Learning to Teach Science from a Contextualized Stance

L'Heureux[1], K., Giamellaro[2]*, M., Beaudry[1], M-C., Buxton[3], C., Ayotte-Beaudet[1], J-P., Alajmi[3], T.

*Contact: giamellm@oregonstate.edu

Université de Sherbrooke, Quebec, Canada
[2]Oregon State University-Cascades, Bend, Oregon, USA
[3]Oregon State University, Corvallis, Oregon, USA

Paper presented at the 2021 NARST International conference
Online
April 7, 2021

This material is based upon work supported by the National Science Foundation under grant no. EHR 1937772

Learning to Teach Science from a Contextualized Stance

Abstract

Contextualization is a curricular approach and a learning process in which science content knowledge is intentionally situated within a context where that knowledge can be authentically applied or observed. Many recent science education reforms include contextualization as a central tenet. Our goal in this review was to examine commonalities across contextualization approaches that could inform a method for preparing teachers to lead contextualized science learning broadly. After screening, 56 journal papers were organized into five contextualization approaches: authentic science practices (ASP), culturally-responsive science (CRS), out-of-classroom experiences (OOC), socio-scientific inquiry (SSI), and context-based curriculum (CBC). The collected papers suggested that despite the approach, teachers needed to develop a deep sense of the context, a clear understanding of the science content specific to that context, and the pedagogical skills to effectively bring content and context together. It was also found that contextualization usually leads to student-centered learning, even if not a specific goal of an intervention. This review suggests that contextualization can be taught as a broad, foundational teacher skill set that can be applied to more specific approaches. Learning this skill set will require long-term, and intensive teacher development efforts.

Introduction

Many reforms in science education over the last twenty years, including Project-Based Learning, Three-Dimensional Learning, Socio-Scientific Instruction, Ambitious Science Teaching, and Culturally Responsive Pedagogy, ask teachers to connect science content to contexts outside of the classroom. In the US, the K-12 Science Framework (NGSS) describes instruction through authentic scenarios and examining phenomena. *Curriculum in Context*, common in Europe, focuses on content that is relevant to everyday life. *Socio-Scientific Inquiry* (SSI) navigates science practice and decision-making as part of the socio-cultural context. *Culturally-responsive pedagogy* centers students' cultures as contexts for establishing relevance. While these approaches are different in important ways, they are similar in asking science teachers to lead students through the process of connecting science content and context. Contextualizing instruction is universally difficult but there are similarities across approaches that can be used to prepare science teachers to effectively use these and future approaches to contextualization.

Context is operationalized here as a set of complex, relatively stable, conditions that can be experienced and communicated, and that have behavioral relevance for learning (Stark, Reagh, Yassa, & Stark, 2017). Context is a social reality (Engle, Nguyen, & Mendelson, 2011), and becomes a mediating tool when it facilitates the work of learning through authentic practice (Vygotsky, 1978). Context always impacts learning, even when it is not explicitly addressed or designed for. Context stimulates cognitive and affective processing for the learner (Giamellaro, 2014) and those learners have variable and subjective access to a context through curriculum and instruction.

Contextualization is "the mechanism that connects the material and temporal world to the world of ideas through an experience or through a series of identifiable experiences" (Giamellaro, 2017, p. 5). It is the process of connecting science knowledge to context and this can be done by the learner, by curriculum, or through instruction, though it must be acknowledged that contextualized curriculum or instruction do not automatically lead to contextualized knowledge for students (King & Ritchie, 2012; Rivet & Krajcik, 2008). Contextualized curriculum implies an intentionality in linking content and context, not through coincidence or as a background assumption.

As with other instructional moves, teachers must learn how to achieve contextualized knowledge by contextualizing instruction and curriculum. Almost universally, teachers see the utility, relevance, and importance of contextualized approaches while also noting challenges to implementation (e.g. Rosenthal, 2018). Part of this tension is the perception that while contextualization may be engaging for students, it can conflict with assessments or other systemic demands (Hartmeyer et al., 2016). Further, the perceived divide between classroom contexts, authentic science contexts, and home contexts requires teachers to learn how to bridge those divides. The difficulties of contextualized science teaching are bound to the complexity of the real world in general. The lack of bounded variables, clear "answers", or well-defined problems can be challenging for teachers and students. Further, teacher identity and belief systems are common barriers to implementing contextualized science as the approaches ask teachers to reframe their relationship to contexts in and outside of school (Lupion-Cobos et al., 2017). Teachers are often reluctant to let go of their own ideas embedded in the contexts of their lives (Can & Seribas, 2019). Similarly, teachers may avoid conceptually-difficult skills required for contextualization and may be more likely to rely on their existing content knowledge in their teaching (Martin-Gamez & Erduran, 2018). However, supporting teachers' identities as scientists, making them part of the context rather than observers, has promise for motivating them to engage in contextualized instruction (McNeal et al., 2017; Miller & Kastens, 2017).

Extensive teacher support is needed for the implementation of contextualized science approaches (Brown & Crippen, 2016b) that often require introspection of personal identity as well as a wholesale change in approach to teaching. Pre-service teacher (PST) preparation programs have limited instructional time and cannot dwell on curriculum or instructional approaches that teacher candidates may never see in professional practice. Teachers who did not adequately learn during their training how to use contextualized learning situations may find it more difficult to perceive the added value. In-service teacher (IST) development programs also suffer from very limited time, competing mandates, and a sense of innovation fatigue from practicing teachers who are regularly inundated by new programs. In this paper we report on a review of studies on preparing teachers for contextualized science instruction. Our goal is to examine commonalities that could inform a method for preparing teachers to lead contextualized science learning as a broad foundation for the spectrum of contextualization approaches.

Methods

As part of a broader study, we conducted a systematic review of published research between 2001 and 2020 that examined contextualization in science learning, resulting in 3986 documents in English, French, or Spanish (due to fluency within the research team). The review was initiated by searching in the Web of Science database for titles, keywords, and abstracts which include, but are not limited to, terms and topics in science learning and/or development, contextualization, context-based, place-based, real-world, authentic, culturally responsive, experiential, outdoor, and fieldwork. The selection was also filtered by fields of research in education, special studies in education, curriculum and pedagogy, psychology and cognitive sciences, and communication and culture. For the review presented in this paper we screened this dataset to include only articles that specifically addressed IST or PST development or support to teach from a contextualized stance. We did not include studies in which teachers were learning science content but not pedagogy. After applying that criteria, the sample was reduced to 131 articles.

We used general inductive qualitative data analysis to screen abstracts, review articles, and condense the text data into categories. The articles were reviewed by at least two screeners from the team and unclear determinations were discussed by the team. Articles were excluded if they did not focus on science education learning or development (n=28), did not fit our definition of contextualization (n=38) or were written in languages beyond our team's ability (n=8). After applying the exclusion criteria, the sample consisted of 57 articles.

Following the screening of papers we categorized the studies into similar groups. Our labels are intended to highlight how the included studies approached contextualization rather than the often broader goals of an individual study. The labels are the results of our analysis rather than specific keywords used in the papers. Our analysis resulted in five general approaches to contextualization: authentic science practices (ASP), culturally-responsive science (CRS), out-of-class experiences (OOC), socio-scientific inquiry (SSI), and context-based curriculum (CBC). These groupings are defined in Table 1. It is worth noting that our team recognizes other approaches to contextualization (e.g. project-based learning, immersive technologies) that were not represented in the sample, perhaps because this literature fails to address both the role of contextualization and teacher development.

Table 1
Five Approaches to contextualized science education

Approach	**n**	**Definition** (provides teacher supports for instruction on…)
Authentic science practices (ASP)	14	Student participation in practices that are parallel to the activity of practicing scientists. Includes teacher-scientist partnerships and research experiences for teachers.
Culturally-responsive science (CRS)	13	Using students' socio-cultural backgrounds to frame science content as relevant and accessible. Includes translanguaging and funds of knowledge.
Out-of-class experiences (OOC)	12	Fostering experiences in a non-classroom setting, including informal and outdoor environments, to highlight or explore science content.
Socio-Scientific Inquiry (SSI)	11	Couching science content within societal issues often with a focus on decision-making and ethical or moral considerations.
Context-based curriculum (CBC)	7	Using or developing curriculum that uses narrative devices to couch science content in real and relevant scenarios. Includes problem-based learning.

Results and Discussion

Operationalizing Contextualization

A key factor in determining the five approaches to contextualization was the way in which each study and each group operationalized contextualization. To analyze operationalization we categorized how each paper described how, why, and to what ends the authors intentionally connected science content knowledge or skills to contexts outside of the classroom. Few papers explicitly used the term *contextualization*.

Our first consideration was the degree to which the approaches emphasized the importance of science knowledge versus the importance of the context itself. Were students ultimately asked to use context to better understand science or were they asked to use science to better understand the context? The culturally-responsive science (CRS), authentic science practices (ASP) and context-based curriculum (CBC) groups highlight the science content knowledge and the role of the context in helping to build understanding, motivation, relevance and engagement. In all three approaches the context is highly-valued and students must come to understand the nuance and details of it, but the measured learning outcomes are focused on the science. The CRS approach asks teachers to consider the contexts that students experience outside of class and to use those contexts to help students find relevance in the science content they are intended to learn. In the CRS approach, *science is relevant because it is part of everyday lived experience*. This work often brings contextualization into a *third space* in which various contexts mingle, converge, and conflict (e.g. Handa & Tippens, 2013). Arguably, this is the most challenging operationalization of contextualization for teachers because the contexts are broad, varied, and difficult for the teacher to know in a meaningful way.

The ASP approach uses the context to teach science through the lived experiences and cultures of practicing scientists. In this group contextualization is operationalized as helping teachers and then students to see and experience how science knowledge, and often skills, are used in authentic science research, often parallel to scientists who participate as partners in teacher PD. The skills and knowledge are situated in specific instances of data collection and analysis and are typically aligned to ongoing research outside of school. Examples include Research Experiences for Teachers, teacher-scientist partnerships, and citizen science. In ASP, *science is relevant because it has real and important applications beyond school and it is engaging work when the task is to solve real problems*.

CBC approaches take a middle tack. They operationalize contextualization as showing how science is applied in authentic science practice but focus on problems that are assumed to be relevant to students' daily lives. For example, this approach might focus on the safety of genetically modified foods or lactose intolerance (de Putter-Smits, et al, 2020). Curricula focus on context-specific, applied science, though unlike ASP they may not be tightly bound to the practices or problems that scientists in those fields are currently working on. Unlike CRS, the approach is generally not focused on the actual lived experience of the students. In CBC, *science is important because it can have a direct impact on your own life*.

The remaining approaches, Socio-Scientific Inquiry (SSI) and out-of-classroom experiences (OOC), value the science learning but also place a higher value on students learning more about the context. In the SSI approach students are asked to see society as a context in which science adds value to the public decision-making process, a space where ethics and morality must also play a role. Many of these studies refer to an informed citizenry as a goal. Contextualization is operationalized as a socio-cultural space where the processes and products of science must be used to solve difficult challenges. In SSI, *science is relevant because it is an important tool for society and it is engaging because it helps us make sense of complicated topics*.

OOC approaches vary more than the other approaches on the degree to which they operationalize contextualization as focusing on the science content or the context itself. In all of the studies there is an intentionality about the place in which learning occurs, whether a museum, a schoolyard, or a natural environment, and there tend to be clear science learning goals. In OOC, *science is engaging because it can be seen and experienced in specific places that reveal otherwise inaccessible aspects of the science-context interactions.*

How each approach operationalizes contextualization is more than an academic observation. It has important consequences for how each approach is designed and enacted. Teachers asking students to make sense of their own experiences is a very different task than asking students to make sense of an abstract context. Similarly, applying science knowledge or skills to an immediate experience is quite different from applying it to a hypothetical aspect of one's own life, and still more dissimilar from applying science knowledge to an abstract societal problem. It is important for teacher educators to strip these approaches down to their basic architecture and then to consider how teachers can be prepared for how and when to use each one.

Strategies for Enactment

At the center of this review is the question of how teachers can be supported to enact contextualized science instruction. It should be noted that although about half of the reviewed papers considered enactment of contextualized instruction, most relied on self report of intentions to enact in the classroom. Only a few studies included observation or measurement of enactment, and this gap represents a much-needed opportunity for future research.

Across the dataset, there was wide agreement that teachers were interested in and understood the value of contextualized instruction. However, many studies also reported significant barriers to implementation, including limited instructional time, ethical concerns, alignment to standards or testing, lack of training, and limited curriculum materials. One barrier that is inseparable from contextualization is dealing with the complexity that is bound to real contexts. Scholars across the approaches addressed this problem through wide-ranging means. Within the ASP, CRS, and OOC studies, findings explicitly state that teacher PD should incorporate immersion into the authentic environments to make sense of the complexity. This includes collaboration with experts, practice of science skills in authentic environments, and teacher immersion into their students' cultures. A first step, described heavily in the SSI studies, could include teachers learning how to problematize the complexity itself (e.g. Sadler et al., 2006). Studies across the approaches reported better teacher outcomes when the interventions provided specific ways for the teachers to address complexity.

Unsurprisingly, learning to manage complexity was often associated with long-term, ongoing, and intensive PD. Non-science early childhood educators, for example, improved CRS instruction and attitudes towards CRS only superficially after a year of intensive PD but made much more significant gains after two years of sustained and intensive PD (Roehrig et al., 2011). Similarly, a two-course graduate sequence helped but did not entirely overcome teachers' difficulties with implementing SSI (Glazewski et al., 2014). Extended support in the classroom, including coaching and mentoring, may be a more effective PD approach if trying to address the vast conceptual and practical knowledge involved with these contextualization approaches (Lehman et al., 2006). The cautionary tale across these studies is that learning to enact contextualized approaches may require too vast a set of skills and knowledge to be reasonably acquired within an isolated PD intervention and may require a concerted effort that spans PST programs or systemic IST PD programs over multiple, intensive years.

Specific contextualization-related skills can be successfully learned in shorter time periods, as in the case of learning the reflective judgment required for SSI (Karisan et al., 2018). Explicit instruction of contextualization skills is shown to be effective but limited. For example, Peters-Burton et al. (2015) showed that teachers changed their ability to apply scientific and mathematical reasoning to data-driven, authentic problems following a cognitive apprenticeship with scientists but then did not readily apply these changes to their own teaching. Supplementing a teacher research experience with instruction on how to translate that to the classroom can improve contextualization in lesson plans (Herrington et al., 2012). Lower level and field-specific skills were shown to be more tractable than broad habits of mind. The ASP PD experiences generally increased teachers' planned implementation of ASPs. There is a broad call in the SSI group and supported by papers in the other groups, for the teaching of specific skills in PST programs that include those that bridge specific and broad contextualization skills, such as argumentation and ethical reasoning. When a contextualization framework is lacking, teachers often try to use contexts but fail to connect them to broader themes (Klosterman et al., 2012). A crosscutting contextualization framework would be necessary for a systemic approach to PD.

Contextualization skills and knowledge are situated in practice. As such, they can be effectively modeled for teachers, with the intention that the teachers learn and then teach them to their own students. In one study, teachers developed a sense of how contextualized approaches build student interest when the teachers acted as students and specific instructional moves were modeled for them (Roehrig et al., 2011). Across the ASP studies, scientists as mentors were also shown to be widely effective in helping teachers to understand how science skills and knowledge could be contextualized in authentic practice. Again, this did not always translate to classroom use, often in part due to teachers not seeing connections between that situated knowledge and the assessment standards they are tasked with. Teachers must come to see contextualized approaches as in alignment with standards, not an alternative (Sadler et al., 2006), and this, too is a skill that must be learned.

Despite the PD approach, teacher background may be a better predictor for enacting contextualized curriculum. Windschitl (2003) showed that teachers who were most likely to adopt contextualized science practices were not those who had the deepest theoretical views on the pedagogy but those who had prior professional experience or undergraduate experience using the specific practices. Further, teachers are most likely to implement those science skills that relate to personal pre-teaching science experiences (Sezen-Barrie et al., 2015). Because teachers need to see the science in the given context, to understand how the science content relates to or is applied in the context, a lack of content knowledge also can be problematic (Glazewski et al., 2014). When elementary teachers, who may have very little science education and experience, are asked to contextualize science, they are likely to focus on the context over content if not supported (Yerrick & Beatty-Adler, 2011). The importance of teacher experiences implies a need for a three-pronged approach that would include better recruitment of science professionals to teaching careers, a greater focus on authentic science experiences in undergraduate and PST experiences, and the provision of similar experiences during long-term IST PD efforts.

Given the importance of teacher background experience, PD seems most likely to succeed when teacher needs are understood and the intervention is responsive to those needs. In one CBC study, teaching experience level was a good predictor of teacher concerns with CBC and all teachers were able to progress when their specific concerns were addressed (de Putter-Smits et al., 2020). Papers across the SSI and CBC approaches stressed the importance of teacher choice and agency in choosing the topics of study in order to align with teachers' experiences and knowledge. Both Sadler et al. (2006) and Nam et al. (2012) present classification systems to measure the level of buy-in and support for contextualized science instruction. Both papers stress that teachers who are focused on barriers to enactment have different PD needs than do teachers who are trying to optimize contextualization for student learning. Formative assessment during the PD can help to identify the changing needs over time (Roehrig et al., 2011) and involving teachers in the planning can help to appropriately match the needs with the PD (Yerrick & Beatty-Adler, 2011).

Curriculum development as PD, an approach that was prominent in the CBC studies, also has promise for supporting enactment of contextualized curriculum. Developing their own curriculum was empowering for teachers (George & Lubben, 2002) and they were more likely to implement CBC when they had a significant role in developing the curriculum (Elster, 2009). A lack of contextualized curriculum is often reported as a barrier to enactment, perhaps due to the localized nature of the context featured in many of these approaches, and so the curriculum development approach to PD also helps to break down this barrier. For example, the provision and adaptation of specific curriculum materials for conducting local citizen science projects led to a commitment of implementation for hesitant teachers in Tanzania (Boger et al., 2013).

Moving from understanding to implementation.

A second pattern in findings across the approaches is an extension of the first. When contextualized instruction did not materialize within these studies, a disconnect between learning and enacting was often the culprit. As one example, teachers improved specific meteorological skills through direct experience but then had difficulty transferring the skills to the classroom (Mandrikas et al., 2018). Indeed, the discomfort experienced by PSTs when quickly immersed in novel pedagogical scenarios can lead to deeper entrenchment in teacher-centered instruction (Wallace, 2013). Even with a solid theoretical understanding of a place-based approach to contextualization, teachers had difficulty incorporating cultural contextualization into the curriculum, particularly if they approached the work from a perspective of placing the science in the culture, rather than finding the places where science and traditional knowledge intersect (Nam et al., 2012).

There is a clear recognition in this body of work that there are two different steps to contextualizing instruction: understanding the context from the perspective of the content and THEN implementing relevant curriculum with students. As an example, a short PST experience of working with students in a school garden left the PSTs with the perception of learning opportunities but the PSTs still relied on teacher-centered pedagogies that did not work well with a contextualized orientation (Rosenthal, 2018). Similarly, PSTs visiting a botanical garden for one day changed their perspective on the potential for inquiry in an OOC setting but many maintained a hesitant view of related pedagogy (Glackin & Harrison, 2017). Asking teachers to learn new pedagogies as well as new content or contexts was repeatedly described as overwhelming for teachers, even with PD that would be considered extensive in other fields. Glazewski et al. (2014) found that teachers fell back to instruction on decontextualized content knowledge when either pedagogical knowledge or understanding of context related to an SSI was not sufficiently developed. However, there were several studies that did see positive results when teachers received sufficient support in content, context, AND were specifically supported to implement them in the classroom. Following a one-year, intensive, research experience for teachers, and despite resistance to change, teachers showed a significant positive change in the contextualized practices, a change they attributed to self-efficacy and confidence built from a combination of the research experience and matched pedagogical instruction (Amollins et al., 2015).

Brown & Crippen (2016a) found that having teachers critically examine their own practice while simultaneously learning about their students' experiences helped the teachers to select topics and strategies that were culturally relevant but they still did not often implement in practice after a six month training. Change in practice is hard and thus reflection on one's pedagogy is important (Glazewski et al., 2014). Teachers seem to be adept at leading the development of student skills that are more removed from the context, such as the general design of inquiry and using instruments, but less so with activities that are more embedded in the context, such as asking testable questions, designing robust methods, or disseminating results appropriately (French & Burrows, 2018). Recognizing these challenges, Schumacher & Reiners (2013) helped PSTs consider implementation before they were ready to do so on their own by asking them to evaluate videos of "authentic" contextualized lessons to determine where students might need support. Across the OOC set, there was agreement that the more teachers are exposed to OOC learning, the better the development of pedagogical and science knowledge.

It is clear that context, content, and pedagogy need to be scaffolded together and this should happen in PST programs through teacher research experiences, and modeled experiences with local contexts (Windschitl, 2003). Teacher confidence and competence need to be used as metrics of success as they are both necessary for classroom enactment (Lindemann-Matthies et al., 2011). There is also an urgent need for research that tracks teacher development into the classroom to measure the effectiveness on student learning.

Teacher motivations and confidence with contextualization.

Teacher confidence, motivations, and beliefs were common themes throughout the approaches, often as a barrier, and sometimes as a goal. Although identity, confidence, motivation, belief systems, and conceptions of contextualization are distinct constructs, the lines between them are blurred within the dataset and they collectively address the ability or likelihood that teachers will implement contextualized science instruction. Overall, teachers seem to see the value of contextualized instruction and waver in their motivation to enact it based on internal and external motivations.

Teachers have multiple motivations that are both inward, they are interested in becoming more knowledgeable in the content, as well as outward, creating opportunities for students and teaching efficacy (Rebull et al., 2018). Teachers are often unsure of how to enact contextualized approaches (Torquati et al., 2014). They may have the external motivations to provide learning opportunities for their students but lack the conceptual means or background to do so. Without well-conceived PD, contextualization can be perceived as too time consuming and a lack of curriculum resources problematic (Kara, 2021). External factors, including momentum of traditional curriculum, parental or student wariness of novel approaches, lack of peer support, and uncertainty about ability to achieve science competencies, can create hesitancy to adopt CBC (Lupion-Cobos et al., 2017). These studies suggest that brief PD experiences were not enough to overcome perceived barriers to implementing contextualized inquiry and that motivations must be addressed systemically.

Contextualization always implies a personal connection to a context, whether the ethical issues of SSI, the local applications in CBC, biographical relationships in CRS, the enculturation into science of ASP, or a sense of place through OOC. Teachers' personal beliefs around advocacy (e.g. environmentalism), their backgrounds, and therefore their identity as a scientist has an impact on their motivation to contextualize with authentic problems or practices. Moral, personal interest in topics and students can be a bigger driver than reform efforts (Lee & Witz, 2009; McNeal et al., 2017). Because contextualization often reaches outside of the perceived objectivity of science, cultural differences in moral, religious, and ethical values create anxiety around teaching SSI issues for some teachers (Kapici & Ilhan, 2016). When teachers perceive tensions between student beliefs and their own, they can be unwilling to adopt an SSI approach (Kara, 2012). Interestingly, the topics that might cause tension were not consistent across the geographical regions reported in these papers, suggesting again that contextualization must have a local component and teacher supports must start with the actual needs of the teachers involved.

Local, indigenous knowledge is a rich source of contextualized science knowledge but the way that teachers conceive of indigenous knowledge has an impact on its use in the classroom and teachers' ability to work it into curriculum, assessment, and overcome other systemic barriers (Anderson et al., 2015). Teachers must reflect on and address their assumptions about science and about indigenous knowledge (Singh-Pillay et al., 2017). Teachers who saw CRS as a two-way exchange were more effective in finding concrete science examples within traditional American Indian knowledge (Nam et al., 2012). Similarly, teachers are often asked to assimilate into a culture of science that may be distant from their own. Wallace and Brooks (2015) have shown that teachers experiencing this tension have a harder time considering the needs and identities of their students but that when well-supported, teacher identities can change in ways that lead to more inclusive pedagogy. Several papers caution against seeing teachers' inner aspects as barriers and rather, encourage supported introspection and understanding of teacher needs.

Consistent with the other themes reported here, the papers examining motivations and confidence suggest that teachers need more contextualized experiences in order to build motivation and confidence. Trauth-Nare (2015) specifically suggests learning experiences in place-based settings, service learning with students, and teachers developing experiential curriculum. In a review of four European PST programs it was found that if students have at least two OOC experiences in their program, they are more confident to enact OOC them, but they were not necessarily more competent in doing so (Lindemann-Matthies et al., 2011). Conversely, a short training experience changed teacher awareness but not affinity for contextualized ornithology (Ortiz et al., 2020). The ASP studies' findings cumulatively emphasize the importance of PD that models and uses the skills and knowledge of practicing scientists to improve teachers' perceptions of using inquiry in the classroom. Interactions with a professional science team, particularly the most novel aspects, increased teacher content knowledge but also motivation and confidence to teach contextualized content even after just a short stay at a rocket facility (Mehli & Bungum, 2013). In sum, while confidence may not lead to competence, the reverse seems to be true and confidence may support ongoing teacher engagement.

Emergence of student-centeredness

Throughout what we consider to be science contextualization literature there is an implicit assumption that through contextualization, individual students will be able to develop a sense of relevance or personal meaning for the science content. It is not surprising then, that across the approaches, student-centeredness was an outcome of supporting teachers to contextualize the curriculum. It is surprising however, that this outcome was often described as emergent or unexpected. Before intervention, PSTs conceptualized OOC experiences as teacher-directed, and being disconnected from classroom instruction (Subramaniam, 2019). This was a common starting point across the approaches, and it often reflected larger societal trends. Tanzanian teachers, entrenched in a cultural norm of teacher-centered instruction, indicated that highly scaffolded PD helped them to see locally relevant science issues that would lead to bringing more of their students' lives into the classroom (Boger et al., 2013). This led to an increase in student-driven research. Teachers in Kenya who were hesitant to implement CBC changed their perspectives when they saw how positively students responded to it, how students began leading the investigations and became "actively emancipated curious learners" (Nashon & Anderson, 2015; Anderson et al., 2015). In the Kenyan example and several others, it was the students' reactions that convinced the teachers to enact more contextualized, student-centered instruction. In other cases, teachers' own experiences as the students in PD helped them to develop "insights into exploratory behavior" and the potential for students' observations, questions, and wonderings as material to work with (Hughes-McDonnell & Burgess, 2011) or to reconceptualize science research as something that all students could do effectively (Peters-Burton et al., 2015).

In testing out contextualized approaches, the focus inherently moved toward students. For example, teachers reported using a wider variety of teaching methods when using CBC and students were more engaged (Elster, 2009). Specific contextualizing instructional moves, such as rephrasing, modeling, and reinforcing cognate use, were shown to have a significant impact on bridging home and school for students (MacDonald et al., 2013). PD helped ISTs change from a focus on indirect experiences to students' direct experiences that provided them with expertise/authority they could bring to the table and co-construct products with the teacher (Brown & Crippen, 2017). Intentionally shifting authority in the classroom can open the curriculum to students' cultural and ethnic differences and leave PSTs feeling more capable of working with a diversity of students (Titu et al., 2018). It seems that starting with student-centeredness can lead to contextualization or starting with contextualization can lead to student-centered learning. This relationship deserves further investigation. Of course, teachers must be open to these changes and one study found that a PD approach that focused on the concerns of individual teachers allowed all teachers to move toward more student-centered instruction (de Putter-Smits, 2020).

Teacher knowledge of local contexts.

A final pattern across the five approaches seems to add a layer to Shulman's (1986) categorization of teacher knowledge. In addition to knowledge of content and knowledge of pedagogy, these papers suggest that teachers must develop a knowledge of context that plays an equally important role in contextualized instruction. For teaching societally-relevant, contextualized topics, such as genetic testing, teachers need to know and to be instructed in the ethical, legal, and social aspects (van der Zande et al., 2011). Teachers' underlying preparation, skills, and assumptions bound to context may position them for more effective CRS. PSTs in bilingual programs were shown to have more nuanced, more asset-oriented, and less stereotypical understanding of cultural contexts (Tolbert & Knox, 2016). In other words, surface level understanding of contexts may not be enough and teachers may need direct and focused development work to more deeply understand the contexts germane to the curriculum.

While teachers can empower students to bring their own experiences into the classroom, students may not be willing or able to bring in cultural knowledge that is robust enough to allow the teacher to make meaningful science connections (George, 2013). Teachers, especially expat teachers, run the risk of students perceiving science knowledge as superior to or disconnected from indigenous knowledge and therefore teachers must use local resources to better understand local and indigenous knowledge (Waldrip et al., 2007). Teachers must do the work of seeking out sources of cultural or other contextual knowledge and actively bring those into the classroom. In Trinidad and Tobago, George & Lubben (2002) had teachers focus on local contexts and in doing so teachers shifted their focus from student deficits to the everyday contexts of their students. Teachers expanded their information sources, looking more externally into the community than they were used to. Teachers experienced tensions when trying to map this back onto a macro-level curriculum because many cultural practices and beliefs were not clearly aligned to current science explanations. Rather than finding bridges, teachers as CBC developers, tended to ignore them (George & Lubben, 2002). This suggests that support for contextualization of curriculum needs to be cyclical, as teachers consider micro-level contexts and macro-level standards.

Deep understanding of a culture or most contexts, and how they can be intertwined with science instruction, requires long-term commitment, teacher immersion, and even communities of practice, as Chinn (2006) showed to be effective in developing native Hawaiian-referenced science curriculum and teacher education. Cultural contexts are not dichotomous and brief introductions to context risk this misconception. Particularly in places with complicated "confluences of indigeneity and modernity", education can become a hybrid space where the multiple cultural contexts can come to be understood individually and convergently (Handa & Tippens, 2012). Teachers must have a role in preserving traditional funds of knowledge by maintaining place as bound to indegenous knowledge, a goal that was achieved through PST immersions in various villages in the Philippines (Handa & Tippens, 2012).

Further Directions and Study Limitations

This collection of largely self-report studies provides a starting point for more objectively examining how teachers can be supported to effectively contextualize their instruction in ways that lead to improved learning outcomes. Only a few studies included observation or measurement of enactment, and this gap represents a much-needed opportunity for future research. Across these approaches researchers need to move toward tracking these teacher interventions to determine their impact on students.

Developing and testing initial ideas that are presented through the specific instances of these papers into crosscutting pedagogies is an important next step in this work. It would be worthwhile to test interventions common to one approach across the other approaches. For example, it would be worthwhile to know if teacher beliefs have as great an impact on CBC or OOC approaches as they do within SSI. Similarly, it would be worth testing whether mentorship can improve contextualized instruction in SSI as it does in ASP approaches.

The strength of considering all of these approaches as instantiations of a common learning phenomenon is the ability to compare more readily across studies. To reliably do so would require the development of instruments to measure inputs and outcomes of contextualization (Giamellaro, 2017) and the studies presented here may provide a good starting point. A crosscutting contextualization skills framework would be necessary for developing and testing a systemic approach to PD. While the skills and PD strategies described here were variably successful for supporting individual approaches, it is not clear to what extent they would be successful across approaches. The gold standard in this field would be to create and test a PST program that introduced all of these approaches through the lens of contextualization and measured PSTs' ability to translate between approaches, eventually implementing them in practice.

Some limitations emerged as a result of this study being developed as a tangent to a broader research effort. First, the keywords used in the orginal search were broader than the aim of this specific study. It would be worthwhile to revisit this search with more targeted keywords. Second, our data collection was limited to a systematic review of published research, introducing publication bias to our sample. We approached the work from a perspective of inclusion such that we valued quantitative and qualitative studies, including interviews with PSTs and ISTs to contribute to a more in-depth comprehension of the proposed strategies in this article. In so doing, we did not have apply a metric to judge the quality or trustworthiness of the studies, relying on peer review to serve that function. Nevertheless, our results provide researchers with a starting point to make and test interventions common across the approaches and to develop a potential crosscutting contextualization skills framework.

Conclusion

In order to create PST methods courses or IST PD opportunities that treat contextualization as a common phenomenon, the field needs to better understand the implications for how we operationalize contextualization. The five approaches described in this review operationalize contextualization differently and this results in different ways of thinking about science education. Is place-based science engaging because it can be seen and experienced, revealing otherwise inaccessible aspects of the science-context interactions, or is it engaging because *the task is to solve real problems*? Is science relevant because it is part of everyday lived experience, because it has real and important applications beyond school, or because it is an important tool for society? Is science actually perceived by students as important because it can have a direct impact on their own lives? Probably all of these considerations are true and important. Certainly, how one answers such questions will have an impact on how a teacher approaches contextualization as well as on the student outcomes. The first step in such an approach is to ask the question of why contextualization is to be used in a teaching-learning sequence. The second step is to pick the appropriate approach to meet those goals.

If these five approaches are based on different operationalizations of contextualization, and the skill sets needed for each are not all common, is it worthwhile to aggregate them for the purposes of teacher education? We argue that it is. Throughout the papers we reviewed, the authors describe similar barriers to implementation (e.g. standards, testing, time, lack of material and professional support). If teachers can learn to overcome these barriers broadly, they are better positioned to address them when adopting any of the other approaches, or a new approach that has not yet been developed. If teachers can learn to see these barriers as applying to contextualization broadly, they can develop transferable tools for overcoming the barriers. Also, in considering the full breadth of approaches, there are findings from some that can inform the others. For example, the SSI literature closely examines teacher beliefs and intentions while the ASP literature is more focused on specific scientific skills. Findings from each can advance the other more quickly when they are recognized as of a kind.

Perhaps the most important finding from this review is at once the most obvious and the most underdeveloped in science teacher education: context matters. It is not just the background, it is an essential mediating tool (Vygotsky, 1978). Teachers and their students cannot be expected to understand context and how it relates to science content without any support for doing so. This is a challenging problem to solve in teacher education because it is difficult, perhaps impossible, to address at scale.

Given the right support, teachers can become more adept at teaching from a contextualized stance, though there are no shortcuts to doing this work and teachers need to be directly involved. Measuring and self-reflecting on beliefs, confidence, and self-efficacy seems like a good starting place across these approaches. Providing teachers with a supported, perhaps ongoing, immersion experience into the context could be next (Rebull et al., 2018). Some building blocks of contextualized instruction, such as teaching authentic scientific practices (Miller & Kastens, 2017), or surface-level context such as general patterns of research within a domain can be learned episodically (Mishra, et al., 2019). Teachers must then be involved in developing or adapting the curriculum but they must be supported and collaborative in this process. They can also accelerate their contextualized science instruction by recognizing synergies such as those that exist between students' cultural backgrounds and local, authentic science contexts (Tolbert & Knox, 2016). Still, transfer to new contexts can be elusive (Mandrikas, et al., 2018) and this is a skill that must be learned by both teachers and students. Finally, teachers need specific tools and methods for bringing together the context and content for their students.

The need for teachers to develop or adapt their own curriculum, to make sure it is localized and aligned to culturally-bound morality and ethics, to make sure it is true to the practices and understanding of science, and to deliver it in such a way that students have agency and see relevancy is an unrealistic expectation if this work is not addressed in a long-term, intentional, and intensive way. Teacher confidence with contextualized methods results from competence in them. PD needs to be designed around actual teacher needs, it needs to support teachers over the long term as they develop competence, and teachers need to experience their students' engagement when these approaches are enacted well. These many requirements for success lead us to conclude that there would be benefit from ISTs and PSTs learning to teach from a contextualized stance first and then branching out to the specific approaches. If they learn how to become more knowledgeable about specific science content, local or germane contexts, and the pedagogy used to bring them together, they should be able to see what student-centered pedagogy looks like and how it is experienced by students. As contextualization emerges as a phenomenon that crosses reform approaches, science education will benefit from the efficiency of understanding and applying it broadly and regularly.

References

Amolins, M. W., Ezrailson, C. M., Pearce, D. A., Elliott, A. J., & Vitiello, P. F. (2015). Evaluating the effectiveness of a laboratory-based professional development program for science educators. *Advances in Physiology Education*, *39*(4), 341–351. https://doi.org/10.1152/advan.00088.2015

Anderson, D., Nashon, S., Namazzi, E., Okemwa, P., Ombogo, P., Ooko, S., & Beru, F. (2015). Transformations in Kenyan science teachers' locus of control: The Influence of contextualized science and emancipated student learning. *Journal of Science Teacher Education*, *26*(7), 599–617. https://doi.org/10.1007/s10972-015-9440-5

Boger, R., Yule, S., & Sparrow, E. (2013). Strategies for teaching to a changing world: Lessons from Arusha, Tanzania. *International Research in Geographical and Environmental Education*, *22*(3), 209–225. https://doi.org/10.1080/10382046.2013.817655

Brown, J. C., & Crippen, K. J. (2016a). Designing for culturally responsive science education through professional development. *International Journal of Science Education*, *38*(3), 470–492. https://doi.org/10.1080/09500693.2015.1136756

Brown, J. C., & Crippen, K. J. (2016b). The growing awareness inventory: Building capacity for culturally responsive science and mathematics with a structured observation protocol. *School Science and Mathematics*, *116*(3), 127–138. https://doi.org/10.1111/ssm.12163

Brown, J. C., & Crippen, K. J. (2017). The knowledge and practices of high school science teachers in pursuit of cultural responsiveness. *Science Education*, *101*(1), 99–133. https://doi.org/10.1002/sce.21250

Buxton, C., Harman, R., Cardozo-Gaibisso, L., Jiang, L., Bui, K., & Allexsaht-Snider, M. (2019). Understanding science and language connections: New approaches to assessment with bilingual learners. *Research in Science Education*. https://doi.org/10.1007/s11165-019-9846-8

Chinn, P. W. U. (2006). Preparing science teachers for culturally diverse students: Developing cultural literacy through cultural immersion, cultural translators and communities of practice. *Cultural Studies of Science Education*, *1*(2), 367–402. https://doi.org/10.1007/s11422-006-9014-0

de Putter-Smits, L., G. A., Nieveen, N. M., Taconis, R., & Jochems, W. (2020). A one-year teacher professional development programme towards context-based science education using a concerns-based approach. *Professional Development in Education*, *Published Online*, 18. https://doi.org/10.1080/19415257.2020.1712616

Elster, D. (2009). Biology in context: Teachers' professional development in learning communities. *Journal of Biological Education*, *43*(2), 53–61. https://doi.org/10.1080/00219266.2009.9656152

Engle, R. A., Nguyen, P. D., & Mendelson, A. (2011). The influence of framing on transfer: Initial evidence from a tutoring experiment. *Instructional Science*, *39*(5), 603–628. https://doi.org/10.1007/s11251-010-9145-2

French, D. A., & Burrows, A. C. (2018). Evidence of science and engineering practices in preservice secondary science teachers' instructional planning. *Journal of Science Education and Technology*, *27*(6), 536–549. https://doi.org/10.1007/s10956-018-9742-4

George, J. M. (2013). 'Do you have to pack?'—Preparing for culturally relevant science teaching in the Caribbean. *International Journal of Science Education*, *35*(12), 2114–2131. https://doi.org/10.1080/09500693.2012.760138

George, J. M., & Lubben, F. (2002). Facilitating teachers' professional growth through their involvement in creating context-based materials in science. *International Journal of Educational Development*, *22*(6), 659–672. https://doi.org/10.1016/S0738-0593(01)00033-5

Giamellaro, M. (2014). Primary contextualization of science learning through immersion in content-rich settings. *International Journal of Science Education*, *36*(17), 2848–2871. https://doi.org/10.1080/09500693.2014.937787

Giamellaro, M. (2017). Dewey's yardstick: Contextualization as a measure of experience in learning and education. *SAGE Open*, *7*(1), 1–11. https://doi.org/10.1177/2158244017700463

Glackin, M., & Harrison, C. (2018). Budding biology teachers: What have botanical gardens got to offer inquiry learning. *Journal of Biological Education*, *52*(3), 283–293. https://doi.org/10.1080/00219266.2017.1357648

Glazewski, K., Shuster, M. I., Brush, T., & Ellis, A. (2014). Conexiones: Fostering socioscientific inquiry in graduate teacher preparation. *Interdisciplinary Journal of Problem-Based Learning*, *8*(1). https://doi.org/10.7771/1541-5015.1419

Handa, V. C., & Tippins, D. J. (2013). Tensions in the third space: Locating relevancy in preservice science teacher preparation. *International Journal of Science and Mathematics Education*, *11*(1), 237–265. https://doi.org/10.1007/s10763-012-9364-x

Hartmeyer, R., Stevenson, M. P., & Bentsen, P. (2016). Evaluating design-based formative assessment practices in outdoor science teaching. *Educational Research*, *58*(4), 420–441. https://doi.org/10.1080/00131881.2016.1237857

Herrington, D. G., Luxford, K., & Yezierski, E. J. (2012). Target inquiry: Helping teachers use a research experience to transform their teaching practices. *Journal of Chemical Education*, *89*(4), 442–448. https://doi.org/10.1021/ed1006458

Hughes-McDonnell, F. J., & Burgess, D. R. (2011). Teacher explorations of science and science learning generate insights into inquiry and teaching. *LEARNing Landscapes*, *4*(2), 195–213. https://doi.org/10.36510/learnland.v4i2.396

Kapici, H. O., & Ilhan, G. (2016). Pre-service teachers' attitudes toward socio-scientific issues and their views about nuclear power plants. *Journal of Baltic Science Education*, *15*(5), 642–652.

Kara, Y. (2012). Pre-service biology teachers' perceptions on the instruction of socio-scientific issues in the curriculum. *European Journal of Teacher Education*, *35*(1), 111–129. https://doi.org/10.1080/02619768.2011.633999

Karışan, D., Yılmaz-Tüzün, Ö., & Zeidler, D. (2018). Pre-service teachers' reflective judgment skills in the context of socio-scientific issues based inquiry laboratory course. *Turkish Journal of Education*, *7*(2), 99–116. https://doi.org/10.19128/turje.7299116

King, D., & Ritchie, S. M. (2012). Learning science through real-world contexts. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (Vol. 24, pp. 69–79). Springer Netherlands. http://link.springer.com/10.1007/978-1-4020-9041-7_6

Klosterman, M. L., Sadler, T. D., & Brown, J. (2012). Science teachers' use of mass media to address socio-scientific and sustainability issues. *Research in Science Education*, *42*(1), 51–74. https://doi.org/10.1007/s11165-011-9256-z

Lee, H., & Witz, K. G. (2009). Science teachers' inspiration for teaching socio-scientific issues: Disconnection with reform efforts. *International Journal of Science Education*, *31*(7), 931–960. https://doi.org/10.1080/09500690801898903

Lehman, J. D., George, M., Buchanan, P., & Rush, M. (2006). Preparing teachers to use problem-centered, inquiry-based science: Lessons from a four-year professional development project. *Interdisciplinary Journal of Problem-Based Learning*, *1*(1). https://doi.org/10.7771/1541-5015.1007

Lindemann-Matthies, P., Constantinou, C., Lehnert, H.-J., Nagel, U., Raper, G., & Kadji-Beltran, C. (2011). Confidence and perceived competence of preservice teachers to implement biodiversity education in primary schools—Four comparative case studies from Europe. *International Journal of Science Education*, *33*(16), 2247–2273. https://doi.org/10.1080/09500693.2010.547534

Lupión-Cobos, T., López-Castilla, R., & Blanco-López, Á. (2017). What do science teachers think about developing scientific competences through context-based teaching? A case study. *International Journal of Science Education*, *39*(7), 937–963. https://doi.org/10.1080/09500693.2017.1310412

MacDonald, G. L., Miller, S. S., Murry, K., Herrera, S., & Spears, J. D. (2013). Efficacy of ACA strategies in biography-driven science teaching: An investigation. *Cultural Studies of Science Education*, *8*(4), 889–903. https://doi.org/10.1007/s11422-013-9517-4

Mandrikas, A., Stavrou, D., Halkia, K., & Skordoulis, C. (2018). Preservice elementary teachers' study concerning wind on weather maps. *Journal of Science Teacher Education*, *29*(1), 65–82. https://doi.org/10.1080/1046560X.2017.1423458

Martín-Gámez, C., & Erduran, S. (2018). Understanding argumentation about socio-scientific issues on energy: A quantitative study with primary pre-service teachers in Spain. *Research in Science & Technological Education*, *36*(4), 463–483. https://doi.org/10.1080/02635143.2018.1427568

McNeal, P., Petcovic, H., & Reeves, P. (2017). What is motivating middle-school science teachers to teach climate change? *International Journal of Science Education*, *39*(8), 1069–1088. https://doi.org/10.1080/09500693.2017.1315466

Mehli, H., & Bungum, B. (2013). A space for learning: How teachers benefit from participating in a professional community of space technology. *Research in Science & Technological Education*, *31*(1), 31–48. https://doi.org/10.1080/02635143.2012.761604

Miller, A. R., & Kastens, K. A. (2018). Investigating the impacts of targeted professional development around models and modeling on teachers' instructional practice and student learning. *Journal of Research in Science Teaching*, *55*(5), 641–663. https://doi.org/10.1002/tea.21434

Mishra, C., Ha, S. J., Parker, L. C., & Clase, K. L. (2019). Describing teacher conceptions of technology in authentic science inquiry using technological pedagogical content knowledge as a lens. *Biochemistry and Molecular Biology Education*, *00*(00), 1–8.

Nam, Y., Roehrig, G., Kern, A., & Reynolds, B. (2013). Perception and practices of culturally relevant science teaching in American Indian classrooms. *International Journal of Science and Mathematics Education*, *11*(1), 143–167. https://doi.org/10.1007/s10763-012-9372-x

Nashon, S. M., & Anderson, D. (2015). Teacher change: The effect of student learning on science teachers' teaching in Kenya. *International Journal of Engineering Education*, *29*(4), 1–7.

Ortiz, J. L., Conkey, A. A. T., Brennan, L. A., Fedynich, L. V., & Green, M. (2020). Wild bird workshop: A professional development opportunity for educators. *The American Biology Teacher*, *82*(1), 3–10. https://doi.org/10.1525/abt.2020.82.1.3

Peters-Burton, E. E., Merz, S. A., Ramirez, E. M., & Saroughi, M. (2015). The effect of cognitive apprenticeship-based professional development on teacher self-efficacy of science teaching, motivation, knowledge, calibration, and perceptions of inquiry-based teaching. *Journal of Science Teacher Education*, *26*(6), 525–548. https://doi.org/10.1007/s10972-015-9436-1

Rebull, L. M., Roberts, T., Laurence, W., Fitzgerald, M., French, D., Gorjian, V., & Squires, G. K. (2018). Motivations of educators for participating in NITARP, an authentic astronomy research experience professional development program. *Physical Review Physics Education Research*, *14*(2), 020102. https://doi.org/10.1103/PhysRevPhysEducRes.14.020102

Rivet, A. E., & Krajcik, J. S. (2008). Contextualizing instruction: Leveraging students' prior knowledge and experiences to foster understanding of middle school science. *Journal of Research in Science Teaching*, *45*, 79–100. https://doi.org/10.1002/tea.20203

Rosenthal, J. L. (2018). Teacher candidates in the garden. *Science Activities: Classroom Projects and Curriculum Ideas*, *55*(1), 20–27. https://doi.org/10.1080/00368121.2017.1403875

Sadler, T. D., Amirshokoohi, A., Kazempour, M., & Allspaw, K. M. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching*, *43*(4), 353–376. https://doi.org/10.1002/tea.20142

Schumacher, A., & Reiners, C. S. (2013). Designing authentic Learning environments in chemistry lessons: Paving the way in pre-service teacher education. *Science & Education*, *22*(9), 2173–2191. https://doi.org/10.1007/s11191-012-9552-7

Sezen-Barrie, A., Moore, J., & Roig, C. E. (2015). Discovering plate boundaries in data-integrated environments: Preservice teachers' conceptualization and implementation of scientific practices. *International Journal of Science Education*, *37*(12), 2013–2037. https://doi.org/10.1080/09500693.2015.1061226

Singh-Pillay, A., Alant, B. P., & Nwokocha, G. (2017). Tapping into basic 7–9 science and technology teachers' conceptions of indigenous knowledge in Imo State, Nigeria. *African Journal of Research in Mathematics, Science and Technology Education*, *21*(2), 125–135. https://doi.org/10.1080/18117295.2017.1327240

Stark, S. M., Reagh, Z. M., Yassa, M. A., & Stark, C. E. L. (2017). What's in a context? Cautions, limitations, and potential paths forward. *Neuroscience Letters*, *680*, 77–87. https://doi.org/10.1016/j.neulet.2017.05.022

Subramaniam, K. (2019). An exploratory study of student teachers' conceptions of teaching life science outdoors. *Journal of Biological Education*, *53*(4), 399–411. https://doi.org/10.1080/00219266.2018.1472133

Titu, P., Ring-Whalen, E. A., Brown, J. C., & Roehrig, G. H. (2018). Exploring changes in science teachers' attitudes toward culturally diverse students during an equity-focused course. *Journal of Science Teacher Education*, *29*(5), 378–396. https://doi.org/10.1080/1046560X.2018.1461006

Tolbert, S., & Knox, C. (2016). 'They might know a lot of things that I don't know': Investigating differences in preservice teachers' ideas about contextualizing science instruction in multilingual classrooms. *International Journal of Science Education*, *38*(7), 1133–1149. https://doi.org/10.1080/09500693.2016.1183266

Torquati, J., Cutler, K., Gilkerson, D., & Sarver, S. (2013). Early childhood educators' perceptions of nature, science, and environmental education. *Early Education & Development*, *24*(5), 721–743. https://doi.org/10.1080/10409289.2012.725383

Trauth-Nare, A. (2015). Influence of an intensive, field-based life science course on preservice teachers' self-efficacy for environmental science teaching. *Journal of Science Teacher Education*, *26*(5), 497–519. https://doi.org/10.1007/s10972-015-9434-3

van der Zande, P., Waarlo, A. J., Brekelmans, M., Akkerman, S. F., & Vermunt, J. D. (2011). A knowledge base for teaching biology situated in the context of genetic testing. *International Journal of Science Education*, *33*(15), 2037–2067. https://doi.org/10.1080/09500693.2010.525797

Vygotsky, L. S. (1978). *Mind in society*. Harvard University Press.

Waldrip, B. G., Timothy, J. T., & Wilikai, W. (2007). Pedagogic principles in negotiating cultural conflict: A Melanesian example. *International Journal of Science Education*, *29*(1), 101–122. https://doi.org/10.1080/09500690600718195

Wallace, C. S. (2013). Promoting shifts in preservice science teachers' thinking through teaching and action research in informal science settings. *Journal of Science Teacher Education*, *24*(5), 811–832. https://doi.org/10.1007/s10972-013-9337-0

Wallace, C. S., & Brooks, L. (2015). Learning to teach elementary science in an experiential, informal context: Culture, learning, and identity. *Science Education*, *99*(1), 174–198. https://doi.org/10.1002/sce.21138

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, *87*(1), 112–143. https://doi.org/10.1002/sce.10044

Yerrick, R., & Beatty-Adler, D. (2011). Addressing equity and diversity with teachers Though informal science institutions and teacher professional development. *Journal of Science Teacher Education*, *22*(3), 229–253. https://doi.org/10.1007/s10972-011-9226-3