knowledge, planning, and so on) that may be leveraged towards becoming well-started beginners. The review also identifies areas where they may need support, recognising that the education preservice teachers experience can impact their growth. What do these preservice teachers know or believe that teacher educators can build on? What can these novices do, in their initial forays into elementary science teaching, that can be used as a foundation for further growth?

Science is not taught much at the elementary level – on average 18–27 minutes per day in the U.S., in contrast to 82–89 minutes of reading per day, and it is prioritised even lower in schools that have fewer resources (Banilower et al., 2018). The data for science are roughly similar (though variable) globally, with an average across available countries of about 121 minutes/week (or 24 minutes/day) for fourth-grade science (National Center for Educational Statistics, 2019). This leads to disparities in children's access to science instruction that, at least in the U.S., break largely along racial lines given the strong correlation between poverty and race (Massey & Denton, 1993). Without science instruction, or with poor science instruction, children may not develop the building blocks that would support them in success with later science learning. Furthermore, with science instruction that emphasises memorisation or vocabulary, certain groups of youth – including youth with marginalised racial, ethnic, and religious backgrounds, youth who speak non-dominant languages, and youth who are differently abled – may not see connections between science as a discipline and their own cultural or linguistic backgrounds (Bang et al., 2017; Calabrese Barton & Yang, 2000).

Yet science is central to high-stakes decision-making as adults, including decisions about health and the environment. Moreover, including a more diverse group of voices in science fields helps to strengthen those fields themselves. Perhaps most importantly, children are curious about the world around them, and science allows children to explore natural phenomena (Duckworth, 2006; Eshach & Fried, 2005). Science takes advantage of their interests to help them answer their own questions. Depriving them of opportunities to learn science denies them of opportunities for joy and wonder. For these reasons and others, science is important for the elementary grades (NASEM, 2022).

That said, English language arts and mathematics are often prioritised in the elementary grades, to the detriment of other subject areas, including science (NASEM, 2021; National Center for Educational Statistics, 2019). This prioritisation manifests not only in less instructional time – as described above – but also fewer instructional resources, less time for professional learning, less actionable classroom data in the form of assessments, and ultimately a teaching force more comfortable and confident in their ability to teach literacy and numeracy than science (Banilower et al., 2018). Thus, better supporting novice elementary teachers in learning to teach science is a critical endeavour.

In this review, we start from an assumption that preservice elementary or primary teachers bring strengths to their work as teachers of science (Zembal-Saul et al., 2020) and that what these teachers know, believe, and can do will have an impact on how well-positioned they are to begin to learn about how to teach science in an environment replete with obstacles. To characterise how well-positioned novices are, we use the framing of *readiness*. We use readiness to refer to a place from which preservice teachers begin their journey towards becoming well-started beginners. By understanding where preservice elementary teachers are starting from – in terms of their knowledge, beliefs, attitudes, identities, and abilities – teacher educators are better able to design teacher education experiences that can build on their existing strengths and provide supports in the places where research suggests they may struggle.

Our primary intents with this review are to describe what the literature documents about preservice elementary teachers' readiness for teaching science:

- their *initial and early characteristics*—that is, their identities, dispositions, emotions, beliefs, attitudes, self-efficacy, and knowledge – with regard to science teaching,
- what they can *do* with regard to science teaching early on, without much support – that is, how they plan and enact science teaching, and
- what features of teacher education experiences seem to *support growth* in those fundamental and nascent characteristics and abilities as they move towards becoming well-started beginners.

We turn next to a conceptual framework that guides our work in this review.

Conceptual framework of teacher readiness

In essence, this review explores preservice elementary teachers' *readiness* for taking up the key ideas and practices that would support the kinds of reform-based science teaching that science educators may want to see in the elementary grades. In using the term 'readiness', we draw on scholarship that in turn draws on the idea of 'reading readiness':

> Kindergarten teachers spend most of their school year helping their students develop 'reading readiness'—skills necessary for students to develop before they can read (for a review, see Farr & Anastasiow, 1969). For example, children need to know how to hold a book, which direction to turn the pages, the letters of the alphabet and the sounds each makes, and the general components of stories. None of these skills is technically 'reading', but every reader has these skills. Similarly, a preservice teacher can learn about the content, how to represent content to learners, and common ideas their learners bring to science class.
>
> *(Davis & Smithey, 2009, p. 760)*

Davis and Smithey (2009) and 2022), drawing on Smithey (2008), describe these initial pieces as 'building blocks' that support a novice in being able to engage – eventually—in the work of teaching. Bismack and colleagues also describe these building blocks as entry points for more sophisticated understanding and practice.

In order to identify the building blocks that contribute to a novice elementary teacher's readiness to teach science, consider that teachers draw on multiple knowledge bases, belief systems, identities, and other characteristics as they engage in their instructional work. For example, Shulman (1986, 1987) identified domains of teacher knowledge as including subject matter knowledge, pedagogical content knowledge, pedagogical knowledge, and curricular knowledge; many others have extended (e.g. Abell, 2007) and further refined these domains (e.g. the six domains of content knowledge from Ball et al., 2008) and explored how they develop (e.g. through situated learning in Putnam & Borko, 2000). Similar investigations into teachers and teaching unpacks constructs like teachers' identities (e.g. Connelly & Clandinin, 1999), beliefs (e.g. Pajares, 1992), and practice (e.g. Grossman, 2018). A recent National Academies report out of the U.S., focused on preschool through elementary science and engineering (NASEM, 2022), names several constructs that are candidates for key building blocks for readiness. That report (p. 8–2 to 8–3) defines these constructs as follows:

- Identity: 'the ways in which a teacher represents herself/himself through her/his views, orientations, attitudes, knowledge, and beliefs about science teaching, the kind of science teacher she/he envisions to be, and the ways in which she/he is recognised by others' (Avraamidou, 2016, p. 863)
- Dispositions: 'professional attitudes, values, and beliefs that support student learning and development' (Eick & Stewart, 2010, p. 785); similar to habits of mind
- Beliefs: teachers' perspectives (about science . . . or science . . . teaching, for example) that can be distinguished from their knowledge (Pajares, 1992), which change over time, across moments, and across contexts (Louca et al., 2004)
- Knowledge: content knowledge for teaching (Ball et al., 2008), or the subject matter knowledge and pedagogical content knowledge related to both science . . . content and . . . practices (Bismack, 2019; Johnson & Cotterman, 2015)
- Practice: the work done by a teacher (e.g. eliciting children's ideas) or the act of getting better at that work (e.g. through rehearsals; Lampert, 2010; see also, for a focus in science teaching, Arias & Davis, 2017; Kloser, 2014; Windschitl et al., 2012)

Why does each of these matter in teaching? The NASEM (2022) report goes on to describe some of these contributions:

> Each of these elements has the potential for shaping how a teacher engages in the work of teaching. For example, an elementary teacher's self-efficacy for science teaching and her identity as a teacher of science might influence how often she teaches science. Her beliefs about children might influence what expectations she sets for which children in her classroom. Her content knowledge for science teaching might help her push children toward sensemaking, or might constrain her from doing so, and in particular her knowledge of science practices might lead her to engage children in [particular forms of activity]. Further, her capacities with regard to certain science teaching practices might support her in engaging children in sensemaking discussions. *(p. 8–3)*

Next, we turn to our operationalisation of these elements to develop the idea of readiness.

Review of previous studies to operationalise readiness

Based on our understanding of the literature on teacher preparation, including previous literature on readiness (e.g. Smithey, 2008), Figure 1 illustrates how we view initial teacher characteristics and abilities as both components and indicators of readiness, and as becoming more sophisticated, over time and with learning opportunities and teaching experiences. These characteristics and abilities position preservice teachers as well-started beginners prepared for ongoing professional growth in the classroom.

In Figure 1, the bottom row – the examples of initial characteristics and abilities – reflects preservice teachers' varied starting points (based, for example, on their previous experiences as science learners). We see these initial and early characteristics and abilities

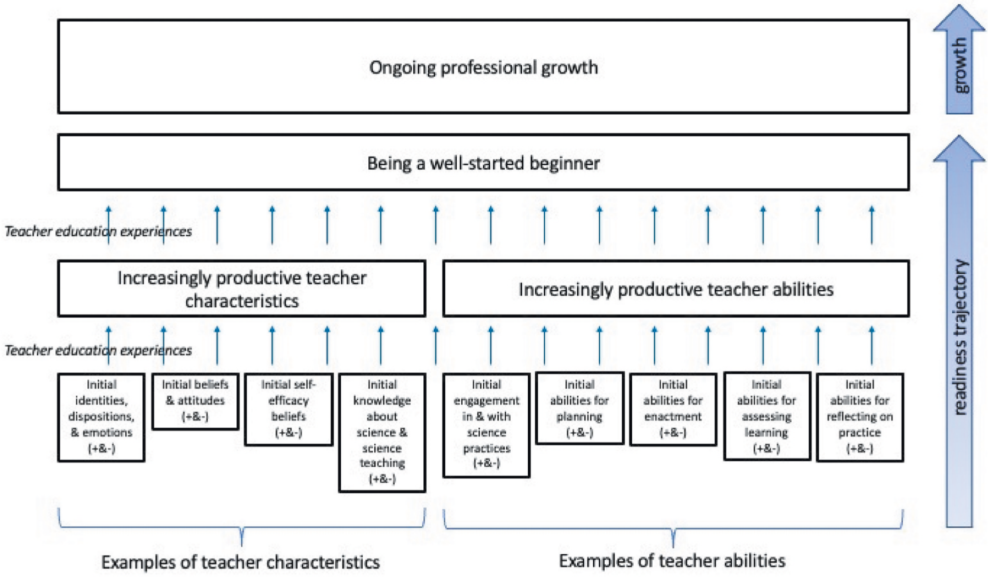

Figure 1. The development of readiness for science teaching.

(and potentially others) as building blocks in their readiness trajectory towards becoming well-started beginners. For example, McLaughlin and Calabrese Barton (2013) found that some preservice teachers saw their elementary students' funds of knowledge as barriers to learning science content, while others saw them as resources to leverage for student sensemaking. Believing children's funds of knowledge are a resource is a helpful building block for readiness – even if the preservice teachers may not yet know what to do with those funds of knowledge. On the other hand, seeing children's funds of knowledge as a barrier to learning is less helpful. Unfortunately, this bottom row – the initial characteristics and abilities – is a place where there can be a great deal of deficit description of preservice teachers in the field – describing, for example, what preservice elementary teachers *don't* know, rather than what they do know. One intention of this review is to name and identify strengths within those initial characteristics and abilities, not just areas of need.

The second row from the bottom – the 'increasingly productive' characteristics and abilities – serves as an indication that a preservice teacher can start to develop further from some of the building blocks in the bottom row *and* start to shed or apply less frequently those that are less productive. This allows teacher characteristics to become increasingly useful and helpful, and it allows teacher abilities to become more actionable. As an example of this way of thinking, Shaughnessy and Boerst (2018), in looking at novice elementary teachers' practice, characterise teachers' skills as including ones that need to be learned (i.e. added to a teacher's repertoire), ones that can be built on, and ones that need to be 'unlearned' or lowered in priority of use. This offers a mechanism for moving along the trajectory of readiness.

What should teacher educators make of those seemingly *problematic* initial characteristics or abilities, like seeing children's funds of knowledge as a barrier? Turning back to reading readiness may help. Imagine a young child who does not identify as a reader and has negative emotions towards reading. As his teacher, you recognise his identity as 'non-reader'. Yet you also know that the child loves butterflies. Perhaps given experiences with books about butterflies, the child can come to identify less centrally as a definitive 'non-reader' and incrementally more with a more productive or useful (in terms of reading readiness) identity of 'reader of books about butterflies'. The child adds a new characteristic – one that can more easily serve as a building block for his reading readiness.

Applying this analogy to the example provided above about children's funds of knowledge, a preservice teacher who believes a child's funds of knowledge could serve as an obstacle to science learning might benefit from developing dispositions of curiosity towards science and children's ideas about it, or strategies for eliciting and responding to students' ideas in their planning and enactment. The preservice teacher might then apply these ideas more often and deprioritize the idea of barriers. Building on these other 'building blocks' for readiness may serve to incrementally shift a preservice teacher's beliefs about students' funds of knowledge. Thus, theoretically, we see those initial characteristics in Figure 1 as intertwined and integrated, one supporting the other in a teacher's development towards becoming a well-started beginner.

These early characteristics or abilities can serve as resources as preservice teachers continue to gain teaching experience and opportunities to learn within teacher education. For example, Smithey (2008) and 2020) explored different dimensions of readiness for being able to notice, use, and respond to students' ideas; Bismack et al. (2022) explored readiness for engaging children in argumentation and other science practices; and Anderson et al. (2000) explored readiness in balancing a focus on the learner with a focus on learning. In this last example, two preservice teachers began the study with quite different beliefs (one with a belief about the importance of keeping children at the centre of inquiry-based learning, and one with a belief about the importance of the teacher being charismatic and creative). After taking different paths, both ended the first year of their teacher education programme with an orientation towards balancing learner and learning concerns – the kind of vision of science teaching espoused by their programme. These (disparate) initial beliefs or dispositions served as important elements of their readiness, even though each would become shaped differently across a year of teacher education experiences and teaching experiences. These studies (Anderson et al., 2000; Bismack et al., 2022; Haverly et al., 2020; Smithey, 2008) and others illustrate different ways in which preservice teachers' initial characteristics and/or abilities could serve as building blocks or entry points to support them as a foundation as they continue to develop as teachers. Indeed, each shows how these teachers' initial ideas, beliefs, or practice – while limited in its own right – can serve as an asset on which the preservice teacher can draw over time to continue their development towards becoming a well-started beginner.

Being a well-started beginner – that is, one with the characteristics and abilities a preservice teacher may need upon entering the field to be well prepared for elementary science teaching – is represented in the third row from the bottom of Figure 1. Mikeska et al. (2009) draw on Hollon et al. (1991) description of a 'well-started beginner', saying,

> Well-started beginners do not possess the same breadth of knowledge and skills of an expert practitioner in the field, but they are capable of using their professional knowledge to focus on key learning issues that arise in classroom practice and to make curricular and instructional decisions. *(p. 679)*

Like Smithey (2008), we connect the idea of readiness to the idea of becoming a well-started beginner by describing a readiness trajectory as preservice teachers develop increasingly productive characteristics and abilities en route to becoming a beginning teacher.

We take a situated (Brown et al., 1989; Putnam & Borko, 2000) and sociocultural (Grossman, 2018) perspective on teachers' learning. From a situated perspective, learning occurs in the context of specific phenomena (e.g. learning-to-teach experiences), and over time what is learned can be generalised across contexts. In addition, from a sociocultural perspective, learning a practice (e.g. learning to teach) requires orchestrating skill, knowledge, and identity to work towards a communal goal (Berland, 2011; Grossman, 2018), such as teaching science well and equitably. Thus, readiness entails integrating and connecting the characteristics and abilities depicted in the bottom portions of Figure 1 within learning contexts.

Characterising the first three rows of Figure 1 is a focal point for our review: the initial characteristics and abilities and the intermediate characteristics and abilities that are becoming increasingly productive (e.g. usable, useful, actionable, integrated), as well as what it might look like to be a well-started beginner ready for responsibility for one's own classroom. Not surprisingly, the study designs we reviewed for this paper capture these 'initial' and 'intermediate' characteristics and abilities at various stages of a preservice teacher's experience in a teacher preparation programme. As a result, there is some messiness inherent in the synthesis. We focus our attention on preservice teachers' readiness as they move through their teacher preparation programmes (as captured in Figure 1 by the long upward arrow on the right) without attempting an artificially precise characterisation of 'stages'.

In sum, in this review, we outline how preservice elementary teachers reflect and develop readiness for science teaching – in terms of the building blocks of knowledge, beliefs, abilities, and so forth – that support them in being well-started beginners. Thus, towards these ends, the research questions guiding this review are:

- What do we know about preservice elementary science teachers' initial identities, dispositions, emotions, beliefs, attitudes, self-efficacy, knowledge, and abilities?
- How can teacher educators support the development of those characteristics and abilities to position preservice teachers as ready to become well-started beginners?

Method

We reviewed sources for relevant reviews of the literature, including *Review of Educational Research*, *Studies in Science Education*, and various handbooks. We identified reviews relevant to our review, but no recent reviews that aligned fully to our focus, focusing specifically on the characteristics, abilities, or experiences of preservice elementary teachers of science. We then searched 12 journals: *American Educational Research Journal*, *Cultural Studies in Science Education*, *Elementary School Journal*, *International Journal of Science Education*, *Journal of Research in Science Teaching*, *Journal of Science Teacher Education*, *Journal of Teacher Education*, *Journal of the Learning Sciences*, *Research in Science Education*, *Science Education*, *Teachers College Record*, and *Teaching and Teacher Education*. These journals' impact factors vary quite a bit (from 1.167 to 5.439), reflecting both the niche focus of some of the journals and the global distribution of others. We selected these journals because they were likely to include empirical papers related to preservice elementary science teachers and elementary science teacher education and because each is well-regarded. These 12 journals include the highest regarded English-language journals in science education, teacher education, and elementary education – the three intersecting areas of focus in this review – as well as other highly regarded journals reaching a broader audience, in which work on elementary science teacher education or preservice elementary teachers of science might be published.

We looked at every paper published in each of these journals between the years of 2010 and March 2020, identifying papers related to elementary science teacher education. In the absence of a clearly analogous recent review focused on elementary science teacher education or preservice elementary teachers of science, we opted to reach back one decade from when we were conducting the initial search to be able to draw in relevant and appropriate literature while maintaining a manageable scope for our review. Because of the scope of the literature base on preservice elementary teachers of science, a period of longer than a decade was likely to be unwieldy in that the amount of literature would be too large to responsibly review. Rather, a decade seemed appropriate – likely to illuminate relevant trends without being overwhelming for the reader.

Scholars globally use different language for talking about elementary or primary teachers who teach science, but these teachers are often not described as 'science teachers'. Therefore, in our initial pass to identify potential papers to include in our review, we did not rely on search terms. We instead focused on the title, first, and then the abstract of the paper to determine potential relevance. For example, if a title explicitly referred to secondary teachers, secondary science teachers, or inservice elementary teachers, we would not further consider the paper, but if a title referred to preservice teachers or science teachers, we would read the abstract to determine if the focal participants were preservice elementary teachers of science or not. We followed this process with searches of our target journals (using search terms like elementary, primary, science, preservice, candidate) to capture papers we might have missed initially. Using these two approaches in tandem, our initial inclusion criteria led us to select empirical studies that focused on elementary science teacher education and/or preservice elementary science teachers. Specifically, with regard to preservice elementary science teachers, we took an expansive perspective on what might contribute to a description of their 'readiness' in terms of their characteristics or abilities. We were interested in papers that could help us describe the lower portions of Figure 1. However, we did not do much filtering out at this stage, choosing instead to maintain any paper that had the potential to inform our focus on elementary science teacher education and/or preservice elementary science teachers. We included papers from any country and did not intentionally seek papers that represented a particular methodological approach or theoretical stance. Through this process, we identified 229 papers that were potentially relevant for our review.

We made an initial tentative determination of the focus of the paper: preservice teachers' characteristics, preservice teachers' performances or abilities, and/or teacher education experiences. If we determined a paper was likely to be relevant for our review, then one of the authors read the paper and entered a summary in our database. Using both a priori and emergent coding (see Table 1), we applied descriptors to each paper.

Our a priori coding categorised papers based on a focus on preservice teachers' characteristics, preservice teachers' performances or abilities, and/or teacher education experiences, as noted above. Our emergent coding elaborated on that initial categorisation (e.g. beliefs, subject matter knowledge, planning). A paper could be coded as relevant to more than one general category (e.g. both characteristics and experiences, or both characteristics and performances) and more than one specific focus (e.g. both beliefs and attitudes, or both attitudes and science practices). However, midway through our review process, we better appreciated the scope of the work we had taken on, and we recognised that it was too broad for a single review paper. Thus, at that point, we used an exclusion criterion for studies focused solely on teacher education experiences, and those papers were moved for inclusion in a different review of the literature (Davis & Haverly, 2022). In the current paper, guided by our research questions, we focused on literature that characterises preservice elementary teachers' characteristics and abilities with an eye towards their *readiness for science teaching*. Our codes were refined over time and eventually became the dimensions of readiness explored in the review.

During this phase, we also further culled our set of papers for the review if we determined upon closer reading that a paper was not relevant. For instance, we determined that some of these papers were not empirical studies or did not focus on preservice *elementary* teachers of science. This process did not involve new inclusion or exclusion criteria but did reflect the ambiguous nature of how scholarship in this space is reported globally. (While we also checked to see if any paper needed to be excluded from the review due to quality – perhaps due to judging it to employ a poor methodology or to present weakly supported conclusions – we did not have to use this exclusion criterion on any papers.)

In this review, our constructs of interest include identities, dispositions, emotions, beliefs, attitudes, self-efficacy, knowledge, and abilities for teaching. We extend the set of constructs beyond those defined above to better align with the scope of the literature we identified. In our review, we group identities, dispositions, and emotions together; the dividing lines among these constructs are murky in the literature, and in our assessment,

Table 1. Initial a priori general focus codes and emergent specific focus codes.

General a priori focus codes	Examples
Preservice teacher characteristics	Beliefs, attitudes, identity, knowledge
Preservice teacher practice	Enactment, planning, noticing, reflection, abilities
Teacher education experience	Programme feature, class assignment, field experience
Examples of emergent specific focus codes	Examples or description
Approximations of practice	Rehearsal, microteaching
Assessment	Formative assessment, summative assessment
Attitudes	Attitudes about teaching, attitudes about science
Beliefs	Beliefs about teaching, beliefs about science
Confidence, self-efficacy	Self-efficacy beliefs about science teaching, confidence in science knowledge
Decision-making	Decision-making about instructional moves
Emotions	Emotions about science, science teaching, children
Identity	Identity as teacher, as science person, as science teacher
Inquiry	Focus on asking questions, using evidence
Knowledge	Knowledge about science, knowledge about teaching
Planning	Lesson design, writing lesson plans
Science practices	Planning and conducting investigations, developing and using models

identity is the best-developed of these three constructs within the field of elementary science education, so we incorporate constructs that seem connected to 'identity' with it. Similarly, although 'attitudes' could easily be grouped with identities, dispositions, and emotions, we instead include it with beliefs, due to the overlapping nature of how these constructs play out in the literature. At the same time, because a large proportion of the literature on teacher beliefs, within elementary science, has focused specifically on teachers' beliefs about their own self-efficacy for teaching science, we opted to separate out self-efficacy beliefs (in essence, teachers' confidence in themselves as teachers) from the broader category of beliefs about science and science teaching. We use 'knowledge' as an overarching category, and within the category, we focus primarily on subject matter knowledge and pedagogical content knowledge, again because of what we found within these papers. We use 'abilities' as a broader category than 'practice' to capture some of the initial abilities of teachers; specifically, we found literature on teachers' own skill with science (most notably, their skill with the science practices) that seemed to fit most neatly into this space of 'abilities'. Abilities for teaching also, of course, includes teachers' planning and enactment of science lessons. All of these decisions about constructs of focus and how to categorise them in the review were made through iterative exploration of the literature, rather than a priori. We also note that though we present the categories separately, for analytic purposes, many of these dimensions are closely related to one another – a feature that becomes clear in the review as we highlight some literature that explores constructs across these analytic groupings.

As a result of this multiphase process, we ended up with 63 unique, individual papers in our systematic review, focused on preservice elementary teachers' characteristics (e.g. knowledge, beliefs) and/or abilities or performances (e.g. planning, enactment). We present the complete list of these 63 papers, along with certain key information, in Table 2.

As we report on the findings in the 63 empirical studies, we make note of traits that may matter to readers, including the scale of the study and the context in which it took place. Indeed, a note about the nature of this literature base is in order. Across the 63 unique papers in the systematic review, the mean number of preservice elementary teacher participants was 97.4, and the median was 51. This means that half of the papers include 51 or fewer participants. The maximum number of participants was 456, and – not surprisingly – the minimum number of participants was 1. Thus, as is often the case in science teacher education research (see, e.g. Davis et al., 2006), there are a few large studies (here, often, though not exclusively, taking place in science content courses), but many of the studies are smaller scale, involving one or two classes (e.g. one or two sections of a science methods course) or one or a handful of individual case study participants. We note the number of participants in many of our elaborations and these numbers are also available in Table 2.

In addition, to further characterise the literature base included in this review, we note:

- 36 papers (of the total 63) reflect studies conducted in the US; an additional 16 papers discuss studies from Europe, 5 papers from the Middle East, 4 papers from East Asia, 3 papers from Australia, and 1 paper from South America. (Note that these numbers do not add up to 63 because 4 papers involved participants from two or more countries, 2 of which crossed regions.)

Table 2. Studies cited on preservice elementary teachers' characteristics and abilities.

Study Citation	Journal	n^a	Country/ies	Cross-Reference, if applicable
IDENTITIES, DISPOSITIONS, AND EMOTIONS				
Identities				
Avraamidou's (2016)	IJSE	3	Southern European country	
Blatt and Patrick (2014)	IJSE	148	US	
Carrier et al. (2017)	IJSE	2	US	
Danielsson and Warwick (2014a)	IJSE	11	UK	
Danielsson and Warwick (2014b)	RISE	11	UK	
M. Gross and Huchberg (2016)	CSSE	8	Israel	
Kier and Lee (2017)	TATE	20	US	
Dispositions and emotions				
Eick and Stewart (2010)	JSTE	4	US	
Hufnagel (2015)	JRST	30	US	
BELIEFS AND ATTITUDES				
Attitudes				
Cartwright and Atwood (2014)	IJSE	30	US	Self-efficacy
Casanoves et al. (2015)	IJSE	407	Spain	Knowledge/subject matter knowledge
Szyjka et al. (2011)	JSTE	87	US	Science practices
Taştan Kırık (2013)	RISE	262	Turkey	Self-efficacy
Wendt and Rockinson-Szapkiw (2018)	TATE	66	US	
Beliefs				
Akerson, Buzellii, and Donnelly (2010)	JRST	4	US	
Akerson, Buzellii, and Eastwood (2010)	JSTE	17	US	
Akyol et al. (2012)	JSTE	415	Turkey	Knowledge/subject matter knowledge
Danielsson et al. (2016)	CSSE	120	Sweden	
L. Gross et al. (2019)	JSTE	76	US	
Gullberg et al. (2018)	RISE	47	Sweden	
Kim and Tan (2011)	IJSE	38	South Korea	
Küçükaydın and Gökbulut (2020)	JSTE	208	Turkey	
Lee et al. (2020)	RISE	129	US, Hong Kong	
Markic and Eilks (2012)	IJSE	52	Germany	
Martin and Carter (2015)	JRST	1	Australia	
Milford and Tippett (2013)	JSTE	127	Canada	
Nilsson and van Driel (2011)	RISE	5	Sweden	
Palmberg et al. (2015)	JSTE	456	4 Nordic-Baltic countries	Knowledge/subject matter knowledge
Palmberg et al. (2018)	JSTE	426	Finland, Norway, Sweden	Knowledge/subject matter knowledge
Rivero et al. (2011)	RISE	25	Spain, Brazil	
Saçkes and Trundle (2014)	JSTE	52	US	Knowledge/subject matter knowledge
Steele et al. (2013)	JSTE	131	Canada	
Subramaniam (2013)	RISE	5	US	
Subramaniam et al. (2018)	JSTE	72	US	
Wang et al. (2010)	TATE	215	Taiwan	
Wilson and Kittleson (2012)	RISE	4	US	
Zapata (2013)	CSSE	119	US	
SELF-EFFICACY				
Bautista (2011)	JSTE	44	US	
Cartwright and Atwood (2014)	IJSE	30	US	Beliefs and Attitudes/attitudes
Deehan et al. (2017)	IJSE	112	Australia	
Gunning and Mensah (2011)	JSTE	23	US	
Köksal (2011)	JSTE	206	Turkey	
Menon and Sadler (2016)	JSTE	51	US	Knowledge/subject matter knowledge
Norris et al. (2018)	IJSE	274	Australia	
Taştan Kırık (2013)	RISE	262	Turkey	Beliefs and Attitudes/attitudes
Wilder et al. (2019)	JSTE	142	US	

(*Continued*)

Table 2. (Continued).

Study Citation	Journal	n[a]	Country/ies	Cross-Reference, if applicable
KNOWLEDGE				
Pedagogical content knowledge				
Cobern et al. (2014)	IJSE	28	US	
Nelson and Davis (2012)	IJSE	4	US	Science practices
Subject matter knowledge				
Akyol et al. (2012)	JSTE	415	Turkey	Beliefs and Attitudes/beliefs
Casanoves et al. (2015)	IJSE	407	Spain	Beliefs and Attitudes/attitudes
Mandrikas et al. (2013)	IJSE	60	Greece	
Menon and Sadler (2016)	JSTE	51	US	Self-efficacy
Nixon et al. (2019)	JRST	169	US	
Palmberg et al. (2015)	JSTE	456	4 Nordic-Baltic countries	Beliefs and Attitudes/beliefs
Palmberg et al. (2018)	JSTE	426	Finland, Norway, Sweden	Beliefs and Attitudes/beliefs
Papadouris et al. (2014)	JSTE	198	Cyprus	
Ratinen (2013)	IJSE	275	Finland	
Rice and Kaya (2012)	RISE	240	US	
Ruiz-Gallardo et al. (2019)	RISE	161	Spain	
Saçkes and Trundle (2014)	JSTE	52	US	Beliefs and Attitudes/beliefs
SCIENCE PRACTICES				
García-Carmona et al. (2017)	JSTE	66	Spain	
Nelson and Davis (2012)	IJSE	4	US	Knowledge/pedagogical content knowledge
Szyjka et al. (2011)	JSTE	87	US	Beliefs and Attitudes/attitudes
PLANNING AND ENACTMENT				
Planning & pedagogical design capacity				
Forbes's (2011)	SciEd	46	US	
Forbes (2013)	JSTE	46	US	
Forbes and Davis (2010)	JRST	46	US	
Ross and Cartier (2015)	JSTE	51	US	
H. -G. Yoon et al. (2012)	RISE	16	South Korea	
Enactment				
Dalvi and Wendell (2017)	RISE	25	US	
Haverly et al. (2020)	JTE	2	US	
Hernandez and Shroyer (2017)	JSTE	12	US	
Wendell et al. (2019)	JRST	2	US	
Zangori and Forbes (2013)	SciEd	4	US	

Note: CSSE = *Cultural Studies in Science Education*; IJSE = *International Journal of Science Education*; JRST = *Journal of Research in Science Teaching*; JSTE = *Journal of Science Teacher Education*; JTE = *Journal of Teacher Education*; RISE = *Research in Science Education*; SciEd = *Science Education*; TATE = *Teaching and Teacher Education*.

[a]*n* references the number of preservice elementary teacher participants.

- 31 of the papers used qualitative methods, 15 papers used quantitative methods, and 17 used mixed methods.

Because our intent is to synthesise themes across the literature, we also note whether claims seem to be warranted by multiple studies or by a single individual study, and whether claims are specific to a particular population or if they seem to have broader reach. When appropriate, we also note counterevidence that we turned up in our review. We cannot elaborate on every paper, and therefore we make choices to illustrate key themes, unique approaches, or central programmes of research. We turn now to the results of the review itself.

Characteristics and abilities of preservice elementary science teachers: A review

We found literature related to multiple dimensions of preservice elementary teachers' characteristics: their identities, dispositions, attitudes, emotions, self-efficacy, beliefs about science or science teaching, and knowledge. In addition, several studies in our review focused primarily on what preservice teachers can *do* as novice teachers: their engagement in science practices as learners, and their planning and enactment of instruction. We encourage readers to also see other recent and older reviews that cover related terrain – including those by Akerson and Bartels (2023), Davis and Haverly (2022), Zembal-Saul et al. (2022), Roth (2014), van Driel et al. (2014), Schneider and Plasman (2011), Abell (2007), and Davis et al. (2006), as some dimensions addressed in this review have a long-standing history in the field.

In the sections that follow – organised around dimensions of preservice teachers' characteristics and abilities – we first provide a brief definition and explicate what we see as more productive versions of that dimension – harking back to Figure 1 and the movement upward from initial to intermediate to well-started beginner. Then, we outline what is known about that area: for example, what does the literature show about preservice elementary teachers' identities as science teachers? Then, we briefly describe some of the literature outside the scope of this review about how that dimension can be supported through teacher education (as depicted in the multiple short upward arrows in Figure 1). These sub-sections, though less systematic, draw on additional literature and are intended to round out what is presented about each component of readiness and to capture what we know about change in response to an intervention.

To guide the reader through the review, Table 3 provides an overview of some of the key findings across the paper.

Elementary science preservice teachers' characteristics

This first set of sections is organised around key domains of elementary preservice science teachers' characteristics that surfaced in the literature – their identities, dispositions, and emotions; beliefs and attitudes; self-efficacy; and knowledge about science and science teaching. We also share what we learned teacher preparation programmes can do to effect shifts in preservice teachers' characteristics that can ready them for science teaching.

Initial and increasingly productive identities, dispositions, and emotions

Seven studies took up preservice elementary teachers' identities as science teachers (Avraamidou, 2016; Carrier et al., 2017; Danielsson & Warwick, 2014a, 2014b; Kier & Lee, 2017), including teaching science outdoors (Blatt & Patrick, 2014) and the connection between place identity and professional identity (M. Gross & Huchberg, 2016). As shown in Table 2, three of these studies were located in the U.S., three in Europe, and one in Israel, with a range in participants from two to 148. By identity, we mean, as noted above,

Table 3. Summary of key findings.

Dimension: Initial and increasingly productive…	Summary: characteristics and performances of preservice elementary teachers of science
Identities, dispositions, and emotions	• Identities are multi-faceted and wide ranging • Identities can be positive or negative towards science and towards students • Identities can be shaped by life experiences and experiences within teacher education • Productive dispositions may help to compensate for weaker science content knowledge
Beliefs and attitudes	• Beliefs about science and science teaching vary, and some can be built upon • Attitudes towards science and science teaching can be positive or negative • Beliefs seem connected to how or how often teachers intend to teach science
Self-efficacy	• Self-efficacy is generally low; preservice elementary teachers lack confidence in themselves as science teachers
Knowledge about science and science teaching	• There is a broad range of topics preservice elementary teachers of science are expected to understand • Some scholars focus on preservice teachers' weaknesses while others focus on their strengths and resources • Subject matter knowledge is linked to greater self-efficacy for teaching science • Novices can make reasonable instructional decisions based on their pedagogical content knowledge in spite of weaker subject matter knowledge • Novices' identities, emotions, and beliefs can mitigate gaps in subject matter knowledge
Engagement in and with science practices	• Some science practices are more familiar to preservice elementary teachers than others
Planning and enactment	• Novices can skilfully make adaptations to curriculum materials • Novices can skilfully respond to student sense-making • Novices can skilfully leverage culturally responsive teaching strategies • Novices may struggle with allowing student-driven inquiry

how a teacher represents herself, what kind of teacher she wants to be, and how she is recognised by others (Avraamidou, 2016); for a preservice elementary teacher of science, a more productive identity (see Figure 1) might include seeing herself as someone who teaches science.

Avraamidou (2016), for example, studied three preservice elementary teachers enrolled in a science methods class in a southern European country. Avraamidou found that the preservice teachers' identities as science teachers varied, with one emphasising scientific inquiry, one valuing and privileging experiences outdoors in nature, and one prioritising children's emotional well-being; these identities were shaped by interactions, events, and experiences in their lives prior to and during teacher education. Carrier et al. (2017) followed two preservice elementary teachers in a STEM-focused elementary teacher education programme in the U.S. from their teacher education programme into their first year of teaching, looking longitudinally at their identity development. One teacher's identity was more positively inclined towards science and science teaching initially than the other's, but both developed towards a science teaching identity. Similar to Avraamidou, these authors found that these identities were shaped both by early experiences with science and experiences in teacher education, including the field. Each study also emphasised the multiple facets of preservice elementary teachers' identities.

Another pair of related studies of identity involved 11 preservice elementary teachers in the United Kingdom (Danielsson & Warwick, 2014a, 2014b). In one (Danielsson &

Warwick, 2014a), the preservice teachers were found to use five distinguishable Discourses as they spoke about their identities: Discourses connected to traditional science teaching, teaching science through inquiry, being a traditional primary (elementary) teacher, being a teacher who is a classroom authority, and being a primary teacher who is a role model. In the other study (Danielsson & Warwick, 2014b), the authors showed how the preservice teachers experienced tensions among these Discourses (e.g. between traditional and inquiry-oriented science teaching, or between inquiry-oriented science teaching and being an authority). It seemed that their life experiences – as with Avraamidou's (2016) and Carrier et al. (2017) studies – shaped these identities.

Two studies took up dispositions and emotions about specific science topics or areas (Eick & Stewart, 2010; Hufnagel, 2015). By dispositions, we mean, as noted above, preservice teachers' habits of mind that may shape students' science learning. By emotions, we mean one's feelings or sentiments towards one or more aspects of science or science teaching. For a preservice elementary teacher of science, more productive dispositions and emotions would include those that might lead them to want to teach science, to do so well, and to not be afraid to do so – that is, dispositions and emotions that have a positive valence are more likely to be productive.

Hufnagel (2015) explored 30 preservice elementary teachers' emotions about climate change in a qualitative study taking place in a science content course for preservice elementary teachers focused on climate change at a large university in the northeastern U.S., drawing on ethnographic field notes, student artefacts, and classroom video. The study found that preservice teachers' expressions of emotion related to the impacts of climate change were focused mainly on the impacts of climate change on others (i.e. other people or other organisms) as were emotions expressed related to the causes of climate change (i.e. preservice teachers focused on how others caused climate change). The study did not focus on how these emotions might shape elementary instruction related to climate change. In another example, more directly connected to teaching, Eick and Stewart (2010) studied four preservice elementary teachers and found that each had dispositions that supported them in being able to use reform-based curriculum materials, such as inquisitiveness and the inclination to learn alongside one's students. The preservice teachers were able to compensate for not having strong science subject matter background by employing their useful dispositions. This study reflects an additional way that dispositions might be productive and play into a teacher's readiness – in actually bolstering a potential weak spot in aspects of a teacher's background or initial characteristics.

Teacher education supports for preservice teachers' identities, dispositions, and emotions: drawing on additional literature. There are many examples in the literature of studies investigating how components of a teacher preparation programme might support the development of preservice elementary teachers' identities, dispositions, and emotions with regard to science and science teaching. Such teacher education experiences would be reflected in the upward arrows in Figure 1, supporting movement from initial identities, dispositions, and emotions to more productive ones, or further movement from there to becoming a well-started beginner. For example, Crowl et al. (2013) looked at 40 preservice elementary teachers in a physics course for elementary teacher education at a public university in the western U.S. The qualitative study focused on 'friends and family' assignments and looked at how these assignments seemed to promote preservice teachers' learning and make science more meaningful for them. The authors found that the friends and family assignments seemed to support preservice teachers in developing positive attitudes towards science and to view themselves as both learners and teachers of science. The experiences also supported them in finding multiple ways to investigate and make sense of the world, and to collaboratively learn science. Similarly, Settlage (2011) found that in a science methods course focused on culture, five preservice elementary teachers in a predominantly White institution in the U.S. with limited exposure to culturally, racially, or linguistically diverse settings were able to make some positive shifts in their identities in response to the course.

Other studies focused on how field experiences seemed to shape preservice teachers' identity, including the roles of supportive mentors (Abed & Abd-El-Khalick, 2015; Kenny, 2010; Miller et al., 2019), opportunities for teaching and coteaching (Fitzgerald, 2020; Siry & Lara, 2012), and action research (Kinskey, 2017). For example, Chen and Mensah (2018), in a qualitative study involving three preservice elementary teachers enrolled in a social justice-focused elementary teacher education programme in the northeastern U.S., gathered data to characterise the preservice elementary teachers' identities – in particular, their identities as science teachers and as social justice teachers. The authors identified several factors that seemed to shape the preservice teachers' identity development, including their personal histories, their coursework at the university, how they were positioned in their student teaching classrooms, and their opportunities to teach science. In particular, their cooperating teachers played an important role in this identity development (as both science teachers and social justice teachers).

With regard to preservice teachers' emotions towards science, and in the context of a science content course, Powietrzyn´ska and Gangji (2016) engaged in a mixed methods study involving 72 preservice elementary teachers taking a conceptual physics class in an elementary teacher education programme at an urban university. The unusual feature of the class was the instructor's encouragement of engaging in mindfulness practices. The authors found that the instructor's approach seemed to support the preservice teachers in experiencing positive emotions in a physics class – often cited as a challenge in working with preservice elementary teachers. As in Crowl et al. (2013) mentioned above, here the instructor was working towards shifts in the emotional or affective side of preservice elementary teachers, in addition to more traditional content learning.

Finally, with regard to preservice teachers' dispositions towards science teaching, Gilbert and Byers (2017) focused on the incorporation of wonder in the elementary science methods course. This qualitative case study took place in Australia with a cohort of 23 preservice elementary teachers as the case. The authors found that infusing wonder into the coursework seemed to catalyse teachers' interest in science and science teaching, which has the potential to counteract the negative associations that preservice elementary science teachers often have with science. This paper illustrates how one productive disposition (interest) could help foster reducing less productive initial dispositions, as a preservice teacher moves along their readiness trajectory.

Synthesis: identities, dispositions, and emotions. Across the studies we found in our review, representative of multiple regions in the U.S., Europe, and Australia, we see that the identities of preservice elementary science teachers are multi-faceted and wide ranging. They can be positively or negatively oriented towards science, can emphasise other aspects of teaching over science, and can be more or less asset-based towards students from different cultural or racial backgrounds; furthermore, they are shaped by preservice teachers' previous experiences as well as their experiences within teacher education. While less is known about how preservice teachers' emotions may impact their teaching, dispositions such as inquisitiveness and an inclination to learn with one's students could compensate for elementary preservice teachers' weaker science content knowledge in being able to teach with reform-based methods. Science teacher educators have worked in many ways to positively influence preservice teachers' identities, emotions, and dispositions with regard to science, science teaching, and students to increase their readiness for science teaching. These efforts include course assignments, course foci on culture, integrating mindfulness and wonder practices, and fostering intentional relationships with cooperating teachers.

Initial and increasingly productive beliefs and attitudes

In addition to preservice elementary teachers' identities, dispositions, and emotions, researchers have also studied the related characteristics of beliefs and attitudes. By beliefs, we mean teachers' perspectives (e.g. about science or science teaching) that can be untangled from their knowledge (Pajares, 1992), as noted above. By attitudes, we mean beliefs that are more emotional in nature (highlighting the fuzziness across dimensions); attitudes are often described as positive or negative (Cartwright & Atwood, 2014). For a preservice elementary teacher of science, more productive beliefs would reflect more sophisticated ones – such as that scientific work may look different across different disciplines or across cultures (to name just one of many possible beliefs). More productive attitudes towards science or science teaching would tend to be more positive in their emotional valence.

Five groups of researchers took up investigations of preservice elementary teachers' attitudes towards science and science teaching along a variety of dimensions (Cartwright & Atwood, 2014; Casanoves et al., 2015; Szyjka et al., 2011; Taştan Kırık, 2013; Wendt & Rockinson-Szapkiw, 2018). Three of these studies were located in the US, one in Spain, and one in Turkey (Table 2). The number of participants ranged from 30 to 407, and nearly all of these studies were also exploring another construct. For example, Casanoves et al. (2015) explored attitudes and subject matter knowledge of 407 Spanish preservice teachers related to biotechnology. Others connected attitudes towards science or science teaching to the preservice teachers' self-efficacy beliefs (Cartwright & Atwood, 2014; Taştan Kırık, 2013), as discussed below in the treatment of self-efficacy. Another study looked more generally at attitudes towards science (Wendt & Rockinson-Szapkiw, 2018). In this study, Wendt and Rockinson-Szapkiw surveyed 300 teachers, including 66 preservice elementary teachers, across the U.S. (The authors did not disaggregate results for in-service and preservice teachers.) The results suggested that participants' attitudes towards science were generally positive; they enjoyed teaching the subject, saw its importance for elementary students, and did not experience high levels of anxiety around it (though the results also found that respondents found science moderately difficult to teach).

Twenty-three other studies, the largest set in this review, explored dimensions of preservice elementary teachers' beliefs. Eleven of these studies took place in North America, two in Turkey, seven in Europe, three in Asia, one in Australia, and one in Brazil (two studies crossed international contexts; Table 2). The range in participants was from one to 456. A subset of these studies was about beliefs about science teaching and science learning (Akerson, Buzellii, & Donnelly, 2010; Akerson, Buzellii, & Eastwood, 2010; Kim & Tan, 2011; Küçükaydın & Gökbulut, 2020; Markic & Eilks, 2012; Milford & Tippett, 2013; Rivero et al., 2011; Steele et al., 2013; Subramaniam, 2013; Wilson & Kittleson, 2012; Zapata, 2013). For example, one study zoomed in on the beliefs of early childhood preservice teachers (Küçükaydın & Gökbulut, 2020) and another looked at the beliefs of preservice teachers of Colour (Subramaniam, 2013). Other scholars focused on preservice teachers' beliefs about science, scientists, and science teaching (Akerson, Buzellii, & Eastwood, 2010), sometimes using the Draw A Scientist Test or variations thereof to capture these beliefs (e.g. Milford & Tippett, 2013; Zapata, 2013). Akerson, Buzellii, and Eastwood (2010) explored the beliefs about cultural values in science of 17 preservice teachers in an early childhood programme in the U.S. The authors wanted to examine how the preservice teachers saw their own cultural values in comparison with how they perceived the cultural values of scientists. The preservice teachers responded twice to a survey about cultural values: once as themselves and once as they assumed scientists would respond. The preservice teachers saw themselves as valuing benevolence and security. In contrast, they saw scientists as more likely to value power, achievement, and stimulation. The authors note that this mismatch between the values preservice teachers ascribed to themselves and to scientists might be a contributing factor that leads them to avoid teaching science. Kim and Tan (2011) explored other dimensions contributing to avoidance, in a study involving 38 preservice teachers in a science methods class in Korea. They identified five main categories of concern for the preservice teachers, including concerns about teaching the correct ideas and that something might go wrong. The authors found that these concerns discouraged the preservice teachers from wanting to teach science.

Still other work focused on preservice elementary teachers' beliefs about specific aspects of science teaching and science learning (Danielsson et al., 2016; Gullberg et al., 2018; L. Gross et al., 2019; Lee et al., 2020; Subramaniam et al., 2018; Wang et al., 2010), including beliefs about, first, assessment among mainly Indigenous preservice teachers in southern Taiwan (Wang et al., 2010), as well as beliefs about field trips (Subramaniam et al., 2018), place (Danielsson et al., 2016), and teaching outside (L. Gross et al., 2019). For example, Gullberg et al. (2018) focused on preservice teachers' beliefs about children's identity construction. In a qualitative study looking at 47 preservice teachers in preschool placements in Sweden, the authors investigated how preservice teachers interpreted events related to gender and science in the preschool placements. They identified that preservice teachers tended to use one Discourse that saw identity as constructed and/or another Discourse that saw identity as essentialist or stable. In the first, the preservice teachers tended to see children as versatile and as having multiple possible interests, and they saw the teacher's role as being to stimulate exploration. In the second, on the other hand, they saw children as having a stable core identity; preservice teachers using this Discourse sometimes reproduced stereotypes related to gender and science. The authors commented that the Discourses served as implicit theoretical frameworks for the preservice teachers and shaped both how they interpreted what children did and how they, as teachers, opted to intervene or not intervene. The identity-as-constructed belief might be considered a productive belief – that is, a building block that can be added onto on the way to readiness – whereas the identity-as-essentialist belief might be a less productive belief, one that might be shed or deprioritized given time, experiences, and support.

In another example, Lee et al. (2020) conducted a comparison across the U.S. and Hong Kong, with a total of 129 preservice elementary teachers (75 from Hong Kong and 54 from the US). The authors found that U.S. preservice teachers had a stronger intention to adopt inquiry-oriented science teaching and had higher scores for understanding inquiry and the nature of science; their ideas were generally more aligned with current visions of science teaching. The preservice teachers from Hong Kong tended to see inquiry as a route for supporting conceptual learning (which could itself be a productive belief on which to build) and were more worried about contextual barriers to teaching with inquiry.

Still other studies explored preservice teachers' beliefs about themselves as science learners (Akyol et al., 2012; Martin & Carter, 2015; Nilsson & van Driel, 2011; Palmberg et al., 2015, 2018; Saçkes & Trundle, 2014). For example, Nilsson and van Driel (2011) looked at preservice teachers' beliefs about their own physics knowledge development, and Saçkes and Trundle (2014) looked at preservice teachers' beliefs about learning and connected this to their subject matter knowledge. Others looked at beliefs about specific topics in science, including beliefs about ecological agency (Martin & Carter, 2015) and beliefs (and knowledge) about species (Palmberg et al., 2015, 2018). Finally, one study (which we return to later in a discussion of subject matter knowledge) looked at the relationships among beliefs about the nature of science, beliefs about evolution, and knowledge of evolution (Akyol et al., 2012). Together, these studies point to interesting interrelationships among different dimensions of beliefs and, in some cases, also knowledge, highlighting how these building blocks that support a teacher's readiness are interconnected and collectively form a foundation for further growth.

Teacher education supports for preservice teachers' beliefs and attitudes: drawing on additional literature. Many studies investigate how various components of a teacher preparation programme – namely, content courses, science methods courses, and field experiences – seem to influence the beliefs and attitudes of preservice elementary teachers towards science and science teaching. For example, Pino-Pasternak and Volet (2018) explored how taking a science content course seemed to shape preservice teachers' attitudes towards science and science teaching. After surveying 108 preservice elementary teachers taking a science content course in an Australian elementary teacher education programme, the authors in essence found that some participants developed more positive attitudes towards learning science whereas others developed less positive attitudes. Movement towards more positive attitudes was somewhat more prominent. In addition, as noted above, Crowl et al. (2013) study in a physics course looking at the effects of 'friends and family' assignments found that the assignments seemed to support preservice teachers in developing positive attitudes towards science, among other impacts. Thus, across these two studies we see how the details may matter in how science content coursework may play a role in shaping preservice elementary teachers' attitudes towards science to be more positive and increasingly productive for science teaching readiness.

Experiences in elementary science methods courses can also positively affect preservice elementary science teachers' beliefs and attitudes about science and science teaching. These experiences include inquiry-based investigations (Avraamidou, 2013), informal education experiences (Avraamidou, 2015), the use of hybrid science notebooks (Frisch, 2019), a methods course with an emphasis on wonder (Gilbert & Byers, 2017), a methods course with an emphasis on linguistic and cultural diversity (Bravo et al., 2014), and a methods course with an instructor who was a woman of Colour (Mensah & Jackson, 2018). For example, in a case study involving 12 preservice elementary teachers taking an elementary science methods course in a southern European country, Avraamidou (2015) found that informal science experiences supported preservice elementary teachers' ideas and beliefs about inquiry-based science, the nature and work of science, and the relevance and meaningfulness of science to their everyday lives. Mensah and Jackson (2018) considered an additional influence on preservice teachers' ideas and beliefs about science and science teaching – the identity of the teacher educator. In their study of seven preservice elementary teachers of Colour in a methods course in a large university in a large city in the U.S., participants' beliefs shifted to science as being for them and their Black and Brown students. The authors attributed this shift largely to the course instructor's identity as a woman of Colour as well as explicitly multicultural curriculum and pedagogy.

Finally, field experiences also shape preservice teachers' beliefs and attitudes in ways that are largely related to shaping identity, as discussed above – with roles of mentors (Abed & Abd-El-Khalick, 2015; Kenny, 2010; Miller et al., 2019), opportunities for teaching and coteaching (Fitzgerald, 2020; Siry & Lara, 2012), and action research (Kinskey, 2017)—as well as a focus on beliefs about diversity, equity, inclusion, and social justice (Bottoms et al., 2015; Chen & Mensah, 2018) and about the nature of science (Hanuscin, 2013). For example, Miller et al. (2019) conducted a mixed-methods, quasi-experimental study involving 224 preservice elementary teachers and 46 mentor teachers who received professional development on mentoring and elementary science. Roughly one-quarter of the preservice teacher participants were randomly selected to participate in the treatment group wherein mentees engaged in debriefing conversations with their mentors after teaching their science lessons. Using an instrument to characterise participants' beliefs about science teaching, among other data sources, the authors found that preservice teachers in the treatment group showed greater improvement in their beliefs about effective science teaching than did 'non-mentored' peers who did not engage in debriefing conversations.

As opposed to the structure of the field placement experience, another study focused on the context of the field placement and its influence on elementary preservice teachers' beliefs and attitudes. Bottoms et al. (2015) found that, among other themes, 19 preservice elementary teachers' deficit views of emergent multilingual learners shifted to recognising a need to change their own instructional practices as a result of their experiences in an elementary science methods course connected to an after school, Spanish/English dual immersion STEM club. This study, taking place in a large public university in the Pacific Northwestern region of the U.S., suggests that supportive justice-oriented field placements can move preservice teachers' beliefs forward with regard to readiness for teaching science equitably.

Synthesis: beliefs and attitudes. Across these studies, drawn from several international contexts, we see evidence of a wide range of beliefs and attitudes among preservice elementary teachers with respect to science and science teaching. For example, we see evidence of preservice elementary teachers' beliefs about the culture of science and their own cultural values as mismatched, and their ideas about science teaching, at least in the U.S., as generally aligned with inquiry-based reform visions of science teaching. While some studies found that preservice teachers had positive attitudes towards or beliefs about science and science teaching, other studies indicated more concerns or negative beliefs or attitudes. Furthermore, preservice teachers' beliefs (positive or negative) often seemed connected to how, or how often, they intended to teach science. We also see that, in many different ways, scholars have engaged preservice teachers in inquiry-oriented, justice-centred, and/or meaningful science, and as a result of these efforts, preservice teachers' beliefs and attitudes about science, science teaching, and/or students from cultural and racial backgrounds different from their own seem to improve. One lesson to be learned from these studies perhaps is that preservice elementary teachers are not a monolithic group and enter teacher preparation programmes with a range of beliefs about science teaching and learning, many of which can be built upon. These studies, while not offering a clear consensus, help us to move towards a more nuanced understanding of who preservice teachers are and what kinds of supports might be generative to potentially move preservice teachers towards improved readiness for science teaching. Overall, these studies of preservice teachers' beliefs show the wide range of facets of the 'beliefs' construct. This suggests the many ways that researchers may be able to look for assets within this population.

Initial and increasingly productive self-efficacy

Related work to the body of literature on beliefs and attitudes looked at preservice elementary teachers' self-efficacy (Bautista, 2011; Cartwright & Atwood, 2014; Deehan et al., 2017; Gunning & Mensah, 2011; Köksal, 2011; Menon & Sadler, 2016; Norris et al., 2018; Taştan Kırık, 2013; Wilder et al., 2019). Five of these nine studies took place in the US, two in Australia, and two in Turkey (Table 2). They ranged in participant number from 23 to 274. By self-efficacy, we mean, essentially, a teacher's confidence in their own science teaching (Bleicher, 2004); clearly, higher confidence, in the case of a preservice elementary teacher of science, would reflect more productive self-efficacy (Figure 1).

This topic included research that connected preservice elementary teachers' self-efficacy to their attitudes as noted above (Cartwright & Atwood, 2014; Taştan Kırık, 2013), to what authors referred to as the science learner type (Norris et al., 2018), and to their subject matter knowledge (Menon & Sadler, 2016). One paper presented a new form of assessment of preservice elementary teachers' self-efficacy (Wilder et al., 2019). In connecting self-efficacy and attitudes, Taştan Kırık (2013), conducting a study in southern Turkey involving 262 preservice teachers, found that science teaching attitude was positively correlated with self-efficacy for science teaching, future middle school science teachers had higher self-efficacy for science teaching than did future elementary teachers, and science conceptual understanding was positively correlated with self-efficacy. Similarly, in connecting self-efficacy and subject matter knowledge, as also mentioned below, Menon and Sadler (2016) studied 51 preservice elementary teachers taking a physics content course. They found that the participants' gains in subject matter knowledge were moderate, positively related to their gains in self-efficacy for science teaching.

Generally, these papers suggest that preservice elementary teachers' self-efficacy is initially relatively low. These papers also suggest that self-efficacy for teaching tends to increase more than does self-efficacy for improving student outcomes. Further, they often characterise how self-efficacy relates to other teacher characteristics (such as subject matter knowledge), illustrating the interrelationships among preservice teachers' building blocks. Notably, most papers that focus on self-efficacy seem to involve an intervention of some sort; some of these are described in the subsequent section, providing a broader perspective on the literature on self-efficacy as a preservice elementary teacher of science.

Teacher education supports for preservice teachers' self-efficacy: drawing from additional literature. Perhaps because of generally low levels of self-efficacy for teaching science among elementary preservice teachers, there are many studies that focus on how components of teacher education programmes can improve their self-efficacy and therefore readiness for science teaching. For example, content classes or experiences can shape preservice teachers' self-efficacy towards science (d'Alessio, 2018; Hechter, 2011; Menon et al., 2020; Riegle-Crumb et al., 2015). Hechter (2011) explored how the number of science courses was related to preservice teachers' self-efficacy. Other studies focused on a finer grain size and add nuance to this issue (e.g. Menon et al., 2020, who looked at self-efficacy for using technology in science teaching). For example, a study of microteaching in an earth science content class at a large state university on the west coast of the U.S. looked at the self-efficacy of several hundred preservice teachers (d'Alessio, 2018). The essential finding of the study was that science content mastery and the quality of microteaching as measured by peers mattered in increasing preservice teachers' self-efficacy beliefs. Furthermore, individuals who increased in their self-efficacy beliefs over time were twice as likely to make comments about science content as those who decreased in their self-efficacy beliefs over time. The 'increasers' were also more likely to claim that they had learned science content during microteaching; the 'decreasers' on the other hand were more likely to comment that the science content or lesson was confusing to them. This study illustrates how building blocks of readiness are not only interconnected, but sometimes change in concert with one another.

Riegle-Crumb et al. (2015) conducted a quantitative comparison study drawing on a range of data sources, looking at self-efficacy in science teaching as well as attitudes towards science. The authors compared 238 preservice elementary teachers in the experimental group, taking a hands-on science course sequence, and 263 non-science and non-education major students in the comparison group, taking a regular lecture-based science course, in the U.S. Their findings suggested that the students in the hands-on science coursework reported more confidence as science learners, as well as more enjoyment and relevance of and less anxiety towards science. On the other hand, in the comparison group, students' attitudes towards science declined after experiencing the traditional course. The authors controlled for differences in the characteristics of the individuals in the groups, and so ascribed the differences in outcomes to the characteristics of the classes. Connecting to the importance of emotion (see earlier section), the authors highlighted the importance of their findings around anxiety reduction for the preservice elementary teachers. This study did not compare the groups' content learning.

Field experiences also shape preservice teachers' self-efficacy (Fitzgerald, 2020; Herbert & Hobbs, 2018; Kenny, 2010; Siry & Lara, 2012). For example, in a study of 146 Australian preservice elementary teachers across two teacher education programmes, Fitzgerald (2020) found that the preservice teachers experienced an increase in their confidence in science teaching after their school-based practicum teaching experiences. Another study, briefly elaborated above in the section on identity, illustrated the importance of the cooperating teacher in supporting self-efficacy as a social justice science teacher (Chen & Mensah, 2018).

Finally, teacher education programmes broadly can support self-efficacy (Deehan et al., 2019; Ford et al., 2013; Velthuis et al., 2014). For example, Ford et al. (2013) studied the effects of an approach of a 'science semester' in an elementary teacher education programme at a large state university in the eastern U.S. This mixed methods study involved 312 preservice elementary teachers and characterised their self-efficacy and beliefs about science and science teaching. In the science semester, preservice teachers took earth, life, and physical science courses and elementary science methods, all in a single semester of the teacher education programme. The instructors co-planned and co-designed the courses, which shared an inquiry-based and problem-based learning approach. The instructors also made intentional cross-disciplinary connections. After these experiences, the preservice teachers better appreciated problem-based learning, better understood inquiry-based instruction, and showed improved personal science teaching efficacy. They did not show improved science teaching outcome expectancy (as is often the case in studies of self-efficacy), and indeed they expressed some concerns about their own experiences with learning through inquiry and about engaging children in investigations. Nonetheless, overall, the 'science semester' experience showed promise.

Synthesis: self-efficacy. The research literature across multiple continents suggests that elementary preservice teachers' self-efficacy for teaching science is generally low – that is, these preservice teachers tend to not have much confidence in themselves as science teachers. As a result, much work has been done in the field of teacher preparation to build the field's understanding about how to increase preservice elementary teachers' self-efficacy (contributing to their readiness for science teaching). Though there are nuanced results in these studies, there appears to be growing consensus that multiple hands-on, inquiry-based science content courses alongside opportunities to practice teaching science as part of a preservice teacher's preparation seems to increase their self-efficacy for science teaching and decrease anxiety, thus readying preservice elementary teachers for teaching science well.

Initial and increasingly productive knowledge about science and science teaching

Another set of papers that explored preservice elementary teachers' characteristics looked at their knowledge. By knowledge, here, we refer mainly to teachers' subject matter knowledge and pedagogical content knowledge (e.g. Ball et al., 2008; Schneider & Plasman, 2011; Shulman, 1986), because of the foci of the work we identified in our review. This knowledge relates to both science content and science practices. For a preservice elementary teacher of science, of course, more productive knowledge (Figure 1) would be both more extensive and more integrated, allowing the knowledge to be usable in practice.

Only two of the papers we found looked squarely at the preservice teachers' pedagogical content knowledge (PCK), without centring on the effects of teacher education experiences (Cobern et al., 2014; Nelson & Davis, 2012). To test the validity of an assessment instrument for measuring PCK, Cobern et al. (2014) involved 28 preservice elementary teachers in a science methods course at a midwestern U.S. university. The preservice teachers were able to make reasonable and appropriate choices about instructional approaches despite limited science subject matter knowledge. Similar to Eick and Stewart (2010), discussed above, the preservice teachers were able to compensate for less extensive subject matter knowledge in science. Using a different technique, Nelson and Davis (2012), also mentioned below, used preservice elementary teachers' evaluations of students' scientific models as a way of capturing changes to their PCK for scientific modelling, in a study involving 4 preservice elementary teachers in a science methods course at a midwestern U.S. university.

Twelve groups of scholars looked at preservice elementary teachers' subject matter knowledge of specific topics or science areas, including greenhouse effect (Ratinen, 2013), wind (Mandrikas et al., 2013), anatomy (Ruiz-Gallardo et al., 2019), biotechnology (Casanoves et al., 2015), species identification (Palmberg et al., 2015, 2018), evolution (Akyol et al., 2012; Rice & Kaya, 2012), energy in physical systems (Papadouris et al., 2014), and lunar phases (Saçkes & Trundle, 2014). Of these 12 studies, one was located in Turkey, seven were in Europe, and four in the US, with a range in participants from 51 to 456 (Table 2). For example, Papadouris et al. (2014) conducted a mostly qualitative study with 198 preservice teachers in a science course in Cyprus. The authors identified six difficulties that the preservice teachers demonstrated in learning about energy in physical systems and also two resources they brought to this content learning. Unusual in this category of studies, these authors were careful not to blame the preservice teachers for the content they did not understand, but rather, used the findings to point to specific instructional changes that could be made to physics classes for preservice elementary teachers – identifying ways of building from where preservice teachers are. As noted previously, in a study focused on evolution, involving 415 preservice elementary teachers in Turkey, Akyol et al. (2012) found that higher levels of understanding of evolution were related to higher levels of acceptance of evolution, and furthermore, both were associated with sophisticated views of the nature of science. The authors' findings with regard to the relationship between knowledge and self-efficacy for teaching evolution, though, were more complex, and the authors note that this is an area for further research.

As another related example, Rice and Kaya (2012) conducted a quantitative study with 240 preservice elementary teachers. Drawing on a (U.S.) National Science Foundation-developed, publicly-available longstanding survey that gets at very basic science knowledge, the authors focus in part on knowledge related to evolution. With regard to strengths, the authors found that more than 90% knew that the centre of the Earth is hot, recognised that oxygen comes from plants, and accepted the theory of plate tectonics. However, only 30% knew that electrons were smaller than atoms, only 60% agreed that humans had evolved from other animals, and 25% said that humans and dinosaurs lived at the same time. Related to evolution, the authors found that the preservice teachers who did not believe that humans had evolved from earlier species of animals scored significantly lower on other, non-evolution questions. Overall, largely consistent with the findings of Akyol et al. (2012), Rice and Kaya argue that knowledge of and belief in evolution is empirically related to science knowledge in other areas, and that this knowledge and belief (or lack thereof) therefore has implications for multiple areas of elementary science teaching, even though evolution per se is not typically taught in the elementary grades.

Other papers explored preservice elementary teachers' subject matter knowledge more generally (Menon & Sadler, 2016; Nixon et al., 2019). For example, in a comparison study, Nixon et al. (2019) compared the subject matter knowledge of 169 preservice elementary teachers at a large private university in the western U.S. to the knowledge of 439 fifth and sixth grade practicing teachers. The findings showed that teachers who had experience in teaching the tested topics scored higher than did teachers who did not have experience teaching the topics. Preservice teachers scored lower than practicing teachers on the assessment. Based on the findings, the authors concluded that even without intervention beyond simply teaching the content, elementary teachers are able to learn the science topics they are responsible for teaching – suggesting that they build on their initial knowledge through the act of teaching. Additionally, Menon and Sadler (2016), as noted above, looked at connections between self-efficacy and subject matter knowledge, and found that there was a moderate positive relationship between the preservice teachers' subject matter knowledge and their personal science teaching efficacy.

Teacher education supports for preservice teachers' knowledge about science and science teaching: drawing from additional literature. As with self-efficacy, there are many studies across all aspects of teacher education programmes that investigate ways to improve preservice elementary teachers' knowledge for teaching science. Most centrally, of course, content courses can help preservice teachers to develop their subject matter knowledge (e.g. Criado & García-Carmona, 2010; Dianovsky & Wink, 2012; Parker & Heywood, 2013; Södervik et al., 2014; Tapia et al., 2019). Some studies explore learning of specific science topics such as species identification (Skarstein & Skarstein, 2020), wind (Mandrikas et al., 2018), and climate change (Hestness et al., 2011; Ratinen et al., 2013) within content or science methods courses.

Elementary science methods courses can also impact preservice teachers' knowledge development. Some studies in this area focus on preservice elementary science teachers' content knowledge development as a result of participation in inquiry experiences (Plummer et al., 2010; Santau et al., 2014; Subramaniam & Harrell, 2013; Thompson et al., 2016), whereas other studies focus on specific content knowledge development such as around environmental science (Lambert & Bleicher, 2013; Weiland & Morrison, 2013). One study, also discussed later, explored connections among a science methods course and preservice teachers' PCK and lesson planning (Beyer & Davis, 2012), while other papers focused on teachers' knowledge development related to multicultural and culturally relevant science education (J. Yoon & Martin, 2019; Mensah et al., 2018). In Weiland and Morrison's (2013) study, for example, the authors qualitatively compared two elementary science methods courses (31 preservice teachers total) in two different universities in the United States. One course focused on content related to environmental education, and the other focused more on teaching methods (specifically, problem-based learning). In both cases, the preservice teachers' content knowledge related to environmental education improved in addition to their beliefs about integrating environmental and science education with English language arts, mathematics, and social studies.

Rivera Maulucci (2011) considered the role of the field placement in a bilingual, immigrant, elementary preservice teacher's knowledge development. The preservice teacher, a student at a prestigious university in the U.S., was placed in two dual language elementary classrooms. Seemingly as a result of her own early experiences as a Spanish speaker and a learner of English, as well as her field placement experience, she developed more sophisticated understandings of the intersections between language learning and science learning, providing an illustration of how her own background and characteristics served as building blocks as she moved towards becoming a well-started beginner.

Finally, a teacher education programme broadly can support the development of knowledge – and beliefs – for science teaching (Bartels et al., 2019; Todorova et al., 2017). For example, Bartels et al. (2019) conducted a qualitative study involving 13 preservice elementary teachers at a small private university in the midwestern U.S. The authors were interested in the preservice teachers' knowledge and beliefs about STEM (science, technology, engineering, and mathematics) in relation to their experiences in STEM-focused science and mathematics methods classes. The authors found that initially the preservice teachers knew what STEM stood for but had limited ideas about it. During the semester, most of the preservice teachers foregrounded science in their 'STEM' lesson. By the end of the semester, their ideas were more sophisticated. In another example, Hanuscin and Zangori (2016) looked at how a science methods class combined with a practicum experience with multiple opportunities to teach science seemed to shape the preservice teachers' subject matter knowledge and their ideas about the NGSS. In a study involving 18 preservice elementary teachers in the U.S., the authors identified themes related to how the preservice teachers viewed and used the standards. The authors' asset framing helped them recognise the strengths that the preservice teachers were able to develop through the field experiences. In these cases, working across experiences within a programme supported preservice teacher development in areas of focus for the programme.

Synthesis: knowledge about science and science teaching. The studies of subject matter knowledge, taken together, show the broad range of (sometimes fundamental, sometimes perhaps esoteric) topics preservice elementary teachers are expected to understand both in the U.S. and abroad. While some scholars emphasise preservice teachers' weaknesses, others identify strengths and resources, and some highlight differences across sub-groups that may have instructional implications. This reflects an important orientation in the field and one that we think could be expanded. Additionally, and unsurprisingly, there is a broad range of interventions that teacher educators have implemented across teacher preparation programmes to target preservice teachers' knowledge development along various dimensions of PCK, subject matter knowledge, multicultural knowledge, and knowledge of students. That said, as shown throughout this review, though subject matter knowledge in general is linked to greater self-efficacy for teaching science, parallel work with preservice elementary teachers in shifting their identities, emotions, dispositions, beliefs, and attitudes can prepare teachers to be ready to teach science despite gaps in their subject matter knowledge. As well, as described above, limited research also demonstrates that preservice elementary teachers' ability to make reasonable and appropriate instructional decisions (as supported by their PCK) can compensate for lower levels of subject matter knowledge. Thus, interconnections across the elements in the bottom two rows of Figure 1 might help to guard against weakness in any one or two of the elements. This is a noteworthy set of findings, especially given that this review also found research suggesting that elementary teachers do learn the content as they gain experience teaching it.

Elementary science preservice teachers' abilities

In addition to surfacing research about preservice teachers' characteristics, we were also interested in learning more about their teaching abilities, or performances. This section is organised around two key domains of performances that were reported in the literature – engaging in and with science practices and planning and enacting lessons – and what we learned teacher preparation programmes can do to build on preservice teachers' existing strengths.

Initial and increasingly productive engagement in and with science practices

Three papers described preservice elementary teachers' engagement in the science practices as learners (García-Carmona et al., 2017; Szyjka et al., 2011) or as learners and teachers (Nelson & Davis, 2012). Two of these studies were done in the US and one in Spain, with a range in participants from four to 87 (Table 2). By science practices, we mean the work scientists engage in as they investigate the world and develop models and theories about it; these practices are used to 'establish, extend, and refine' scientific knowledge (National Research Council, 2012, p. 26). An elementary teacher needs to be able to engage children in the science practices to work towards a vision of science learning that brings together knowledge and practice (e.g. Australian Curriculum Assessment and Reporting Authority, 2014; National Agency for Education, 2018; National Research Council, 2012; United Kingdom Department for Education, 2015). Thus, more productive engagement in and with the science practices (Figure 1) would be engagement that reflects some understanding of what the practices are, why and how scientists would use them, and how children can be supported in engaging in them as they are exploring phenomena and making sense of the natural world.

For example, García-Carmona et al. (2017) analysed the written responses of 66 preservice teachers in a science methods class at a Spanish university. Prior to instruction on science inquiry, preservice teachers were given an investigation question regarding the conductivity of a set of objects, and they were asked to develop a hypothesis, plan and conduct an experiment, analyse data, and develop a conclusion. The authors found that the preservice elementary teachers struggled with practices like using scientific models and making sense of data, and that some of the areas in which they struggled in inquiry seemed related to holes in their understanding of or exposure to the science content (e.g. in lacking knowledge of particular measurement instruments). That said, the preservice teachers also showed some strengths. For example, the preservice teachers were able to draw on their scientific and/or everyday knowledge to develop hypotheses. Nelson and Davis (2012), also mentioned above, looked at how 4 preservice elementary teachers in a science methods course in the midwestern U.S. used children's scientific models to evaluate student work, providing a bit of additional insight into one of the challenges – scientific modelling – identified by García-Carmona and colleagues. Preservice teachers were better able to apply model evaluation criteria for student models of familiar content.

Teacher education supports for preservice teachers' engagement in and with science practices: drawing from additional literature. Aspects of teacher preparation programmes can support preservice teachers' engagement in and with science practices. For example, Seung et al. (2014) explored how preservice teachers understood inquiry and the science practices through how they included these in their teaching. Seven preservice elementary teachers were taking an elementary science methods course in the midwestern U.S., and seven mentor teachers were working with them. Using qualitative research design and both qualitative and quantitative analysis methods, the authors found that the preservice teachers implemented some of the features of inquiry that were presented in their methods course in their teaching. While some features of scientific inquiry presented challenges in terms of the preservice teachers' understanding (e.g. formulating, evaluating, communicating, and justifying explanations), their understanding of other features was stronger (e.g. scientific questions and exploration). Arias and Davis (2017) narrowed their focus to the science practice of constructing evidence-based claims. They showed how a multi-pronged approach across a practice-based teacher education programme helped to develop preservice teachers' knowledge of the scientific practice and their support of children in engaging in the practice.

Gilbert and Byers (2017), referenced previously, also investigated how to support teachers' engagement in science practices, but they did so by infusing wonder into an elementary science methods class. This seemed to spark interest in science and in science teaching, while providing a vehicle for engaging preservice teachers in science practice and in learning about the nature of science.

Synthesis: engagement in and with science practices. While limited in scope, taken together, these studies suggest that some science practices (e.g. drawing on scientific and everyday knowledge to develop hypotheses) are more intuitive or familiar to preservice elementary teachers than others (e.g. using scientific models). Though this variable familiarity may be explained by formal experiences preservice elementary teachers have or have not had in the natural sciences, a few studies point to promising approaches in methods courses and teacher preparation programmes more broadly that may support preservice teachers' productive engagement in and with science practices.

Initial and increasingly productive planning and enactment

In addition to preservice elementary teachers' engagement in and with the science practices, of the set of papers focusing squarely on preservice teacher abilities, many of them focused on teachers' planning of science lessons and/or enactment of science lessons. In focusing on teachers' planning and enactment, we understand planning as the teacher's skill at designing instructional sequences for students, whether modified from existing instructional materials or not; enactment captures the teacher's instructional practices in the classroom when facilitating a science lesson. For a novice elementary teacher of science, more productive planning (see Figure 1) would perhaps reflect better ability to anticipate children's ideas and needs, more coherent approaches to working on content and/or science practices, better alignment with a vision for science teaching and learning, and/or more sophisticated and equity-oriented pedagogical approaches (as just a few examples). More productive enactment might be more responsive to children's contributions and more supportive of equitable participation (again, naming just a couple of examples). The studies we found reflect this wide variety in what they deemed productive or useful for preservice teachers. Here, we focus on readiness for classroom teaching, and look at initial or intermediate performances that, as they develop, could contribute to becoming a well-started beginner.

We surfaced five studies clustered around dimensions of planning and pedagogical design capacity (Forbes & Davis, 2010; Forbes, 2011, 2013; H. -G. Yoon et al., 2012; Ross & Cartier, 2015). Four of these studies were conducted in the US, with one study from South Korea (Table 2). The range in participants was 16 to 51. For example, Forbes and Davis (2010) conducted a quantitative study of 46 preservice elementary science teachers' lesson plans and other teaching artefacts. This study took place in an elementary teacher preparation programme at a large public university in the midwestern United States. The authors found that preservice teachers were able to adapt lesson plans, and that the more inquiry-oriented the curriculum materials were that the preservice teachers had to work with, the more inquiry-oriented the lesson plan adaptations were of the preservice teachers. Additionally, in almost all cases, the adaptations made by the preservice teachers maintained or improved the inquiry elements of the lesson plans from the original curriculum materials – suggesting that this ability to modify curriculum materials can serve as an important building block for readiness. Forbes's (2011) mixed-method analysis of the same data set, focusing on six focal cases, found that preservice teachers were able to adapt curriculum materials to include all features of inquiry-based learning, although, similar to findings from H. -G. Yoon et al. (2012), student-driven inquiry was the most challenging aspect to include. Complicating these findings, with another mixed-methods analysis of the same data set, Forbes (2013) argued that more important than the curriculum materials themselves was the influence of the field placement on preservice teachers' curricular adaptations, thus illustrating how other factors also contribute to a novice teacher's readiness. In another study on curricular adaptations, Ross and Cartier (2015) found that preservice elementary teachers (51 participants attending a large university in the eastern U.S.) were able to use or adapt instructional tools provided in curriculum materials, or to generate tools (e.g. graphic organisers, Venn diagrams) if the curriculum materials did not provide them.

Another five studies we reviewed focused specifically on preservice elementary teachers' enactments of their lessons (Dalvi & Wendell, 2017; Haverly et al., 2020; Hernandez & Shroyer, 2017; Wendell et al., 2019 Zangori & Forbes, 2013). All five of these studies were conducted in the US, with a range in participants from two to 25 (Table 2). For example, Haverly et al. (2020) conducted case study research with two preservice elementary teachers in a midwestern university in the United States, observing and interviewing them about their science instruction. They found preservice teachers could shift epistemic authority to students when the preservice teachers made space in their instruction for student voice. However, participants did not often notice students' ideas and contributions as productive sense-making, but rather characterised these moments as mistakes or chaotic. In another example, Dalvi and Wendell (2017), working in the northeastern United States, analysed 25 preservice teachers' responses to a questionnaire about what they noticed about students' ideas and engineering practices in a video clip and how they might respond. Similar to Haverly and colleagues' study, Dalvi and Wendell found that participating preservice teachers had a harder time noticing student ideas and engineering practices, though they were able to produce responses to student ideas that could be productive. Across these studies, we see that it was difficult for some of the preservice teachers to notice students' ideas and practices in the science (or engineering) classroom (reflecting an area for growth), but there is some evidence that they were able to enact responses to students' ideas to make space for students' voices and promote student sense-making (reflecting a strength on which the novices can continue to build).

Taking a different approach to the study design and analysis, Hernandez and Shroyer (2017) studied the teaching practices of 12 Latinx preservice elementary teachers in the midwestern U.S. in a grow-your-own teacher preparation programme using a framework for culturally responsive teaching. The authors found that these preservice teachers, who shared a common linguistic and cultural background with the students in their field placements, demonstrated teaching practices within several domains of culturally responsive teaching, including connecting content to students' lives and cultural backgrounds, building relationships with students, holding high expectations for them, and using native language supports. However, they struggled in particular with practices related to teaching for social justice, examples of which would have included developing critical thinkers, fostering students' critical consciousness, and acting as agents of change.

Teacher education supports for preservice teachers' planning and enactment: drawing from additional literature. Few papers focused on how teacher education can support preservice teachers' lesson planning or enactment. As one example, Beyer and Davis (2012), referenced previously, studied 24 preservice teachers in an elementary science methods course in the midwestern U.S. The course had a focus on using criteria for evaluating and modifying science curriculum materials. The goal of the study, which used quantitative research methods, was to use the preservice teachers' lesson plan analyses to characterise their PCK – methodologically, this approach was unusual. The practice or performance here, then, was the preservice teachers' lesson planning and lesson plan analysis – not their enactment itself. The preservice teachers' planning struggles centred on assessment (e.g. assessing only conceptual ideas and not practices; using a group assessment but making claims about individual learning), alignment (i.e. assuming alignment of learning goals and activities, within commercial curriculum materials), and instruction (e.g. assuming whole-group instructional strategies would meet the needs of individual students). In terms of strengths, the authors found that the preservice teachers were able to develop a purpose and learning goals for their lessons, and to establish experiences for children to engage in scientific inquiry.

Synthesis: planning and enactment. In sum, these U.S.-based studies suggest that preservice teachers can be adept at making adaptations to given curriculum materials, responding to student sense-making, and leveraging culturally responsive teaching strategies in order to advance inquiry-based learning or to support student engagement – though allowing more student-driven inquiry remains challenging for them. Perhaps because science is so rarely taught in elementary schools, or perhaps because it is easier to measure with an instrument or interview study, less research has been published that considers the role teacher preparation programmes can play in supporting preservice elementary teachers' readiness for planning and enacting science instruction. Furthermore, much more needs to be done to explore elementary preservice science teachers' readiness for teaching for social justice and interventions on the part of teacher preparation programmes to increase their readiness for planning and enacting equitable science instruction.

Implications and conclusions

This review sought to uncover what the research literature tells us about preservice elementary science teachers' readiness for teaching. Though preservice elementary teachers are commonly perceived as weak with regard to their capacities for science teaching, we wanted to discover those characteristics and abilities that research suggests are assets that these teachers begin with. In essence, we wanted to be able to paint a more nuanced portrait because we view these early characteristics and abilities as building blocks for getting teachers ready to start teaching science in classrooms. As such, we also used this review to highlight studies from teacher preparation programmes that either build on preservice teachers' strengths and/or work to close the gap on areas that are more challenging. Considering the number of barriers to elementary science teaching, including but not limited to the deprioritisation of science relative to literacy and mathematics (Banilower et al., 2018; Marshall et al., 2021; National Center for Educational Statistics, 2019), it is imperative for preservice elementary teachers to enter the classroom as well-started beginners who are prepared to overcome those barriers and to teach science well.

It is worth noting, before going further, a key limitation of this review. We needed to exclude studies published in languages other than English given our own linguistic backgrounds and limited facility in other academic languages. We did this from the very beginning by only searching journals that publish articles in English. As a result, our review undoubtedly omits relevant research that has been done across the globe and published in languages other than English. As such, a generative next step for this kind of review would be to engage in a cross-cultural, cross-linguistic collaboration wherein studies from languages other than English may be sought and synthesised, allowing for an even more in-depth and rigorous study and review of how our field globally understands preservice elementary or primary teachers' readiness for teaching science. As well, a secondary limitation resides in our decision to search within select journals that are well-regarded in the field and were likely to have published studies on our topic rather than to search databases for articles; it is possible that we missed some articles published elsewhere as a result of this decision.

That said, a review of this size and scope allows us to 'see' across the field of work and draw out a sketch of the big picture. This big picture shows us two primary things: the range of assets that elementary preservice teachers bring to their science teacher preparation programmes and some specific characteristics and abilities that preservice teachers might already have or develop that can compensate for areas of weakness when it comes to their readiness for science teaching (Figure 1). This orientation can take our collective gaze away from deficit descriptions of novices' weaknesses and instead focus our attention on productive steps forward towards developing well-started beginners.

This review shows that preservice elementary teachers' characteristics with regard to teaching science are complex and multi-faceted, shaped by their early experiences with science as well as their experiences in teacher education. Though some research supports the standard narrative about preservice elementary teachers of science as anti-science, lacking knowledge of science, and/or fearful of science, this narrative masks the assets that other research suggests preservice elementary teachers may bring. These assets may include inquisitiveness, an orientation towards inquiry, understandings of inquiry, capacities for learning through teaching, and knowledge of instructional approaches. Teacher educators can leverage these assets in support of preservice elementary teachers' science teaching readiness.

Similarly, synthesising across the papers in this review helps us to get a sense of what preservice elementary science teachers are capable of doing. For at least some preservice elementary teachers of science, noticing students' expressed ideas and sense-making in the classroom and engaging in inquiry with more sophisticated scientific tools, practices, and concepts can be challenging. However, the literature also provides evidence that preservice teachers are able to modify existing curricular materials to be more focused on inquiry or student engagement. They may also be capable of responding to students in ways that make space for more student sense-making about phenomena. Finally, they can apply their everyday and scientific knowledge and skills to engaging in science inquiry themselves, which helps them in turn support children in doing so. Teacher educators may leverage these strengths to support preservice elementary teachers' movement towards increasingly productive science teaching abilities.

As an example of how complex this picture is, it may be worth taking a closer look at preservice elementary teachers' science content knowledge. Many – though not all – studies of teachers' content knowledge in this review corroborate a general perception of preservice teachers' low science content knowledge. Some studies, however, measured this with esoteric science topics that many highly educated adults – or even scientists in other disciplines – may not deeply understand. Regardless, other research also suggests that preservice teachers' positive attitudes towards science, inquisitive dispositions, or their pedagogical content knowledge may help to compensate for their gaps in subject matter knowledge. In other words, there appear to be interconnections among these three dimensions laid across the bottom row of our readiness model that allow preservice elementary teachers to accommodate weaknesses in their subject matter knowledge by drawing on their strengths in other areas. To complicate matters, we also found evidence of increased subject matter knowledge having a positive effect on preservice elementary teachers' self-efficacy for teaching science.

Keeping our attention on Figure 1, this review also points to opportunities for future research. For example, more research exploring the interconnections across those initial abilities and characteristics of teacher readiness would benefit the field. Additionally, we found no recent literature that focused squarely on preservice elementary teachers' initial abilities for assessing student learning or reflecting on their own teaching practices. These are critical skills for a well-started beginner to have, and it would benefit the field to better understand how ready novices are to engage in these practices.

Four key operational implications surfaced for us in this review with regard to preservice elementary teachers' readiness for teaching science. The first two implications are related to preservice teachers' science content knowledge and other characteristics. The third is related to their science teaching practice. And the fourth is related to conducting research with preservice elementary teachers of science.

The first implication is for elementary science methods courses to focus – in part – on shifting preservice teachers' characteristics for science teaching. Traditionally, methods courses are designed to prepare teachers with knowledge of best practices for teaching a given subject area. This is clearly still a role that elementary science methods courses must play – and in fact, it is an area that could be more researched, especially with regard to methods for teaching science for social justice. That said, elementary science methods courses serve a multitude of other roles. Given a concern for preservice teachers' readiness for teaching science, and in light of the (perhaps reasonable) limitations of their subject matter knowledge, this review suggests that a critical focus for methods courses, in addition to teaching practical teaching methods, is to focus on shifting preservice teachers' identities, beliefs, attitudes, and dispositions towards science and science teaching. Engaging in this work through an asset-based approach might involve intentionally building meaningful relationships with preservice teachers (Mensah & Jackson, 2018) and redefining science engagement as a joyful, culturally responsive endeavour (Bravo et al., 2014; Hernandez & Shroyer, 2017; J. Yoon & Martin, 2019; Mensah et al., 2018). In other words, since positively oriented characteristics can compensate for low content knowledge, a key leverage point for methods courses may be to focus on the range of characteristics preservice elementary teachers have and concentrate on bolstering those 'bottom-row' characteristics (Figure 1) to be increasingly productive.

The second implication is for science content courses to focus – in part – on increasing elementary preservice teachers' self-efficacy for teaching science through more innovative approaches to teaching science content. Content courses are typically designed with the intention of improving preservice teachers' subject matter knowledge. However, as noted earlier, there is some consensus in the research literature that repeated experiences with science content courses that are hands-on, inquiry-based, and/or offer microteaching opportunities, may also positively affect preservice teachers' self-efficacy. Thus, focusing on inquiry-based science experiences in content courses may provide double benefit, supporting preservice teachers' subject matter knowledge while also bolstering their self-efficacy. Again, returning to our readiness model (Figure 1), science content courses that focus on both subject matter knowledge and self-efficacy lay a stronger foundation on which to continue building as preservice elementary teachers move towards becoming well-started beginners. A shift towards repeated hands-on, inquiry-based content courses may also have an impact on preservice teachers' engagement in and with the science practices, though more research would be needed to determine those effects.

The third implication is for methods courses and other teacher education experiences to leverage the strengths that elementary preservice teachers tend to have when it comes to their science teaching practices. Too commonly, teacher educators presume that preservice elementary teachers will not be able to engage in sophisticated science or science teaching practices, but research from this review shows that they can do some of this work albeit with some challenges. For example, research suggests that preservice teachers are able to be responsive to students' sense-making in particular ways, so teacher educators may offer opportunities for them to practice those skills while adding onto those skills to more effectively notice students' science ideas during class discussions. Members of the National Elementary Science Teacher Education Group (NESTeg) in the U.S. are collaboratively exploring asset-based ways of accomplishing this through developing preservice teachers' critical consciousness and adopting asset-based perspectives on elementary students' funds of knowledge (Haverly et al., 2022), and there are certainly other important efforts ongoing as well. That said, there is limited literature on this topic for teacher educators to draw on, suggesting a need for more research on elementary preservice teachers' early science and science teaching abilities and the types of supports that may further their readiness and development. In particular, it is worth repeating that there is a need for research around preservice elementary teachers' readiness for equitable and just science teaching.

A final implication of this review is for researchers. Across the studies that we reviewed, researchers took on either deficit- or asset-based perspectives of preservice elementary teachers of science. This phenomenon is well documented by Gray et al. (2022) across elementary and secondary preservice science teachers. Given our read of the literature for this review, and of related asset-oriented scholarship (Gray et al., 2022; Zembal-Saul et al., 2020), we believe there are some concrete ways that researchers might more intentionally frame our studies from asset-based perspectives. For example, scholars can attend to not just what new teachers do not know or cannot do, but also, what they do know and can do. Taking a sociocultural perspective, scholars can recognise the role of the learning environment and other aspects of the context, in shaping what novice teachers understand, believe, or do. This can help scholars better understand *why* novice teachers see the world and act as they do. Finally, scholars and teacher educators may be able to design research that involves novice teachers as co-designers, which would allow novices to productively participate in designing their own learning experiences. An extensive base of literature already argues for asset orientations towards children and youth in their learning experiences; the field of elementary science teacher education (and teacher education more broadly) can also benefit from such an orientation. Building on extensive literature that aims to take an asset orientation towards children and youth in their learning experiences, the field of science teacher education (and teacher education more broadly) can also benefit from such an orientation.

In conclusion, a key takeaway from this review is that preservice teachers enter teacher preparation programmes not as a monolithic group of individuals who dislike science, but rather as a group of individuals with a range of multifaceted identities, dispositions, beliefs, attitudes, self-efficacy, and abilities. Many of these characteristics and abilities are assets to their readiness for science teaching (Zembal-Saul et al., 2020), and it is the responsibility of teacher educators and researchers to identify those assets and leverage them in order to begin to close the gap on preservice teachers' challenges and to prepare them to be well-started beginners in the field.

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Notes

1. We use the term 'elementary' in the paper to refer to young students in early grades, typically pre-kindergarten through fifth grade in the U.S., or approximately ages 5 to 11. In many other parts of the world, this age group is referred to as 'primary'.
2. The term 'novice' may refer to preservice or early career inservice teachers. In this paper, we use the term novice interchangeably with preservice to refer specifically to preservice teachers.

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