Collaborative Professional Development on Authentic Science May Reduce Barriers to Implementation in High School Classrooms

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Abstract

Teachers face challenges implementing authentic high school science lessons, particularly around inquiry practices and contemporary context. We created a collaborative curriculum design workshop to integrate authentic science activities on local invasive species into their classrooms while supplementing content knowledge via field trips to research sites and invasive species infestations. 36 teachers attended then implemented lessons they revised at the workshop in their classrooms. After implementation, we interviewed participants about barriers to lesson implementation. Teachers reported barriers of standardized testing, district mandates, time, and collaboration with other educators, all identified in previous literature. We also identified physical proximity as a barrier. Following professional development, several of the barriers were reduced or expected to be reduced for implementation of authentic science lessons, including collaboration, time, and physical

proximity. We demonstrate the power of authentic science practice-based teacher professional development workshops that emphasize collaborative planning time for teachers while incorporating content presentations, in line with recommendations for teacher professional development writ large. We recommend collaborative professional development designs bringing together personnel from the same job site or district as well as from different districts while partnering with universities to retain university campus features such as access to active, authentic research sites.

Keywords: collaborative curriculum design, authentic science, inquiry, science practices, professional development, science teacher education

Introduction

Since at least the 1980s, U.S. agricultural and science education reformers have called for teachers to present contextualized, authentic science learning opportunities; that is, teachers should facilitate lessons with content relevant to learners and embedded in everyday situations (National Commission on Excellence in Education, 1983; National Research Council (U.S.), 1996). However, for at least as long, science curricula have tended to emphasize discrete facts rather than contextualized knowledge and science practices (National Research Council, 2012; Rivet & Krajcik, 2008; Thoron & Myers, 2008), those skills and habits needed "to engage in scientific inquiry" (National Research Council, 2012, p. 2). The Next Generation Science Standards underlying framework suggests K–12 students should have learning experiences which "engage [students] with fundamental questions about the world and with how scientists have investigated and found answers to those questions" (National Research Council, 2012, p. 9). Preparation in authentic science[1] in formal school promotes a skilled agricultural and STEM (Science, Technology, Engineering, and Math) labor force (Carnevale et al., 2011) and an engaged populace (National Research Council, 2012).

Authentic natural resources problems with community-level impacts, such as preventing and dealing with invasive species, require creative solutions integrating and weighing multiple sources and types of data and involving interdisciplinary STEM and social studies (Netherland & Schardt, 2009). Authentic, especially locally-relevant problems under investigation also provide a tie to ongoing university research, offering opportunities to build teacher-scientist partnerships for content expertise (Bokor, 2016; Tammen et al., 2018) and provide students insights into potential careers in their own communities (Bajema et al., 2002; Riegle-Crumb & Moore, 2014). Invasive species, that is, species moved by humans outside of their historical geographic ranges that establish, spread, and cause economic, ecological, or human health harm (Iannone et al., 2021), can provide authentic problems that are tangible to students while introducing a global, interconnected issue. At the same time, given the relatively small numbers of people employed in natural resources management versus healthcare or engineering (U.S. Bureau of Labor Statistics, 2022), or limited environmental education in U.S. secondary school (*About EE and Why It Matters*, 2015; Jorgenson et al., 2019; Monroe et al., 2019; NGSS Lead States, 2013), natural resources problems may not be salient to curriculum and professional development designers looking to support authentic science learning experiences.

Even when appropriate curricula and professional development for authentic science lessons exist, science and agriscience teachers still face technical and institutional barriers to implementing authentic science practice-based lessons, though they value related professional development materials (Johnson, 2006; Penuel et al., 2007; Zhang et al., 2015). While there is a gap in research on

[1] *Authentic science*, as we use it here, includes several elements of contextualized lessons, based on a variety of sources: *contextualized, everyday* problems, and *relevancy* (Linn & Muilenberg, 1996; Rivet and Kracjick 2008; Sutherland & Markauskaite, 2012)); *inquiry-based* and *practice-based* (Crawford, 2013; NGSS Lead States, 2013); or come from practitioner-focused materials to show *real-world, contemporary,* and *local* problems for relevance (Lee & Butler, 2003; Netherland & Schardt, 2009).

barriers to implementation specifically for high school science teachers, these barriers likely include those faced by many teachers, such as time, collaboration opportunities, and curricular or district restrictions (e.g. deChambeau & Ramlo, 2017; Hancock et al., 1992; Krajcik et al., 1994; Mentzer et al., 2017; Ntemngwa & Oliver, 2018; Spell et al., 2014). Much research on inquiry-based practices for teachers focuses on middle school teachers (Capps & Crawford, 2013a, 2013b; Fogleman et al., 2011; Lakshmanan et al., 2011) or pre-service science teachers (Chichekian & Shore, 2016; Cian et al., 2017; Kang et al., 2013), leaving a gap around in-service high school science teachers.

Therefore, we created a collaborative, also known as co-design (Kelly & Curwood, 2022; Potvin et al., 2023), professional development workshop featuring curriculum redesign to overcome barriers such as time, curriculum constraints, and lack of collaborators teachers report. The goal was to support in-service high school agriculture and science teachers in integrating authentic, locally relevant science lessons in their classrooms. We report the results of interviews with teachers from three years of workshops after they implement the lessons in their classroom to investigate the effectiveness of such professional development at lowering barriers to implementation of authentic STEM lessons.

Literature Review

Authentic learning involves facilitating activities that include real-world experiences (Sutherland & Markauskaite, 2012), providing students with opportunities to develop their knowledge in actual contexts of use (Lee & Butler, 2003). Authentic problems draw students' enthusiasm and develop attitudes for lifelong learning (Linn & Muilenburg, 1996), providing motivation to learn (Hume & Coll, 2010; Rivet & Krajcik, 2008; SENCER, 2014; Spell et al., 2014), using. Lessons on authentic science promote adoption of scientific practices that help students learn attitudes, tools, techniques, and social interactions held by scientists (Edelson, 1997).

While knowledge, skills, and abilities emphasized by content-based curricula are necessary, they are not sufficient to promote student desire to pursue work in STEM fields and become engaged citizens. Students must have awareness of potential STEM careers and envision themselves as capable and enthusiastic participants in those careers (Riegle-Crumb & Moore, 2014). Rural youth in particular may have limited role models and career aspirations in STEM due to their smaller communities with different cultures than urban environments (Bajema et al., 2002). Authentic science lessons can incorporate such role models. For example, natural resource managers and research biologists monitor and manage invasive species in local communities. Invasive species cost governments billions in loss of crops, interrupted recreational activities, and environmental damages (Diagne et al., 2021; Fantle-Lepczyk et al., 2022). They can also be highly visible (e.g., in natural areas, parks, or bordering roads, or featured in the news) and may therefore be observed regularly by students. Using local invasive species as the focus of high school science lessons can provide students with a learning experience that combines issues their communities face in the real world with global scientific content typically presented in the classroom (Balschweid, 2002; Vandenbosch, 2007). Teacher professional development in partnership with university researchers studying invasive species can connect teachers with resources to share more about potential careers as well as highlight current researchers (Bokor, 2016).

Teachers face several barriers in implementing new curricula. Confidence, pedagogical familiarity, and reluctance regarding science curricula creation and adaptation are documented inter-related issues (Chichekian & Shore, 2016). Researchers have also documented teacher difficulties implementing practice-based (previously, inquiry-based) class sessions in tandem with district-mandated content objectives (Johnson, 2006, 2007; Lakshmanan et al., 2011; Loucks-Horsley et al., 2010; Sandholtz & Ringstaff, 2014; Supovitz & Turner, 2000). A lack of available resources and other institutional barriers such as lack of support from principals (McNeill et al., 2021), curricular pressures, and time constraints of standardized testing are also commonly cited problems (Arora et

al., 2000; Bauer & Kenton, 2005; Christian et al., 2021; Fitzgerald et al., 2019; Keys & Bryan, 2001). Finally, teachers repeatedly cite scant collaboration and lesson-preparation time as well as time within curricula for new material (Darling-Hammond et al., 2009; Fay, 2019; Ingram & Golick, 2018; Merritt, 2016) as implementation barriers.

Research on implementation of science practices-based lessons often focuses on student outcomes (Fogleman et al., 2011; Minner et al., 2010), observations of classroom implementation (Chen & Terada, 2021), or the relationship between instructional practice and student achievement (Cairns, 2019). Research tends to overlook the ability of teachers to implement lessons from professional development in their classrooms with fidelity to successfully achieve intended practice-based outcomes. Research on teachers suggests pre-service teachers may learn to use practice-based methods in their university studies, but when they get to the classroom they may perceive inquiry practices as additional work (Cian et al., 2017). Finally, there is a gap in research regarding the potential of innovations in professional development to lower barriers for implementation of practice-based authentic science lessons.

While teacher professional development is essential to improving curriculum implementation and ultimately, student achievement, rigorous data and systematic reviews are only recently emerging on effective professional development (Cribbs et al., 2022; Darling-Hammond et al., 2017; Desimone & Garet, 2015; McGill et al., 2021; Podolsky et al., 2019; Sims & Fletcher-Wood, 2020). Some authors (Sims & Fletcher-Wood, 2020) have reviewed the effectiveness literature and challenged the consensus views of characteristics of effective professional development, arguing instead for rigorous evaluation of interventions as compared to human development research. Moreover, existing individual studies often do not focus on high school science teachers or implementation barriers (Cribbs et al., 2022), or are discipline-specific and need evidence for transferability (McGill et al., 2021). Collaborative curriculum design has shown promise for improving teacher content knowledge (Tammen et al., 2018), but co-design solutions for professional development to overcome implementation barriers have not been widely empirically studied (Darling-Hammond et al., 2017; Desimone & Garet, 2015; Penuel et al., 2007; Zhang et al., 2015). Some solutions proposed include involving peer mentoring (*Academic & Classified Employee Support Mentoring Network @ UW Oshkosh*, n.d.; Cooper, n.d.; Sweeny, n.d.) and opportunities to reflect on practice (Darling-Hammond et al., 2009; Tran & King, 2011).

Conceptual Framework

Overall, our conceptual framework is pragmatic (Thayer, 1982), with the goal of building practical professional development for curriculum designers and teachers. Therefore, we use a bricolage approach (Kincheloe & Berry, 2004). For workshop design, we rely on a combination of co-design within (Kelly & Curwood, 2022), but not of, professional learning experiences (Potvin et al., 2023), elements of Desimone's (2009) pathway model of professional development, and scientist-teacher partnerships (Brown et al., 2014; Tanner et al., 2003). For the latter, though they were not available at the time of the workshop's conception in 2015, we followed many of the principles highlighted by Warwick et al. (2020). Stofer and Flory, along with the predecessor to science educator Albrecht[2], conceived the model for the grant application. Stofer, Flory, Albrecht, Fahey, and Keel finalized the agenda after USDA awarded funding. The 3-day session involved presentations of ongoing invasion ecology research by Flory, Fahey, Keel, Petri, and Kendig, including field trips to their research sites and local sites with non-native plant invasions; teacher lesson goal-setting facilitated by Stofer and Albrecht; 5E lesson planning overview, and in total, a full day of lesson design by teachers in groups

[2] Albrecht's predecessor had left the university by the time funding was awarded. They were contacted but declined interest in authorship on this manuscript.

with input as needed from Stofer, Flory, Albrecht, Fahey, Keel, Petri, and Kendig. See https://osf.io/3ps7d/?view_only=67c70aafb2b041b79f3ec05c590b8e07 for full workshop agenda.

Our conceptual framework and methodology for data collection and analysis are designed to answer questions of interest about teachers' self-perceived changes in practice with regard to a specific type of lesson implementation after professional development. We use a single case holistic study (Yin, 2009) of three years (2017–2019) of participants at a university campus hosted professional development experience; secondary school teacher participants from Florida self-selected as interested in invasive species content for professional development. Data collection and analysis focused on inductive coding of participant interviews based on Desimone (2009) for teachers who had participated in the workshop and indicated interest in the interview after implementing the lesson in their classroom. Our qualitative analysis methodology examined teacher self-perceptions of changes in their own knowledge, skills, and abilities as identified by Desimone but specifically teachers' ability to navigate Desimone's contextual factors perceived as barriers to implementation of an inquiry-practice-based authentic science lesson in the high school classroom.

Purpose and Objectives

To investigate the value of a collaborative curriculum design professional development workshop in helping high school teachers implement authentic locally contextualized lessons, we used the topic of invasive species. We had the following research questions:

1. How did the collaborative curriculum design workshop affect teachers' implementation of authentic science lessons about invasive species?
2. What barriers to implementing authentic science lessons remained after teachers attended the collaborative curriculum design workshop?
3. What barriers to implementing authentic science lessons did teachers feel were lowered by attending the collaborative curriculum design workshop?

Reflexivity Statement

Stofer, Watts, and Hall conducted the data analysis and present their positionality here. Stofer began authentic scientific research during high school in organic chemistry. After years of biology research as an undergraduate and beyond, Stofer switched for several years to practicing science communication and public engagement, working in informal science education developing and offering public and teacher professional development programs. Stofer returned to a PhD in science education over 10 years ago but has retained a practitioner-based research perspective and primarily uses qualitative methodologies to understand authentic science public and teacher professional development experiences in depth. As a faculty member, Stofer led the collaborative design, development, implementation, and evaluation of this study's authentic science collaborative curriculum design workshop, working with the other authors whose expertise covered ecology and science education research and practice. Stofer's lens on the research is heavily focused on supporting practitioners and unearthing practical outcomes to support practitioners' work in authentic science.

Hall first participated in environmental based scientific research throughout high school. During their time as an undergraduate student, Hall studies natural resource conservation with a focus on human dimensions. Their research goals are to better understand the connections that humans have to agriculture and natural resources, and how these connections may be improved. As an undergraduate research assistant, Hall assisted with post workshop data collection, analysis, and writing. Hall does not have any specific connections to the research participants but hopes this study can help to improve the teaching and learning process for science teachers and their students.

Watts is a scientist at heart, coming from a grounded theory research perspective. He started practicing authentic scientific research by working at the Gainesville, FL, VA Medical Center as a technician, where he became fascinated with progressive neuroscience research. Watts began to realize how complex the scientific field is and was encouraged to initiate his own projects and explore new avenues while educating others to do the same. To achieve this, Watts graduated with a B.S. in 2016 with sights set on a master's and Ph.D. in science education. While Watts is not an educator, he shares commonalities with the participants in his desire to hone skills related to synthesizing research. During his master's in science education, Watts worked as a graduate research assistant with Stofer and began his first qualitative education research. While agriscience was a foreign concept to him at first, Watts quickly saw the parallels between his research and Stofer's in professional development for teachers in the pursuit of scientific literacy in classrooms. Additionally, both advocate for the improvement of teacher critical thinking and problem-solving skills while gaining hands-on exposure in a controlled setting. Ideally, these efforts will help inspire further education and cultivate skills that are vital for numerous careers.

Methods

We designed, implemented, and evaluated the results of a collaborative curriculum design professional development workshop for high school teachers funded by the USDA-NIFA Environmental Literacy Initiative program. We used qualitative semi-structured interviews with participants to conduct research on lesson implementation during the school year following the summer workshop. All teachers who attended the workshop received $500 for initial participation as research incentive for pre-post- and other evaluation measures discussed elsewhere, using funding from USDA NIFA. The participants who completed the interview after implementing the lesson received an additional $500 research incentive. The University Institutional Review Board approved the study.

Participants

Fifteen teachers in 2017, 10 teachers in 2018, and 11 teachers in 2019 attended a two-and-a-half-day summer residential workshop on campus at a large southeastern U.S. public land-grant university. Teacher participants came from schools throughout the state, including large metropolitan and small rural public and private schools. Teachers had a variety of backgrounds and variously taught biology, agriculture, chemistry, and environmental science across grades 9-12, including below-, on-, and above-level (i.e., honors, Advanced Placement, etc.) courses. See Table 1.

Workshop

Some of our participants had attended a traditional week-long content-focused invasive species management workshop at the university previously. In fact, the desire for follow-up professional development on this topic prompted our workshop development. We interviewed five teachers from the content-based workshop to guide design of the current collaborative workshop (Stofer, unpublished data).

In Year 1, we invited teachers who had attended the original workshop to apply as a pair with a teacher from their school or district; we hoped the pairing would facilitate collaboration during the school year and introduce additional teachers to the content without requiring them to attend the original workshop. We dropped this requirement in Year 2 and 3 due to teacher feedback about the burden for the application as well as the lack of collaboration facilitated during the school year by the pre-workshop pairings, focusing instead on the collaboration in the workshop itself. As part of the application, teachers described a lesson they planned to revise during the workshop. When we had more applications than we had space to accommodate, we prioritized teachers from counties that had not previously had a teacher attend the workshop.

Our workshop included short presentations on current invasive species ecology research provided by university ecology and biology researchers ranging from undergraduate to faculty level (Flory, Fahey, Keel, Petri, and Kendig); sessions on planning inquiry- and practice-based instruction from education researchers, including Stofer, who facilitated the overall workshop with Albrecht; and field trips to the researchers' invasive species experiments and nearby examples of invasive plant infestations. Approximately half of the total hours were teacher collaborative work to redesign existing lessons to include authentic science practices and local content. Redesign time involved both small-group work and presentations to the whole workshop with ongoing feedback from fellow teachers, education researchers (Stofer and two education graduate research assistants), invasive species education practitioners (Albrecht), and ecologists (Flory, Fahey, Keel, Petri, and Kendig). Teacher lesson plans ranged from single 45-minute class period offerings to multi-semester projects; many involved more than one class period. At the end of the summer after returning home, teachers in Year 2 and 3[3] also collaboratively designed an 11-question student assessment based on state standards and overall invasive species concepts from the workshop via synchronous videoconference.

Data Collection

Following the summer workshop, we asked teachers to implement the lessons in their courses during the school year. After implementing their lessons, we invited teachers to take part in a 45-minute interview asking about the reaction of the students and remaining barriers to implementing the lessons; the initial interviews took place in fall 2017 and continued to summer 2020. For sampling, we attempted to reach data saturation (Mohd Ishak & Abu Bakar, 2014), conduct a census if saturation was not feasible due to classroom context variations, or exhaust the interested participants if neither saturation nor census were possible. In practice, due to the disruptions from the COVID-19 pandemic to in-person instruction, we did not completely reach any of these goals for sampling, though we achieved much overlap in many responses indicative of data saturation.

Stofer, a faculty member in education research with ten years' experience in qualitative research, designed and conducted the semi-structured interviews, which asked about teacher experience with the implementation, barriers to implementation, and the influence of the workshop on teaching using authentic science context and practices. Stofer used a pragmatic lens to develop the interviews based on Desimone (2009), aimed at asking questions that most fit the answers sought rather than testing an existing framework (Thayer, 1982). When needed, questions probed for barriers to implementation as identified from the literature.

Questions in the interview included:

- How did this new lesson plan fit in your curriculum?
- Did you have to do any additional preparation following the workshop before implementing your lesson in the classroom?
- Were there any elements of the CCD workshop that your felt were most helpful in creating these updated lessons?
- What made it difficult to implement the lesson in your classroom?

The full interview protocol can be found at:
https://osf.io/u4kyq/?view_only=aee0382cbeb4455e84f9c1df3e016660.

[3] Teachers from Year 1 were intended to also design the assessment, but a hurricane disrupted most of the state in late summer, so the assessment design did not happen.

Data Analysis

Use of multiple investigators, including Stofer, who designed, conducted, and attended all the workshops and the interviews for prolonged engagement, alongside Flory and Albrecht, who brought outside perspective as researchers not involved with the research, provided triangulation for this analysis. Peer debriefing occurred through multiple submissions to conferences and drafts of this work with co-authors. Together, these activities establish the credibility of our findings. We provide thick, rich descriptions of themes, often in the teacher participants' own words, to establish dependability, and offer context about the teachers to aid transferability. We present evidence from two workshop participants who were unable to implement their lessons at all and five who were extremely disrupted by disasters (hurricanes, a school shooting, and the COVID-19 pandemic) as a type of disconfirming or alternative evidence. Together, these factors establish the trustworthiness of our work.

Hall and Watts conducted the primary analysis under the supervision of Stofer beginning in early 2018 as the initial data came in to follow constant comparative analysis (Glaser, 1965). Hall is an undergraduate researcher majoring in natural resources conservation who joined the project in March 2020, after Watts, a master's student in science education at the time of analysis, left the project. Stofer is a faculty member in agricultural and STEM education with over 10 years' experience in qualitative methods.

Stofer and Watts prepared the initial codebook together using a combination of deductive, expected codes while remaining open to inductive, emergent codes. Expected codes came from the literature on professional development and barriers to implementation as well as from pilot interviews from our previous content-based workshop participants conducted when designing the collaborative curriculum design workshop. During original coding, Watts and, later, Hall, iteratively discussed codes and themes with Stofer during weekly meetings. Together they refined definitions and built themes. Sample codes and sub-codes included:

- Barriers/Constraints – Anything that prevents the teacher from reaching their realized goal, such as time, physical space, or finances, e.g., sub-code *district requirements*
    - District Requirements – District-mandates including content objectives that served as barriers to authentic scientific investigation, e.g., curriculum maps.
- Affordance – The quality or property of an object that defines its possible uses or makes clear how it can or should be used, for example, in the sub-code *collaboration*
    - Collaboration – Where the teacher collaborates or works with other teachers positively, as opposed to proximity issues, which is a constraint

Hall and Watts applied the codebook to the interviews using MaxQDA18 and 20. The full codebook can be viewed at https://osf.io/u4kyq/?view_only=aee0382cbeb4455e84f9c1df3e016660.

Results

Twenty-five teachers (69% of total attendees), including 12 teachers from summer 2017 (80%), seven from 2018 (70%), and six from 2019 (55%) completed interviews after attempted implementation. Eighteen (72%) interviewees, half of the total workshop participants, implemented their lessons successfully as designed; two teachers changed the species content focus from terrestrial to aquatic when a field site at their school became unavailable. Of the remaining seven teachers, four teachers from 2019 had completed implementation and described the partial disruption of their curricula due to the COVID-19 pandemic starting in Spring 2020, one teacher from 2019 had only partial implementation, and one teacher each from 2017 and 2019 were unable to implement their lessons at

all due to the COVID-19 pandemic (2019 teacher) and a hurricane and school shooting (2017 teacher). See Table 1.

Table 1. *Characteristics of Teacher Participants*

Pseudonym	Years of Experience	Courses Taught	Grade Level	Successful Implementation
		2017 teachers		
Eugenia	13	Honors Biology	9–10	Yes
Kelly	33	AICE Environmental Management AP Environmental Science	10–12	Yes
Kira	23	General and Honors Biology	9–10	Yes
Leslie	13	AP Environmental Science	11	Yes
Karrie	10	AP Environmental Science	9	Yes
Jessica	20	Pre-AICE Biology, AICE Biology	9,12	Yes
Kali	16	Biology, Environmental Science	10–12	No[1]
Victor	16	AgriScience Foundations	9–12	Yes
Cindy	15	Biology, Environmental Science	9–12	Yes
William	3	Environmental Science, Honors Biology	9–12	Yes
Alice	10	AP Biology	10–12	Yes
Ethan	18	Biology	9–11	Yes
		2018 teachers		
Amber	4	Environmental Science, Earth and Space Science	9,11,12	Yes
Daniel	15	Integrated Science, Biology	9	Yes
Kathy	16	AP Environmental Science, Honors Biology	9,11,12	Yes
Susan	11	AP Environmental Science	10–12	Yes
Ellie	9	Biology, chemistry, physical science, life science	6–11	Yes
Rita	8	Anatomy, Biology	9–12	Yes
Alexa	10	Biology Environmental Science	9	Yes
		2019 teachers		
Jared	3	Biology	9–11	Yes[1]
Phil	4	AP Environmental Science	11	Partial[1]
Claire	6	General and Honors Biology	10	No[1]
Sandy	20	AICE Environmental Management	10–12	Yes[1]
Jill	19	General and Honors Biology	9–12	Yes[1]
Elsa	4	Honors Biology	10	Yes[1]

Note. [1] Disrupted implementation due to natural or human-caused disasters.

For the first research question, we examined the general ways in which the collaborative curriculum design workshop was beneficial for teachers in implementing authentic science lessons. The goal of implementing these authentic science lessons is to expose students to real world scientific issues and practices in the classroom. Many teachers were able to successfully implement their lessons and tell us about the reactions of their students. When asked about her lesson, Rita (2018)[4] said, "it really opened their eyes to a lot of things that they see in everyday life, but never knew what it meant." She

[4] All names are pseudonyms.

also told us the lesson was a good change of pace for her students, who were normally just memorizing content for their tests; with Rita's revised lesson, she noted,

> [my students] had to actually think about the problem and the solutions in the future. And I think a lot of times they don't make that connection in science. I think they just like to memorize what they need for the test.

Daniel (2018) said his lesson allowed him to go more in depth on the topic in his on-level biology course because his students were able to connect the concepts from the classroom to examples they see in their communities. He said it successfully created critical thinking moments for his students by engaging them in local issues, noting, "I don't know if I would have seen that critical thinking moment we talked about if it wasn't for this local situation that we could see with our own eyes." Jill (2019) recalled the discussions her students had about management strategies, invasive species, and ecological processes, even though her lesson was interrupted by COVID-19. She thought it was important that a lesson like this could instill the idea that one day these students could be community members who will be responsible for making decisions on environmental issues. Sandy (2019) told us her students usually have a hard time figuring out invasive species management strategies because of the critical thinking strategies involved; however, she reported her students struggled less with the revised lesson, so she will be continuing the new approach in future years. Ellie (2018) said the implementation of authentic science lessons in the classroom has been very beneficial for her and her students. She reported plans to add authentic components to all her lessons due to the improvement she has seen with her students. It is noteworthy that she has a great deal of curriculum flexibility as a private-school teacher.

Teachers reported they benefitted from the learning experiences offered at the workshop. According to Ethan (2017), there are limited options for high school science teachers to attend professional development workshops in his district. He claimed this workshop helped him learn new things and that it felt good to be on the other side of the blackboard. Many teachers discussed the value they found in the field trip elements of the workshop. Phil (2019) noted the trips made the workshop experience unique compared to others he had attended; he also added that the field trip was a good experience because the teachers got to see research examples of the species discussed at the workshop. Another teacher, Jessica (2017), said she liked the hands-on aspect of the workshop because it added to her knowledge, saying, "the field trips were nice too because we got to see actual invasive species, I didn't know the [plants the facilitators] were pointing out." Kali (2017) also spoke of the ways the field trips stuck out as an important part of the workshop for her. She said, "the dynamic makes a difference… being able to go into the field was something that I very much enjoyed…and sometimes, depending on the way the content is presented, it can determine how engaged you are." Kathy (2018) told us she was able to look back on the field trip and the research experiments when explaining current invasive species issues to her students.

Barriers Remaining After the Workshop

Our second research question focused on what remaining barriers teachers faced in the classroom following the workshop, and how these barriers prevented teachers from implementing authentic science lessons. Teachers mentioned facing many barriers identified in the literature, plus one, physical proximity for collaboration, which we did not identify in the literature previously. In particular, teachers discussed in-depth the following themes related to barriers: *time*; *district mandates; standardized testing, collaboration with other educators,* including both time and proximity*;* and *access to nature.* Further discussion of each of these barriers follows.

Out of the 25 teachers we interviewed, 20 reported time as a constraint to the implementation of lessons in their classroom; of the five who did not, two were teachers from 2019 who experienced disruption from COVID-19 (See Table 1). Teachers reported time constraints were a difficult obstacle

to overcome, “my biggest enemy ultimately” (Amber, 2018, on-level environmental science). For many of the teachers, time constraints increased when combined with other reported barriers. Jared (2019), an on-level biology teacher, spoke of his difficulty trying to balance his workshop lesson plan, course standards, and limited time. He said, “there is a standard on invasive species…my only concern was would I have the time for this specific standard to be covered.” Cindy (2017) and William (2017), both biology teachers, ran into a similar problem. Cindy claimed her only roadblock was time because their curriculum maps are not very flexible. Curriculum inflexibility on top of preparing students for standardized tests can make time more of a constraint. William added to this by discussing his experience switching from teaching a course with no standardized tests to teaching Biology, which has an end of course exam. He noted the switch was difficult because the standardized test limits his time preparing students with certain content. Daniel (2018) added to this sentiment, saying, “the last month and a half are a lot of testing, a lot of missing class… that’s where the invasive species lesson would take place.” He also mentioned that during the standardized testing time of year he has to do a lot of picking and choosing when it comes to teaching certain topics that seem important for testing.

Another time related barrier teachers brought up was the limited time they have for lesson planning, especially with other teachers. Ellie (2018) told us, “It’s the writing the lesson plan part that’s killing me because it’ll take me 48 hours to do one class worth of lessons for one week.” This lack of time for lesson planning can both contribute to and be affected by teachers’ inability to collaborate with their colleagues. Rita (2018), a biology teacher, mentioned she only gets about 45 minutes a week to try to get together with other teachers for collaborative lesson planning. Time and physical proximity barriers intersect to create even more difficulties for teachers. Several teachers told us that they were located far from teachers of the same subject, even within the same campus. Eugenia, an honors biology teacher (2017), noted this limitation, “you’re only meeting 45 minutes basically once a week, three weeks a month … if you’re not physically near the people you need to have those conversations with, [communication] tends to not ever happen.” Kelly (2017), who teaches Cambridge AICE learners, also discussed physical constraints on collaboration, especially for new teachers to an area, saying, “there was no one at my school ... I think it’s great to work with somebody else just to bounce ideas off each other and develop something.”

Finally, access to nature and time for authentic science lessons were barriers reported by teachers. Ethan (2017) described his difficulty implementing authentic science lessons throughout the school year because they take longer. He said, “that’s the big barrier is, it takes three times longer. So, it’s kind of like too much to cover.” Susan, an AP Environmental Science teacher (2018), identified another barrier she faced when trying to implement authentic science lessons in her classroom: little to no access to nature. “I wanted them to do this stuff in the field… it’s frustrating, not being able to do more, but living in the middle of a city and then the constraints of having high school kids.” William and Cindy, who mentioned time as their biggest barrier, ran into unexpected disturbance of the natural area they had planned to use; despite an inflexible curriculum map and associated time constraints, they were able to shift the lesson focus from terrestrial to aquatic species and finish the implementation successfully.

Barriers Alleviated by the Workshop

For the third research question, we examined which barriers to implementation our collaborative curriculum design workshop alleviated for teachers. Although there were some remaining barriers, teachers noted the workshop diminished or alleviated several of those surfaced in research question 1: *time,* specifically time to design or revise lessons; *collaboration*; and *content knowledge.*

Time. Time was a barrier reported by almost all teachers in all three years, and lack of time often caused or confounded additional barriers. Alexa (2018) explained that the workshop allowed her to feel adequately prepared to implement the lesson in her classroom. She said the collaboration with

other teachers and the information provided at the workshop resulted in very little additional preparation during the school year. Amber (2018), who previously noted time as her biggest barrier to implementation, spoke of the way the workshop helped alleviate both time and collaboration barriers, saying, "when you gave us time [to work on the lessons] and … actually having to put it all together and present [our ideas to other teachers], that was helpful." Amber had a similar lesson plan to Alexa. When asked whether she had to make any revision or additional preparation after the workshop, Amber responded, "I think the time that you gave us in the workshop was helpful in making sure everything was pretty much set." Some teachers, like Susan (2018), took a different approach and planned for their students to design and carry out experiments using local invasive species. Susan, whose lesson plan involved students growing invasive plants and measuring growth rates, said, "the only time I really needed was for the actual setting up of the experiment… I got a lot done at the workshop; I had all the lesson plans laid out."

Collaboration with Other Teachers. Several teachers found the collaboration, especially with other teachers, valuable. Karrie (2017) spoke of the benefits of making this new connection. The collaboration aspect of the workshop can alleviate some difficulties teachers face if they lack collaborators at their own school, introducing teachers to new potential collaborators at other institutions within and across districts. Even though Karrie and her collaborator, Kelly, are at different schools, both teach AP Environmental science, and they work together and communicate frequently. Karrie said, "I think that's a big deal, being able to ask other people's questions, you know, and get their ideas and just see things from different perspectives." Amber (2018) told us that having the time and ability to bounce ideas off other teachers that work at other schools with different kids was the most beneficial aspect of the workshop. As Ethan (2017), a middle and high school biology teacher put it, "I don't have that many contacts … that are going to understand what I'm talking about … [Peer discussion] was really, really helpful for someone like me who doesn't have anyone at my school to collaborate with."

Collaboration with Researchers and Education Practitioners. At the workshop, teachers worked with researchers and professionals in the fields of education and invasive species. Like the collaboration with other teachers, multiple workshop attendees found this approach beneficial. Ethan (2017) told us that having the workshop faculty around while creating lesson plans aided him in not getting stuck and added to the collaboration aspect of the curriculum design portion. Similarly, Jessica (2017) said, "[the workshop facilitators and science faculty] were coming around and helping me… you know, having all the expertise on one room was what really made it, made it worthwhile." Claire (2019) added the collaboration not only helped her come up with ideas and create lesson plans, but it also encouraged her to add more relevant scientific concepts. Claire remarked, "having other teachers providing feedback and university personnel providing feedback and just having that nudge to include more pure science… that's always valuable." Claire is one teacher disrupted by COVID who was unable to implement her originally designed lesson.

Content Knowledge and Confidence in the Classroom. Some teachers noted an increase in their own knowledge and confidence levels as a teacher after attending the workshop. Kali (2017), originally from Michigan, told us the workshop increased her familiarity with the local ecology and invasive species saying, "it helped me to be more knowledgeable either presenting the information or the content to my students." Kali's response was especially salient as she was unable to implement the lesson as planned in the 2017–18 school year and then changed subject matter she taught in subsequent years; even though she no longer had immediate use for the complete lesson she designed, she noted the confidence boost provided by the workshop was still very helpful as a new teacher in this area. Victor (2017) said he was able to learn about areas that are geographically different than his part of the state and his local invasive species. He told us this was an important thing for him to bring back to the classroom because not all his students will stay in his part of the state. Others claimed creating a lesson plan at the workshop made them feel confident when returning to the classroom to

implement it, though they had not identified confidence as a barrier explicitly. Rita (2018) said she was able to learn a few new things and expand her knowledge. She then said regarding her confidence levels, "after going to the workshop…I felt confident. I already had a lesson plan made and I felt confident in what I could do and bring back." Improved confidence was not limited to teaching invasive species content or the lesson created at the workshop. Claire noted attending the professional development workshop made her feel more comfortable with creating and revising lesson plans in general. She reported the experience has helped her become much more comfortable when creating content to bring into her classroom and managing the curriculum she plans to cover throughout the year.

Discussion, Implications, and Conclusions

Our research offers several contributions. First, we document empirically the barriers high school teachers face when implementing authentic science lessons after professional development, including identifying a new barrier not in the literature. Second, we demonstrate that a workshop based on literature-recommended principles of collaboration can lower some of those barriers, including time, lack of collaborators at their schools, and standardized testing. However, it is important to note that these barriers were intertwined for many teachers and highly dependent on local constraints from school districts.

Many of the barriers to implementing science lessons our teachers reported are similar to those demonstrated previously for middle school teachers (Johnson, 2006). These barriers include time constraints, district requirements, and standardized testing. Additionally, we note that physical proximity could play a role in affording or constraining collaboration, which we have not seen reported in the literature. A lack of physical proximity may be a particular problem for high school teachers who teach more specialized science courses or who are at smaller institutions and where they are the only teacher offering any science courses.

While the barriers identified both by our teachers and in literature cannot be completely alleviated by a professional development workshop, we found that these barriers can be diminished. Providing teachers with time and space to plan, valuing their expertise as collaborators, introducing them to new collaborating teachers and researchers, and helping them imagine ways to address content in the scope of authentic local problems all added to teacher success in implementing the revised lessons, as suggested by professional development recommendations (e.g., Johnson, 2006) and our conceptual framework (Desimone, 2009; Potvin et al., 2023; Tanner et al., 2003). Our evidence indicates that teachers need these opportunities and yet still do not get adequate professional development of this type focused on authentic science lesson design.

Our evidence also demonstrates how these barriers do not occur in isolation and vary across districts and even schools within the same district. Simply providing teachers time is not a solution if they do not have collaborators to help them reflect and refine their ideas; providing curriculum flexibility is not a solution if teachers do not have adequate time to design lessons. Therefore, we echo Garet et al.'s (2001) recommendation of professional development involving collective participation of personnel from the same job site or district, while partnering with universities to retain university campus features such as access to active, authentic research sites.

Some teachers found the opportunity to learn about the struggles and triumphs of other types of students most valuable. While ideally teachers would have physically proximate collaborators to share successes and challenges and co-design in the long term, we struggled to recruit teachers from the same district to come together to the workshop and dropped that requirement in Year 2. We found teachers in Year 2 and 3 still reported value in the co-design aspects of the professional development. Teachers especially noted the benefits of working collaboratively with other teachers and researchers to create their lesson plans. Providing teachers with the time and resources to work with colleagues

allowed them to approach lesson plans and content from different perspectives. Collaboration at the workshop also alleviated the physical proximity barrier teachers mentioned. Teachers made new connections across different schools and districts both to create their lessons as well as to stay in contact with each other following the workshop. This latter affordance also supports a hybrid model for professional development that brings together teachers from nearby schools but makes use of off-site features of partnering with active researchers. With the additional capacity for online collaboration afforded by the COVID-19 pandemic, physical proximity may mean not simply in-person collaboration but synchronous, though virtual collaboration. Such variations, including how cross-district co-design may compare to within-district co-design, could be explored in future research.

Our finding that teachers improved their content knowledge aligns with Tammen, et al. (2018) and suggests our design can provide benefits beyond the single lessons redesigned in the workshop. Collaboration with university researchers and inclusion of field trips for teachers were both noted to have increased knowledge of local invasive species. Improved content familiarity along with pre-prepared lesson plans had a positive impact on the confidence of teachers when returning to their classrooms. Attending professional development workshops that focus on providing teachers with the time, space, and resources to create lesson plans can also increase teacher confidence and comfort with lesson creation, which can then be applied to other lessons, content, or classes. Our teacher with the fewest external constraints based on her position at a private school demonstrated the transferability of the collaborative, contextualized, practices-based approach to science education we facilitated.

Alleviating barriers for teachers makes the implementation of authentic science lessons easier. At the workshop, we gave teachers resources to create authentic science lessons. These resources not only relieved barriers, but they also made the general authentic lesson planning easier (Chichekian & Shore, 2016). Teachers were provided with time, space, expert opinion, and opportunities for collaboration, which all contributed to the success of lesson implementation and prevented teachers from having to do extensive or time-intensive additional preparation or revisions. The workshop also equipped teachers with the content knowledge and information to create lessons surrounding issues related to local invasive species. Engaging students in science lessons that combine real world issues on a local scale with authentic science practices can increase engagement and critical thinking.

Limitations of the present work include the single case study in one U.S. state of one professional development experience, the self-selection of teachers to apply for the workshop and complete the post-workshop interviews, and the qualitative and self-report nature of the barriers teachers experience. Despite these limitations, in addition to supporting previous work through additional evidence of barriers to curriculum implementation, we suggest our work contributes rich transferable qualitative evidence for effective elements of professional development to improve the likelihood of in-service high school science teachers implementing authentic science lessons in their classrooms. Additionally, our work can be used to add to theory for the elements of our conceptual framework including co-design (Potvin et al., 2023), scientist-teacher partnerships (Tanner et al., 2003), and pathway professional development (Desimone, 2009).

Researchers need to directly compare content-focused vs collaborative co-design workshops after lesson implementation to determine whether, in what situations, and for whom each model of professional development might be most appropriate. Continuing to ask teachers about the barriers they face and their confidence with authentic science lesson planning through quantitative surveys could pinpoint areas to address specifically in future co-design workshops. Future research could also examine teacher workshop experiences from the perspective of andragogy (Knowles, 1978) and the scientists' perspectives on their learning from co-design with teachers (Knowlton et al., 2015). Comparing this workshop design across content foci will lend to the credence of its broad applicability in agriscience. Finally, while we collected teacher artifacts such as lesson plans for

sharing at the end of the workshop, we could compare teacher lesson plans, worksheets, slide decks and other artifacts before and after the workshop as well as after implementation in the classroom to teacher interview responses for triangulation of data.

We demonstrate the power of high school science practice-based teacher professional development workshops that emphasize collaborative planning time for teachers while incorporating content presentations, similar to previous recommendations for teacher professional development writ large (Darling-Hammond et al., 2017; Desimone, 2009; Desimone & Garet, 2015; Garet et al., 2001; Kelly & Curwood, 2022; Potvin et al., 2023; Tanner et al., 2003). Since collaborative planning remains relatively underused in professional development, we suggest professional development leaders clearly emphasize the nature of the workshop activities upfront, (i.e., during application or registration) to prepare teachers for such an experience. One way to assist with this goal would be to involve more teachers and even students, the ultimate stakeholders, directly in short-term workshop and longer-term professional development planning, as another element in co-design (Potvin et al., 2023). Ultimately, co-design both enhances teachers' confidence with the underlying material while providing time for planning, reflection, and feedback, to create and iterate authentic science lessons with local context.

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