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Supporting Students' Science Content Knowledge and Motivation through Project-Based Inquiry (PBI) Global in a Cross-School Collaboration

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Abstract: Inquiry is featured prominently in the Next Generation Science Standards (NGSS) as a promising pedagogical approach. Building on current conceptions of inquiry, a mixed-methods research design was used to explore the effects of Project-Based Inquiry (PBI) Global on student science content knowledge, motivation, and perspectives related to inquiry in a cross-school collaboration. The data sources included pre-/post-tests on science content and student motivation (n = 75), transcripts from student focus groups (n = 26), and students' multimodal learning products (n = 18 teams). The quantitative findings indicated School B students were more motivated by the project than School A students, which mirrored student performance. The student focus group findings generated three themes: constructing empathy, learning for impact, and navigating challenges. The discussion focuses on an integrated view of what students gained and did not gain from the PBI Global experience, including a nuanced explanation of how motivation and content knowledge may be influenced by student experiences and school contextual factors during PBI Global. Implications for instructional practice highlight how relationship building, mutual respect, and consensus making are essential components of constructing cross-school collaborations and the importance of integrating instructional frameworks with teachers and students. Future research will focus on investigating the effects of PBI Global on student learning in cross-school partnerships through experimental-designed studies, and the systemic and structural barriers to scaling cross-school inquiry-based learning.

Keywords: inquiry-based learning; collaborative inquiry; Project-Based Inquiry (PBI) Global; cross-school partnerships; student motivation; science content knowledge

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1. Introduction

The teaching and learning of science, technology, engineering, and mathematics (STEM) receives considerable attention among educators, researchers, and policymakers due to the powerful influence foundational STEM experiences play in educational and economic advancement [1]. According to the U.S. Department of Education [2] report STEM 2026: A Vision for Innovation in STEM Education, the need for STEM knowledge and skills will continue to grow and "graduates who have practical and relevant STEM precepts embedded into their educational experiences will be in high demand in all jobs" (p. i).

A pedagogical approach that aligns with the real-world relevancy and career-readiness focus of STEM is inquiry learning [3]. Twenty-five years ago, the National Research Council [4] defined inquiry as an iterative, student-centered learning process that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results (p. 23).

In particular, inquiry learning is a long-standing tradition in science education [5] and is prominently featured in the Next Generation Science Standards (NGSS), specifically in the Science and Engineering Practices dimension [6].

In the following study, we explored how a specific interdisciplinary inquiry learning approach influenced students' science content knowledge and motivation through a cross-school partnership. Students from two different community contexts collaborated across time, space, and culture to solve enduring global challenges, specifically UN Sustainable Development Goal (SDG) 6: Clean Water and Sanitation.

2. Theoretical Background

Our theoretical framework is organized around sociocultural views of learning. Constructivism advocates that knowledge is actively constructed by the learner [7–9] and holds that information generation and meaning making are based on personal or societal experience [10]. Inquiry-based learning emerged from constructivist learning theories and has been encouraged for over a century [11].

Dewey [12] contended that scientific knowledge is the product of inquiry and recommended a shift in science education from emphasizing facts during instruction to cultivating thinkers [13–15]. Krajcik and Blumenfeld [16] also asserted that students "learn and apply important ideas in the discipline" while engaged in inquiry toward answering a driving question (p. 318). Science education has continued to develop and implement curricula based on constructivist theories and inquiry-based approaches to learning [17]. Inquiry-based learning is established through student questioning and the exploration of new knowledge for the purpose of integration with prior knowledge and skills. With an inquiry-based approach to learning, teachers do not establish themselves as lecturers or purveyors of information; rather, students are positioned as leaders in the unfolding of their own education.

Moreover, inquiry-based approaches in the classroom are valuable because they allow students to increase science content knowledge, as well as practice skills needed in the 21st century workplace [18]. Inquiry-based learning is a process of discovering new causal relations, with the learner formulating hypotheses and testing them by conducting experiments and/or making observations [15]. Through open-ended group work (components of inquiry), students engage in activity that closely reflects scientists' research processes [13,19]. Thus, Barrow [13] asserted that teachers of all grades should value inquiry. In fact, there is a diverse array of studies that underscore inquiry's effectiveness in the middle and secondary education levels [20] and several research studies that support the effectiveness of inquiry-based learning as an instructional approach appropriate for students of all ages [21,22].

An essential component of inquiry is appropriate instructional scaffolds that can support student thinking as they are learning new concepts. Often, inquiry as a pedagogical tool is established through an overarching, or guiding, problem apportioned into smaller components for scaffolding [23]. Successful inquiry-based learning happens when teachers act as guides who "nudge" students forward into their "Zone of Proximal Development" as students and teachers collaborate and problem solve in long-term projects [24]. In a cross-school collaboration, like the one in this study, instructional scaffolds play an important role in nurturing students' motivation and science content knowledge through shared expectations for communication and knowledge construction.

3. Literature Review and Research Questions

Our literature review involves an overview of research outcomes related to project-based learning (PBL), a subset of inquiry-based learning. We highlight studies demonstrating PBL's impact on learning across disciplines and grade levels. We then provide an exemplar PBL approach that we call Project-Based Inquiry (PBI) Global [25], followed by prior research results related to PBI Global.

3.1. Research Outcomes of Project-Based Learning (PBL)

PBL is experiencing renewed attention in the educational landscape. Researchers have defined PBL in a variety of ways over the years. The Buck Institute for Education [26] defines PBL as "a teaching method in which students learn actively by engaging in real world and personally meaningful projects" (np). Wilhelm et al. [3] examine the role of the teacher in PBL, noting the importance of instructional milieu in successful project-based endeavors. Across various conceptions of project-based approaches, core features include: (1) a challenging problem or question [3,27]; (2) student voice and choice; (3) authentic community engagement; (4) benchmark lessons/activities [28]; (5) reflection, critique, and revision [26]; and (6) public product.

One of the long-standing premises drawn from a Deweyian perspective is that PBL, as a contemporary example of learning by doing, increases student motivation [29,30]. Research focused on the student outcomes of learning through project-based approaches is promising in terms of academic content knowledge as well [31]. One study of high school students with teachers who participated in the Buck Institute PBLWorks professional learning demonstrated statistically significant growth in reading, math, and history when compared to peers whose teachers did not participate in professional learning [32]. As the most definitive experimental study of PBL to date, Duke et al. [33] conducted a cluster randomized control trial of second-grade students engaged in PBL in which students demonstrated higher growth in social studies content and informational reading. Although this study took place with elementary students, it demonstrates that PBL can result in student learning gains as opposed to just motivational gains as other studies have demonstrated. Moreover, Craig and Marshall [34] found, through a randomized control study of secondary students at a nationally recognized model STEM school, that students taught through PBL matched the performance of conventionally taught students for the 11th-grade science and 9th-, 10th-, and 11th-grade mathematics achievement measures and exceeded the conventionally taught students' performance for the 10th-grade science achievement measure.

A limitation in the literature is how PBL can be implemented collaboratively across school sites. In their metasynthesis of PBL, Minner et al. [20] found that only 6% of PBL studies (8 out of 138) encompassed multiple settings. In this study, we examine student motivation and science content knowledge outcomes throughout a cross-school PBL collaboration, using PBI Global.

3.2. Project-Based Inquiry (PBI) Global: A PBL Instructional Exemplar

As a type of PBL, PBI Global has a defined, five-phase, collaborative inquiry cycle and focuses students' research on one or more of the UN Sustainable Development Goals (SDGs). An impact-driven pedagogy, PBI Global alters traditional classroom instruction through a hands-on, minds-on approach to learning, encouraging students to make sense of their world, locally and globally, through inquiry.

PBI Global Cycle. PBI Global has five phases (see Figure 1), including composing a compelling question, gathering and analyzing sources, creatively synthesizing claims and evidence, critically evaluating and revising research findings, and finally, communicating (i.e., share, publish, and act) learning products to a larger audience. Typically, prior to developing compelling questions, students engage in background knowledge building by reading a narrative or informational text. PBI Global has three distinguishing inquiry cycle features that differentiate it from other models of inquiry-based learning, such as the 5Es instructional model [35], the C3 Teachers Inquiry Design Model [36], and the International Baccalaureate inquiry process [37]. Those features are (1) a focus on the UN Sustainable Development Goals as the framework for learners' solutions-oriented inquiry; (2) an interdisciplinary approach to the inquiry cycle; and (3) an explicit call for students to take social action as a result of their inquiry findings.

Figure 1. Project-Based Inquiry (PBI) Global. From [25].

UN Sustainable Development Goals. Through PBI Global, teachers and students focus inquiry-based interdisciplinary instruction and learning around global themes embedded in the UN Sustainable Development Goals (SDGs). These 17 goals set forth a "shared blueprint for peace and prosperity for people and the planet" [38]. For the purposes of this study, Goal Six: Clean Water and Adequate Sanitation served as the PBI Global thematic focus. In the United Nations [39] Sustainable Development Goals Report, UN Secretary-General Antonio Guterres shared that 29 percent of the global population still lacked safe drinking water while 61 percent were without adequate sanitation (p. 4). Access to clean water and adequate sanitation has wide-ranging consequences in terms of health outlook, gender, ethnic and racial equity, peace and conflict, education, economic development, and environmental impact. Thus, a PBI Global initiative focused on Goal Six afforded students and teachers diverse, complex, and impactful opportunities for inquiry.

Prior Research Results from PBI Global. PBI Global has been implemented in a variety of instructional contexts, including US middle-grade classrooms [40] and high school classrooms [41]. Moreover, we facilitated PBI Global to explore how students are motivated to transform their local and global environments [42,43]. In these studies, we found that students and teachers engaging in PBI Global experienced growth in educational cosmopolitan outlooks to varying degrees. Specifically, teachers became "actively involved in constructing themselves rather than being [solely] acted upon in the midst of a change process" [42]. With students, the development of educational cosmopolitan outlooks, specifically Wahlström's [44] four cosmopolitan capacities of self-reflexivity, hospitality, intercultural dialogue, and transactions of perspectives, was tied to explicit global connections facilitated by the teacher during the project, such as setting the expectation for students to design "compelling questions that necessitate a comparative cross-cultural response" [43].

Two recent studies on PBI Global illustrated how the cycle can be applied in high schools. In the first study [41], we assessed how engaging in critical inquiry through PBI Global fostered social action with high school students. Employing a collective case study approach, we focused on six diverse students from 2 of the 18 teams who participated in a PBI Global examining global water and sanitation over a two-month period. Data sources included semi-structured student interviews, students' posts and uploads in a shared writing space, and students' multimodal products of learning. Three themes emerged from the analysis across the data sources: (a) synergistic collaboration, (b) critical analysis and creation of multimodal texts, and (c) understanding global and local interdependence to take social action. The discussion illuminated how students' engagement in critical inquiry and social action amplify Freire's [8] idea of critical consciousness, which represents one's ability to intervene in reality in order to change it.

In the second study, we conducted a PBI Global addressing global hunger with a rural school [45] through which we described the challenges associated with junior high students developing critical, digital, and global citizenship competencies. We found that the students acquired new perspectives through the PBI Global cycle, although the teachers observed that their school culture was oftentimes at odds with the goals and philosophy of the project.

The current research builds on and extends initial findings with PBI Global by assessing ninth-grade students' science content knowledge and motivation in a cross-school collaboration. We addressed the following three research questions:

(1) How does inquiry through the PBI Global cycle support student science content knowledge in a cross-school collaboration? (QUANT)
(2) How did the students' motivation change after participating in PBI Global in a cross-school collaboration? (QUANT)
(3) How do the students' perspectives of the PBI Global cycle, as a specific inquiry-based learning process, evolve throughout the project? (QUAL)

4. Materials and Methods

4.1. Research Context and Participants

Prior to engaging with participants, this research was approved by our institute for higher education's Institutional Review Board (IRB), which includes student assent and parental consent. Studies were conducted with two high schools with diverse student populations in the southeastern United States. School A, which is in an urban community, has 248 students, including 43 students who identify as African American, 29 as Hispanic, 135 as White, 28 as Asian, and 12 as Multiracial. Additionally, 15% of the students are eligible for free and reduced-price lunches and 50% of the students are first-generation college-goers. School A has received national recognition for their magnet program, including their emphasis on collaborative learning through the Engineering Design Process. School A also has a longstanding tradition of implementing grade-level projects with students across disciplines

Conversely, School B is relatively new to PBL and is situated in a rural community. School B's magnet focus is innovation and leadership; the school has a total of 150 students. Demographics include 40 students who identify as African American, 17 as Hispanic, 84 as White, 1 as Asian, and 8 as Multiracial. A total of 38% of the students are eligible for free and reduced lunches and 80% of the students are first-generation college-goers.

Both schools were selected for participation based on expressed interest from the principals and lead teachers at each school. We intentionally selected schools that would allow an entire grade level to participate in the project. All 9th-grade students from each school participated in the study.

For this project, we worked with 11 teachers (science, math, English, social studies, and Spanish) and two principals at the two schools. The two schools collaborated for four weeks to implement the PBI Global cycle across time, space, and community cultures on the topic of UN SDG Six: Clean Water and Adequate Sanitation. Prior to compelling question development, students read *A Long Walk to Water* by Linda Sue Park in order to build background knowledge on the global water and sanitation context, specifically in South Sudan.

4.2. Design, Data Sources, and Procedures

A mixed-methods research convergent parallel design [46] was used to explore the effects of PBI Global classroom implementation on student science outcomes and motivation. Quantitative and qualitative data sources were collected concurrently and analyzed separately, as shown in Table 1. The data were collected before, during, and after the PBI Global cycle was implemented by the teachers; the project duration was four weeks.

Table 1. Data Collection Measures.

Project Phase	Quantitative Data (RQ 1 and 2)	Qualitative Data (RQ 3)
Pre-Implementation of PBI Global	• Pre-test: Researcher-developed content assessment • MUSIC® Inventory	• Focus groups: Student expectations of PBI Global cycle
During Implementation of PBI Global		• Focus groups: Student experiences with PBI Global cycle
Post-Implementation of PBI Global	• Post-test: Researcher-developed content assessment • MUSIC® Inventory	• Focus groups: Student reflections on PBI Global • Students' multimodal learning products

Quantitative measures. A total of 47 students from School A and 28 students from School B participated in the quantitative assessments (total n = 75). First, students' science content knowledge of global water and sanitation issues was assessed through a researcher-designed content test consisting of 20 multiple choice questions. The researcher-designed science content knowledge test is available as Supplementary Material accompanying the article. To design the test, we mined item banks, such as the National Assessment of Educational Progress (NAEP) Question Tool [47] and the American Association for the Advancement of Science (AAAS) 2061 Science Assessment Item Bank [48], for appropriate items related to the grade-level earth science concepts to be targeted through the global water and sanitation theme. The Cronbach's Alpha for our assessment is 0.76, which indicates an acceptable degree of internal consistency [49].

Second, students completed a written survey on factors that affect student motivation through the MUSIC®Model of Motivation [50,51]. We use this Inventory to define motivation within our study. The MUSIC®Inventory does not measure constructs related to music, rather it measures the five key components of the MUSIC®Model of Motivation: eMpowerment, usefulness, success, interest, and caring. Researchers have gathered a variety of validity evidence for the Middle/High School Student Version of the MUSIC®Inventory, including evidence for internal structure and reliability [52–55].

Qualitative data. We conducted two focus groups per school with 5 to 7 students in each group; 26 students across both schools participated (School A, n = 12; School B, n = 14). These students were selected by their teachers, using criteria of ethnic, racial, and gender diversity to ensure we had a representative sample of voices in the focus groups. These focus groups transpired before, during, and after PBI Global implementation to ascertain student expectations and experiences with PBI Global. The student semi-structured focus group questions are available as Supplementary Material accompanying the article. Additionally, students' multimodal learning products from all 18 teams were captured via photograph at the PBI Global showcase. These learning products included trifold displays and water filtration models.

4.3. Data Analysis

To answer the first research question, the quantitative data from the pre- and post-tests were analyzed using t-tests to determine if there were changes in students' science content knowledge after participating in PBI Global. Similarly, to answer the second research question, we utilized t-tests from data collected on the MUSIC®Inventory to determine if there were changes in students' motivation.

For the qualitative data analysis, we employed an iterative coding process to fully understand and analyze the data. The transcripts were open-coded [56,57] by two of the researchers. Using the third research question as a guide, the researchers individually coded one student focus group transcript and then met to reconcile differences. The coding process continued until all transcripts had been analyzed and differences reconciled with 100% agreement between the two researchers. Themes emerged relating to students' expectations and experiences in PBI Global. Table 2 includes themes, sample codes, sample definitions, and sample quotes from our coding process.

Table 2. Sample Code Book.

Themes	Sample codes	Sample definitions	Sample quotes
Constructing empathy	Understanding conditions globally	Demonstrating empathy in regard to the human aspects of global challenges.	"I think all the statistics I learned on how many people are struggling related to water in the world was the most important thing I learned. It made me feel really grateful for what I have in this country."
	Working in diverse groups	Understanding and valuing the perspectives and contributions of the different people in their group.	"And I think like collaborating with other schools also gives you a different perspective about what they know and what we know because like they might've been taught something else and being able to see like maybe if they have an idea about how we could save the Earth better, then we could take that into account and get it more widespread."
Learning for impact	Relevance of instructional content	Acknowledging the importance and interconnectedness of concepts pertaining to water and sanitation.	"I'm learning that clean water and sanitation, it's like a major part of marine life and stuff. Like without the clean water, like marine life wouldn't thrive and we wouldn't be able to get food from the seas and stuff."
	Value in showcase	Expressing merit in sharing inquiry findings with an audience.	"So, it's been good cause each group is doing a different thing, and we're all learning new things. And of course, when we present it, we're going to learn from the other groups."
Navigating challenges	Collaboration	Obstacles students experienced related to collaboration and communication.	"Working in groups can be difficult. These are not people we know. So, we don't really have a foundation on how we like to communicate with each other."
	Project expectations	Challenges students experienced related to confusion with or difficulty fulfilling project expectations.	"I guess for a lot of the different classes it feels like we're working at different paces . . . It feels, like, very disconnected."

Researchers used data triangulation [46] to increase the credibility of analysis and to help inform a fuller picture of students' evolving perspectives on PBI Global. Once themes were identified in focus group data, two researchers returned to student multimodal learning products to add nuance in response to research question three.

5. Results

5.1. Quantitative Results

On the science content knowledge assessment, averaged across both schools, students scored 62.66% on the pre-assessment and 64.11% on the post-assessment. However, when analyzing the data by schools, (See Table 3), School B showed a significant increase from pre-assessment (μ = 48.83, σ = 16.95) to post-assessment (μ = 54.50, σ = 16.98) ($t_{28} = -2.403$, $p = 0.023$). School A showed a nonsignificant decrease from pre-assessment (μ = 71.44, σ = 15.14) to post-assessment (μ = 69.81, σ = 16.92).

Table 3. Student Pre- and Post-Assessment Mean (Standard Deviation) Scores on the Science Content Knowledge Assessment.

	Pre-Assessment	Post-Assessment
School A	71.12 (15.15)	70.00 (16.93)
School B	48.83 (16.95)	54.50 (16.99) +

Note. + includes a significant increase from pre- to post-assessment.

On the MUSIC®Inventory, students across both schools showed a significant increase in their empowerment ($t_{75} = -2.67$, $p = 0.009$) and caring ($t_{75} = -2.67$, $p = 0.009$) scores.

When disaggregating the results by schools (see Table 4), students at School A had significant decreases in scores for usefulness (t47 = 2.45, p = 0.018), success (t47 = 3.78, p < 0.001), and interest (t47 = 2.45, p = 0.018). School B showed a significant increase in empowerment (t28 = −3.13, p = 0.004), interest (t28 = −2.08, p = 0.047), and caring (t28 = −4.422, p < 0.001).

Table 4. Student Pre- and Post-Assessment Mean (Standard Deviation) Scores on the MUSIC®Inventory.

	Pre-Assessment	Post-Assessment
School A		
Empowerment	4.27 (1.01)	4.37 (0.84)
Usefulness *	4.39 (1.01)	4.02 (0.83)
Success *	4.91 (0.82)	4.38 (0.75)
Interest *	4.17 (1.07)	3.71 (0.95)
Caring	5.19 (1.04)	4.95 (0.80)
School B		
Empowerment +	3.29 (1.91)	4.38 (1.25)
Usefulness	3.93 (1.75)	4.24 (1.31)
Success	4.08 (1.58)	4.56 (0.96)
Interest +	3.43 (1.79)	3.99 (1.44)
Caring +	3.41 (2.53)	5.54 (0.64)

+ indicates a significant increase from pre- to post-assessment; * indicates a significant decrease from pre- to post-assessment.

5.2. Qualitative Results

Three themes, focusing on students' evolving perspectives of the PBI Global cycle and their final digital products, emerged: building empathy, learning for impact, and navigating challenges. The three themes highlight the affordances of this learning approach experienced by students before, during, and after PBI Global. Following is a discussion of each theme and accompanying sub-themes.

Theme 1: Constructing Empathy. Developing capacity to empathize is foundational to understanding different perspectives and becoming a change agent [58,59]. Derived from the German word Einfühlung, empathy implies "the power of mentally identifying oneself with a person or object of contemplation" [60]. Noddings [59] suggests that empathy is feeling with someone rather than for them. Empathy has been studied as an important component toward student motivation in science learning [61].

Students from schools A and B felt that the PBI Global experience gave them opportunities to become more empathetic, both with regard to the human aspects of global challenges, as well as with diverse perspectives within and across schools. In particular, they felt that interacting with fellow students within and across schools supported their evolving perspectives on global water. It was especially important for the teachers to support the students "to see that global systems are complex and that no easy answers exist," which helps them develop empathy rather than pity for people in lower- and middle-income countries [45] (p. 27). Empathy was constructed in two ways: (a) working in diverse groups and (b) understanding the global water context.

Empathy through working in diverse groups. Two to three students from each school were paired together to form teams, with students across schools then collaborating remotely to address their compelling questions. Students within schools knew each other, while students from across schools developed relationships as the project progressed. From the outset, students were aware that both schools were part of the state's early college high school network but were also aware that geographic locales were markedly different. The students' cross-school collaboration included weekly synchronous sessions through

Zoom and as-needed asynchronous communication through email and texts. As students progressed through the project, they grappled with community differences on at least two levels: differences related to the rurality and urbanity of their school contexts and differences related to circumstances (i.e., global water and sanitation crises) in lower- and middle-income countries.

A student from School B noted the value of working with students from a different school with a focus on collaboration:

> Collaborating with other schools will also give you a different perspective about what they know and what we know because like they might've been taught something else and being able to see if they have an idea about how we could save the Earth better. Then we could take that into account and get it more widespread so more people would know about it instead of just keeping it at one school. So, collaboration is really key.

One student from School A extended this point of view by highlighting and valuing differences in perspectives based on rural and urban geographical locations:

> I also kind of agree since our two communities are very different; one is urban, and one is rural—it's a lot different. So, it's a different experience and environment. So, when we come to talk about a project like water for example, like where I live, it's a different scenario. So, you get all these different points of view based on where you live . . . So I feel like it's always good to have those extra ideas and experiences that you can put on the table.

Students made connections between the content they were studying and the structure of working in cross-school collaborative groups. One School B student shared, "You can see other points, other people's point of view, how they think about this serious problem." In this way, some students demonstrated emerging understandings that solutions for complex global challenges, like access to clean water and adequate sanitation, grow out of idea sharing, feedback loops, and implementation support among diverse stakeholder groups.

Because the PBI Global experience was conducted across time, space, and cultures, initially students struggled to understand the basic goal of the project. A student from School A affirmed the importance of having perspectives from the other school as they deliberated on the project goal. They said:

> We had a different member who had a lot of questions, and she would help us flesh out our projects. So as far as the frame of the project, that helped us learn how to communicate with more types of people because we were both trying to learn what the actual project was together.

A student from School A shared insights on the importance of congeniality during the project collaboration process and how that contributed to being open to different styles of communication:

> It was really nice to meet people. At least one member was very friendly, helpful, and communicative. So, it was interesting working with her because she communicated differently than we were used to. But it helped us learn how to talk to more types of people.

The experience of working with peers within the same US state, but across rural and urban environments, prompted students to examine and reflect on the value in working with diverse groups. This was particularly notable in terms of the expectation of what lay ahead for students as they approached college and work contexts. "I feel like if you talk to people outside of just your classmates and people inside your school, it would probably help you out in the future, such as for job interviews," commented a student from School B. Echoing this sentiment, a student from School A commented on the fact that overall the project was a good experience and had significant implications for the preparation of challenges "that will be faced in the workplace after graduating from high school or college."

Another student from School A shared the value of learning to collaborate remotely through the project and how it was helpful for a work internship that they were involved with:

> This project taught me a lot about telecommuting. So, I recently started an internship where I have to meet on Zoom with my boss. And so now like after communicating with [School B] and Zoom is the only method that we can communicate. It's really given me more soft skills. And understanding how important communication is, especially in scenarios where we're not meeting face to face.

The conversation took a turn to weighing the value of being in diverse groups against the challenges the students were facing with the actual logistics of the collaboration between the two schools. Along these same lines, a student in School B explained:

> I would definitely say if we could get things to run a bit smoother, we should still keep working with the other school. 'Cause it does teach you life lessons, along with how to work things out. It kind of makes it pay off better in the end, but of course still there's some things that probably could run smoother to make it a little bit easier for everyone.

A more in-depth discussion of the challenges students faced during the collaborative process of implementing PBI Global will be addressed in Theme 3 of this section.

Empathy through understanding the global water and sanitation context. At the beginning of the project, many of the students were not aware of the critical conditions surrounding global water and sanitation. As they began their inquiry cycle through the reading of informational and narrative texts on the subject combined with discussions with their classmates within and across schools, students developed an understanding of the global water crisis, including, as a School B student observed, the sobering fact "that many kids die every day from infectious diseases [spread through dirty water]."

A student from School B noted, "I learned more about global conflicts. I don't really get news 'cause I don't have cable. I just use streaming services. So, finding out what's actually going on around the world, that was something I found interesting." A student from School B underscored this perspective and valued the knowledge gained about the water crisis, when they said, "I think all the statistics I learned on how many people are struggling related to water in the world was the most important thing. It made me feel really grateful for what I have." Sometimes when students become aware of global struggles, the initial reaction, understandably, is a comparison of the differences in terms of their lived experiences in the US. This is a common first analysis as a means to relate to others' struggles within the human experience. An instructional goal is to create learning conditions so that, as students move deeper into the inquiry cycle, they also intellectually evolve from comparisons to more complex, analytical understandings of the context. For example, students might move from thinking about the lack of access to clean water in South Sudan as a unique deficit to those living in lower-income countries to making parallels with the experiences of community members in Flint, Michigan, who are also struggling with access to clean water due to infrastructure failures.

By initiating the project through the students' reading of *A Long Walk to Water*, in which they encountered the true stories of children in South Sudan who were living in crisis from a lack of readily available clean water and adequate sanitation, it established the groundwork for putting themselves in other people's shoes. A student from School A commented on the emotional impact of reading the dual narrative text about people in South Sudan who spend hours on a daily basis walking for clean water:

In reading *A Long Walk to Water*, there was this quote, 'one death is a tragedy; 1 million deaths is a statistic.' So, you know, we hear all of these people don't have access to clean water and it doesn't seem like an issue. But we read one book about a handful of people, and it suddenly hits very close to home. And you see the emotional and familial effects of not having water.

Moreover, a student from School B empathized with the physical toll endured by characters in the book who had to carry water for survival on a daily basis. "After I did the walk, I was sore for a few days, and I could barely move. It did not feel good, and I could not imagine having to do that every day to get some water." Thus, students' participation in reading *A Long Walk to Water* prior to conducting their inquiry projects and the post-inquiry simulation activity of carrying water enabled them to "step outside their personal experience to compassionately imagine the lives of others" [62].

Reflecting on the school walk, it was clear that students embraced an empathic stance and came to understand the compounding issue of gender bias inherent in the global water crisis. One student from School B claimed, "it helps you put yourself in their shoes ... knowing what especially the women have to go through." Through their inquiry cycle, several student teams were able to delve deeper into the issue of young girls in lower-income countries confronted with spending much of their time walking for water and not having available time to attend school.

The role of the instructor is key in supporting students toward critically examining the complexity in how these enduring challenges manifest, not only in diverse global contexts but also locally. A student from School A commented, "I think that one thing I learned was that water access isn't just a problem in foreign countries. It's something that's local here ... especially making sure it's clean." A particular challenge for teachers who implement PBI Global is creating a learning context that allows space for students to develop a deep understanding of global challenges while simultaneously eschewing stereotypes of "others." Teachers have the aim of empowering students as empathic change agents who act out of compassion, building empathy toward a collective "we" [63] as their research opens their eyes to "how many people in the world are struggling." Additionally, investigating these enduring challenges from a local lens can personalize students' engagement with the science curriculum.

Theme 2: Learning for Impact. Prior to engaging in PBI Global, students from Schools A and B shared the characteristics of learning experiences that motivate them, including real-world relevance, hands-on applications, and an emphasis on skill building. Consequently, the motivational elements that students reported aligned with the NGSS Lead States [6] eight science and engineering practices. As students' understanding of and engagement in PBI Global deepened throughout the course of the project, students recognized that a distinctive feature of this inquiry cycle is its solution- and action-oriented approach toward addressing enduring global challenges. A student from School A elaborated that PBI Global makes people "want to go out into the world and try to fix the problem." PBI Global's focus on learning for impact manifested in three ways during student focus groups: (a) learning as stewardship, (b) socially-relevant content, and (c) creating to learn.

Learning as stewardship. In education, stewardship often refers to the caretaking of environmental ecosystems [64,65]; in PBI Global, the concept of stewardship emerged in a more generalized way regarding students' mindsets and reflections on the purpose of their learning. Given the topical focus of the UN SDGs, students were immersed in the language of collective goal setting and target meeting toward a more sustainable present and future. Additionally, the teachers set solution-oriented expectations for the structure of students' evidence-based writing product, including the need for each group to design a technical or social innovation toward meeting one or more of the SDG targets. These instructional design elements communicated an expectation to students that their project work centered on making a difference in our world. As a School B student shared, through PBI Global, "I learned clean water and proper sanitation can help a lot of people in the world...and how we must solve this problem ourselves."

By empowering students as change agents and acknowledging a collective responsibility for addressing enduring global challenges, this PBI Global situated students in the role of stewards. Students from Schools A and B recognized how this positionality can be motivational. "If schools focused on these goals [SDGs], we would be able to accomplish them faster," asserted a student from School B while their schoolmate affirmed, "And it would motivate kids to learn more...knowing that you're doing something that could possibly help better other people's lives and fix something."

Building on these sentiments, a student from School A acknowledged the generational responsibility to achieve the SDGs, asserting that we need to "make sure that our generation knows about water...the world is depending on us to be the solution." Students from both schools also communicated this sense of urgency and responsibility regarding their PBI Global work through their digital learning products. Team 6 incorporated quotes on their trifold display to highlight expert assessments and time-bound predictions of the local, national, and global water infrastructure landscape (see Figure 2).

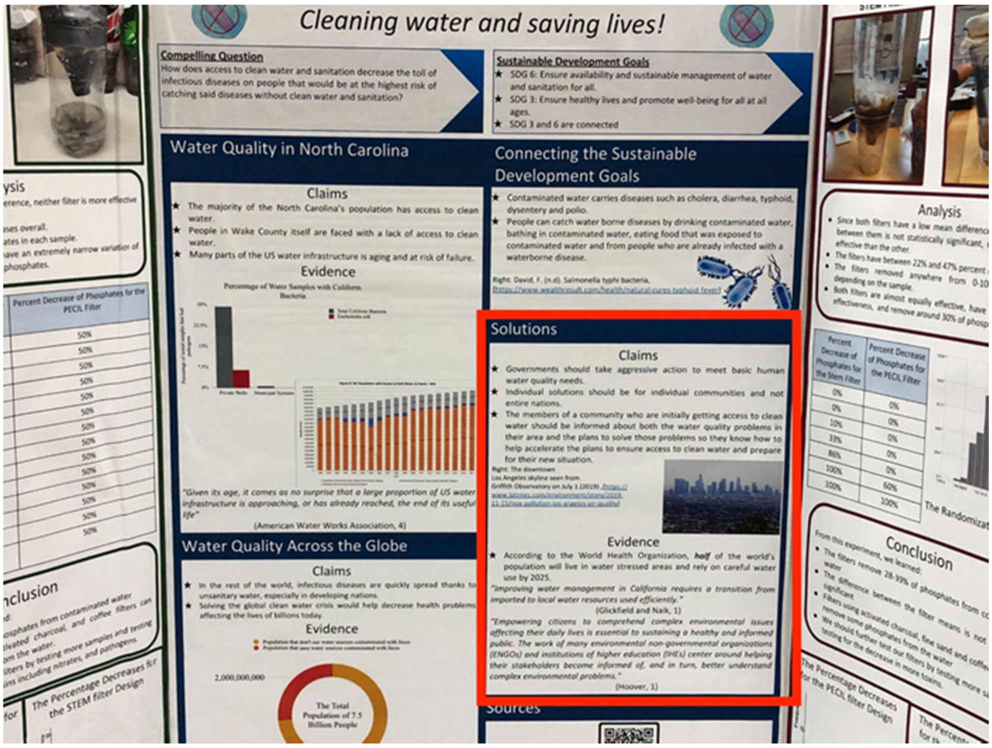

Figure 2. Team 6 trifold display.

Additionally, a hallmark of the team's suggested solutions was to involve an active citizenry in the decision-making process regarding a community's water resources.

By guiding students' inquiry with the SDG framework and setting solutions-oriented expectations for digital products, the PBI Global cycle positions learners as local and global caretakers, harnessing the motivational powers of learning as stewardship.

Socially-relevant content. Another important aspect of learning for impact that students surfaced during and after engaging in PBI Global was the focus on locally and globally relevant content. One student from School B appreciated "learning more about water and sanitation." Meanwhile, a peer from School A recognized how immersing oneself in academic literature and data during the inquiry cycle opened their eyes to "how many people are struggling related to water in the world."

The organization of students' learning products reflected the project's aim of examining water and sanitation issues in global and local contexts, with the goal of complexifying students' understandings of how the SDGs are not limited to applying in the developing world, but rather they need to be addressed and pursued by humanity writ large. In Figure 3, Team 2's trifold display shows how they examined the connections between access to clean water and adequate sanitation and educational equity in their local community, as well as in communities across the world.

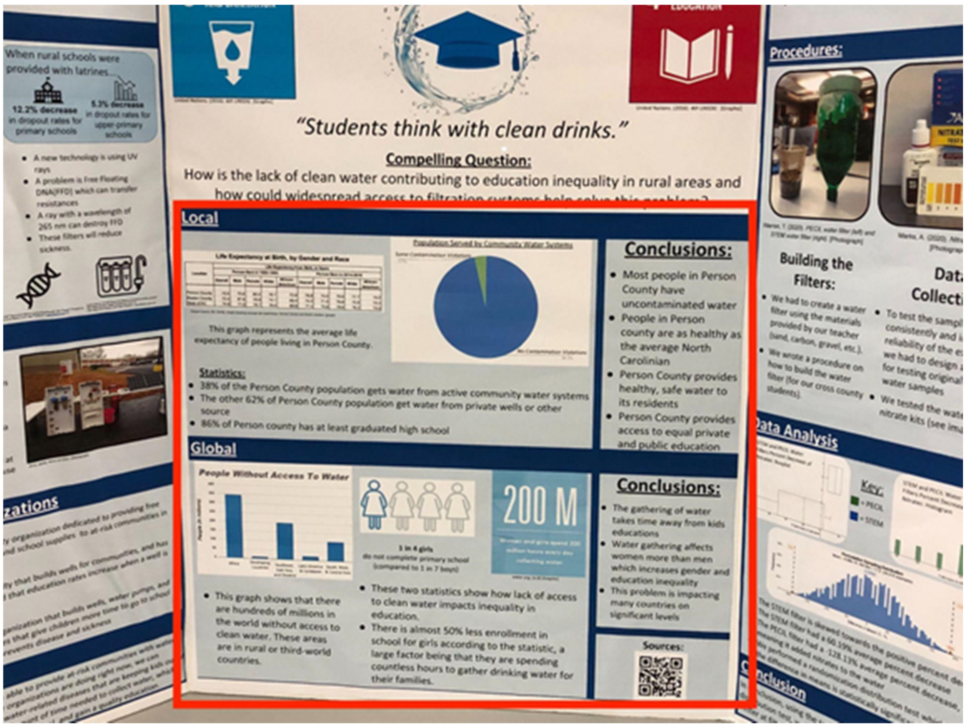

Figure 3. Team 2 trifold display.

The role of the teacher in prompting and guiding students to critically examine how an SDG is situated in the local and national contexts (in addition to the global) is essential. One student from School B articulated the importance of investigating the local water and sanitation context, noting "The local energy company [pseudonym] has two coal ash ponds that are contaminating our groundwater . . . I used this as evidence to explain how our community is affected." Without this intentional home community evaluation, students tend to perpetuate the savior complex, seeing their learning through the PBI Global cycle as important for helping global others but not particularly relevant in their local communities.

In addition to the intentional curation of resources and scaffolding of learning activities by the teachers to make explicit the social relevance of this project, students also commented on how their knowledge of the audience for their own learning products served as a guidepost for social relevance on the creation side of PBI Global. A School B student put it succinctly, saying, "Knowing that you have to present your product to an audience, you need to think about how they will understand what you are saying and present it professionally." Considering what would be most compelling and engaging for the students' showcase audience led another School B student and their team to create a project presentation that was "geared closer towards local...since the audience is people from our town." In this way, they tailored their presentation to share inquiry findings related to their rural community, such as the percentage of people in the county who rely on well water versus municipal water. Thus, the social relevance of the project content was a motivating factor from the project design and product creation standpoints.

Creating to learn. The creation of student multimodal products to share the teams' inquiry findings with a broader audience amplified the impact of the students' learning throughout PBI Global. Each student team created a trifold display, an evidence-based writing piece, a water filter made from commonly available materials, and an advocacy pitch for a technical or social solution. Additionally, one cross-school team of students enrolled in an engineering design elective course created a solar-powered UV water filtration system.

For some teams, creating the water filter added a welcome engineering design component to their inquiry. A student from School A remarked, "The water filter was actually a really fun part . . . we could see our own creation be successful, which made us happy because we made it and made it work." Designing an effective water filter helped a School A peer recognize "the application of skills that you need to do the project, involving your own creativity in coming up with a sustainable solution."

With the advocacy pitch and trifold display, students reflected that these creative syntheses helped to effectively and succinctly communicate their inquiry findings to the showcase audience. A student from School B summarized the purposes of these two products as "The advocacy pitch gave you a brief overview of what was going on, while the trifold gave you a more diverse and thorough explanation." A student from School A contrasted the PBI Global cycle and product creation with other instructional approaches, saying that creating products to showcase one's learning "really motivates students to push forward rather than if we had a packet. We are creating and troubleshooting our own ideas." This positioning of students as knowledge creators, rather than information consumers, amplifies motivation and agency.

Additionally, product creation influenced the evolution in complexity of students' knowledge throughout the project. A student from School A who was a member of the cross-school team designing and building the UV water filtration system shared:

> It's [UV water filtration] very technical...we've been looking at a lot of systems and how they incorporate the water and how they clean the water ... Initially, it seemed like it was just 'put the UV light on water.' But there's a lot of different ways to do it. And there's a lot of pros and cons to using UV light, and you have to sort that out yourself.

Figure 4 shows School B students demonstrating their UV water filtration system for the showcase audience.

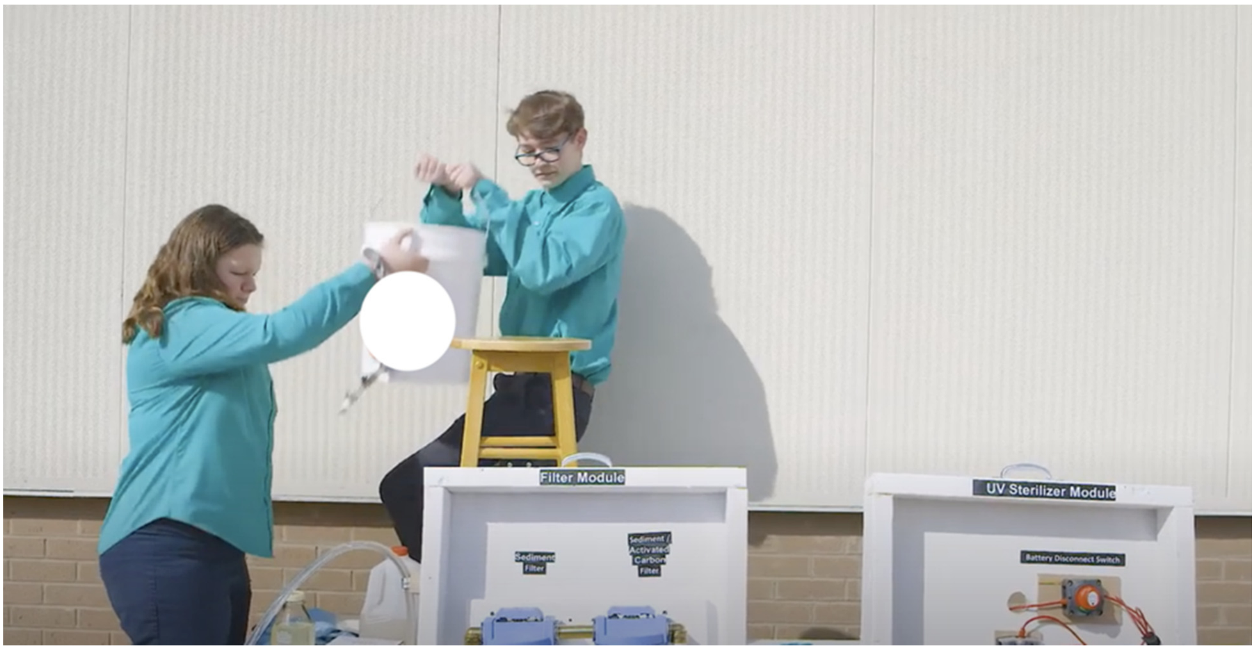

Figure 4. School B students demonstrating their UV water filtration system at the PBI Global showcase.

Synthesizing and showcasing their inquiry products required students to think deeply about what they were learning, how their evolving understandings apply in diverse contexts, and why this learning matters. As a School B student articulated, creating the digital products "helped me learn more about water, sanitation and water filtration and [more broadly] about science and innovation. It [PBI Global] opened up a whole new thing. The fact that we're helping with something so big in such a small school."

Theme 3: Navigating Challenges. Students discussed many challenges with working across schools during the PBI Global cycle. We grouped these challenges into two categories:

collaboration and project expectations. When navigating challenges, the context of PBL in each school came into play. For School A, the students and faculty had a history of engaging in group projects across disciplines within a grade level; School B was new to PBL. For this reason, when challenges emerged during the partnership, School A students and faculty became frustrated more quickly than School B because School A had previously experienced high levels of functionality and success with PBL in-house. A School A student shared, "We had one [grade-level project] last semester that went a lot more smoothly." A School A peer added, "It was a little bit more stressful" because the School B students had never participated in a project like this before, resulting in a steep learning curve for how to engage in inquiry.

Given the differing school contexts (e.g., rural/urban, new to PBL/prior experience with PBL, more rigid schedule/more flexible schedule, digital products assessed through one course/digital products assessed across multiple courses, etc.) and the collaborative nature of the project, students recognized that intentional relationship-building is foundational to avoiding many of these challenges for future iterations of the project. Student teams had differing experiences working across schools based on the effectiveness of the relationship building each team undertook. Reflecting at the project midpoint, a School A student noted, "These are not people we know [referring to School B teammates]. So, we don't really have a foundation on how we like to communicate with each other." In contrast, a School B student became "pretty close" with the people in their group because "we communicate...We're building a friendship together. We're not only just partners."

Although the launch day of the project did have team-building time designated, many of the students were unable to interact with their cross-school partners due to technical difficulties. A School B student highlighted, "So on the first day, the launch day, we weren't able to get in contact, like to Zoom them." A School B peer added, "And then it was kind of awkward trying to talk to them [afterward] because we didn't know anything about each other."

Further emphasizing the need to embed time and structures before, during, and after the cross-school project for relationship building and maintenance, students pondered the effectiveness of meeting face-to-face for launch day rather than virtually. "If it would have been possible to be face-to-face at the launch, that would have been really helpful," a School A student asserted. School B students elaborated, meeting in-person at the beginning of the project would have facilitated teammates getting "a better feel for who you are" and "what role you should play in the project."

Each school's contextual factors as well as students' varying relationship-building experiences within cross-school teams influenced how students collaborated and their clarity with project expectations.

Collaboration. At the beginning of planning for this PBI Global, the researchers set the expectation with School A and School B teachers that the students would be engaging in inquiry as cross-school teams. Previous cross-school PBI Globals afforded the researchers with opportunities to examine international collaborations [25,42,43]; however, this project, in the spirit of the SDGs and the intrastate rural/urban school context, sought to explore the value and challenges in schools partnering to investigate an enduring global challenge grounded in differing local contexts.

During project planning, the researchers facilitated face-to-face and virtual meetings with both schools, providing guidance and recommendations for what a cross-school PBI Global could look like. The teachers were then invited to bring to bear their knowledge of students, school contexts, content areas, pedagogy, and instructional tools in planning the implementation of the project.

The researchers found it challenging to strike a balance between supporting teachers and maintaining fidelity in the implementation of the PBI Global cycle with students. These challenges of collaboration among the project's researchers and teachers were mirrored among students.

One structural feature of the partnership that made it difficult for students to work together across schools was the difference in instructional schedules. As cooperative, innovative high schools, the students were dual-enrolled in college and high school courses. For School B, in particular, these courses contributed to a certain level of rigidity in their schedules that directly impacted collaboration. A School A student reported, “The fact that they [School B] had college classes in the mornings so we weren’t able to talk to them at all until the afternoon...didn’t make much room to work with them.”

Although the School A students’ schedules allowed for more flexibility in meeting with teammates, the demands of multiple, concurrent projects impeded their ability to devote the necessary time to the collaborative work. A student from School A shared how engaging in three substantial projects simultaneously shifted their mindset from “We have time. We have time for this. We can do [a good job with] this” to “We’ve got to do this. We also have to do this, this, this, and this." Recognizing that when you are “in a rush to get it [a project] done,” learning suffers as a result of not being able to work together to “make it the best that we can actually do.”

Despite this, many students commented on the water filter design lab as a key collaborative component of the project experience. All students across both schools were tasked with developing a water filter with the same available materials. Teammates from each school kept detailed descriptive and visual notes as they built their filters in order for their cross-school partners to replicate their build. The goals of this activity were to (1) design a replicable system, (2) test the effectiveness of the design, (3) replicate and test your teammates’ design, and (4) compare results.

In terms of collaboration, the replicable filtration system design proved to be challenging. A School B student noted, “Some of the instructions that I gave [my cross-school teammates] when saying how to make the filter, they weren’t very clear...I had to go back and fix them.” These challenges with replicability presented opportunities for students to explore the scientific concepts of precision and accuracy more deeply. A School A student spoke to this saying:

> We didn’t use exact measurements when we were making our water filter...so we all had to go back and fix it...so when they [our cross-school partners] make our filter they can do it correctly...We were supposed to be using grams, and we were just going by inches in our filter. And we didn’t realize that that was an issue until afterwards. So, we had to go back and change how much of each material we had.

With much of the students’ time needed to figure out initial filter designs and how to accurately and precisely describe those designs in writing, time constraints limited some student teams’ ability to meet subsequent activity goals. For example, a School A student expressed a desire for “more time to test more water,” affirming that one’s science content knowledge development is inherently tied to experimentation opportunities and data analysis. Additionally, a schoolmate hoped to learn more about “how to improve it [the water filter]” in order to “understand it [the filtration process] a little bit better.”

Despite these constraints, students who were able to test their teammates’ design and compare results found it to be helpful in shaping and affirming their science content knowledge in this area. “We got to test out somebody’s filter who thought it was a smart idea to put charcoal at the beginning of it,” reflected a School A student, “and I got to watch the charcoal sizzle. It was exciting knowing why their filter didn’t work.” Although the collaborative nature of this project posed challenges for students with regard to time management, working across schools also afforded students opportunities to authentically engage in scientific practice.

Project expectations. Another area in which students expressed a desire for more coherence and clarity was with the project expectations across disciplines and schools. As an interdisciplinary endeavor, the PBI Global cycle necessitates explicit connection-making during inquiry across content area classrooms to student teams’ compelling questions. When reflecting on interdisciplinary project connections, a School A student shared:

> You have the compelling question, and from there you build off that with research and then you finally come out with a creative solution. But I feel like the way our project was set up, we had multiple [inquiry] cycles. So, math had that cycle; Spanish had that cycle, which was different from math...They were all completely separate.

When these connections are unclear or become murky with students, potential synergies in understanding how disciplinary concepts and practices are interrelated, particularly in the case of multi-faceted enduring global challenges, become diminished.

School B students drew attention to the tradeoff between autonomy in compelling question development and clear connections to project components. One student asserted, "I don't really see how it [the water filter] had anything to do with my team's compelling question...on gender equality and water." A schoolmate replied, "The data does connect to it . . . 'cause people who can't afford clean water, they can build filters like that." However, the schoolmate eventually conceded that some project components were "more relevant to the compelling question that we had."

For some students, the interdisciplinary connections were more apparent when components of a project task were taken up across multiple classes. For example, a School A student identified "some relation between math and science with the [designing and building of the water] filter and testing the data." This observation was echoed by School B students in their request for a project overview document to "see what we have to do each week" and get "everyone on the same page...about what to expect."

Creating shared project expectations across schools highlighted the importance of open and effective communication among teachers and students. A School A student identified communication as a "big factor" for a high-functioning cross-school project. Students from both schools stressed the interrelationship between communication, shared project expectations, and effective collaboration. As one student from School A noted, sometimes our schools "felt so separated, like we were each doing individual things." To mitigate the disconnects in the schools' geographic locations and project work time, a School B student remarked, "I think that splitting it [project responsibilities] up helped ease us into the project a little bit." Thus, clarity in roles and responsibilities within cross-school teams played an important part in students' perceptions of project alignment.

Differing assessment approaches across schools impacted the extent to which project expectations were shared. With School A, PBI Global was "a grade-level project, so every class has a subject in this project and that subject is being graded," while with School B, project components were collectively being assessed for students' first-year seminar course. These structural assessment differences led to project expectations being communicated to students through "different standards and different rubrics," leading to frustration among some students. Despite the challenges faced by students during the project, the showcase experience was widely recognized by students, teachers, and the research team as successful in demonstrating students' complexified and deepened knowledge of water and sanitation issues and their capacity to unite and share their collaborative work.

6. Discussion

The findings of this study add to a growing body of research on inquiry-based learning in science [17]. The results have the potential to extend the current theory by demonstrating how socio-constructivist theories [24] and inquiry-based approaches to learning can be applied to collaborative inquiry across two schools. The discussion is organized by addressing (1) the integration of the mixed methods results across research questions and (2) the implications of the study in terms of practice and future research.

6.1. Integration of Mixed Methods Data for Questions 1, 2, and 3

The first research question addressed how the PBI Global cycle supported student science content knowledge in a cross-school collaboration with the second question exploring how students characterize their motivation after participating in PBI Global. School B experienced a significant increase in science content knowledge from pre- to post-assessment and a significant increase in empowerment, interest, and caring on the MUSIC®Inventory, while School A experienced a non-significant decrease in the content assessment and a significant decrease in usefulness, success, and interest per the Inventory. For each school, trends in student performance on the science content knowledge assessment mirrored trends in their motivation in the project per the MUSIC®Inventory.

When examined in light of the findings from the schools' student focus group data for the third research question, the science content knowledge assessment and MUSIC®Inventory results reveal how motivation and content knowledge may be influenced by student experiences and school contextual factors during an inquiry project. Since inquiry and PBL pedagogies were relatively new to School B, the students and teachers did not have well-defined, pre-existing instructional expectations for a grade-level project of this nature. The School B principal set the expectation with teachers and provided ongoing support (via time and resources) for teachers to co-plan and co-enact instruction during the project. Conversely, School A students and teachers had a grade-level project model that structured students' inquiry on a cross-disciplinary theme through separate disciplinary-specific components. One School A student noted:

> The way this project is structured is that each subject has their own little part . . . Oftentimes it's hard for us to kind of link together how each thing ties up . . . We're just not sure how they connect.

These structural differences in the schools' approaches to inquiry-based learning likely influenced students' knowledge and empathy construction. They may explain differences between the two schools in student science content knowledge and motivation outcomes.

The collaboration challenges were a frequent point of discussion in student focus groups, possibly shaping science content knowledge assessment and MUSIC®Inventory results, particularly with School A. One confounding factor with regard to student collaborative challenges was a lack of buy-in and ongoing investment across the schools' teaching faculty. Additionally, the research team struggled with supporting the teachers toward implementing the PBI Global cycle collaboratively and with fidelity. For example, teachers from School A felt strongly that in addition to their team products, students needed to complete individual choice products (e.g., writing children's books, developing artwork, designing websites, etc.). Teachers from School B did not share this goal. This led to confusion for the students across schools because not all students on the same team were working collaboratively toward the same product goals for the PBI Global Showcase.

When the added value of a pedagogical shift is not readily apparent to teachers, effective planning and enactment of instruction is often impacted [66]. Moreover, teacher emotions may be communicated to students intentionally and/or unintentionally, which impacts learning [67]. A School A student recounted: "I was talking to a teacher about what we're getting told [regarding project expectations] from School B students, and they were as confused as the students were."

Despite these challenges, students from both schools experienced an increase in empowerment per the MUSIC®Inventory, with School B demonstrating a significant difference from pre to post. A student from School A highlighted how they felt empowered by navigating the PBI Global cycle through being "able to answer the [compelling] question within our project . . . We were able to find curves that we could go around instead of having to get blocked. We were able to [figure it out]." Additionally, a School B student shared how the PBI Global cycle affirmed that young people "can solve these problems ourselves."

6.2. Limitations

The strengths as well as the limitations of using a mixed-methods research convergent parallel design have been discussed extensively in the literature [46]. In general, a limitation of this type of design is the length of time and feasibility of resources it takes to collect and analyze both quantitative and qualitative data. Based on the nature of our research questions, we decided that this design was most appropriate because we would be able to collect different but complementary data. Clearly, the most notable limitation to our study was the lack of randomization of participants, which resulted in a lack of generalizability from our analyses. An additional limitation to our study was the lack of focus on teacher processes. Because the teachers were a central part of the project, it is difficult to obtain a full picture of the classroom implementation without an analysis of their processes.

6.3. Implications for Instructional Practice and Future Research

We derived two implications for instructional practice and suggestions for further research based on the integration of our mixed methods data. First, it is clear from the research that relationship building, mutual respect, and consensus making are essential components of constructing cross-school inquiry collaborations. A school stakeholder buy-in and coherent leadership are foundational elements for project success [68]. There must be an intentionality on the part of school leaders for modeling these elements with students and colleagues in order for the collaboration to function at a high level. As our research team reflected on this project, we were reminded of the value in constructing strong foundations among project partners (within and across schools) and continuing to invest the time and resources in nurturing these relationships throughout a project. Identifying and valuing each partner's assets provides a strong backdrop to the collaboration so that when challenges and complexities arise, as they undoubtedly do, they can be absorbed into the project process rather than become a stumbling block for student learning.

Second, researchers have noted inconsistency in the definition and therefore enactment of inquiry-based learning approaches [69]. Moreover, teachers are often confronted with implementing multiple instructional frameworks with their students at any given time [70]. For example, in this study, School A had previously used the Engineering Design Process. This was evident in the shared language among students and teachers. While PBI Global and the Engineering Design Process are complementary, students in School A grappled with integrating both processes. Thus, when a new framework is introduced, teachers need to (1) be intentional about defining the relationship among instructional frameworks and (2) clearly communicate these relationships with students.

Addressing these implications becomes more complex when engaging in collaborative inquiry-based learning across school sites. The challenges that emerged in this cross-school PBI Global reflect the complexities of negotiating and constructing shared meaning [10] and collaboratively solving enduring issues on a global scale.

In terms of future research, our team is interested in investigating the enactment of PBI Global via an experimental design approach to more deeply understand the affordances and limitations of interdisciplinary inquiry-based learning to understand and solve global challenges, particularly when collaborating across schools nested in diverse community contexts. Recent experimental studies have shown promise for inquiry-based learning in science and mathematics with pre-K, elementary [71], and secondary students [34]. We are interested in conducting similar research with secondary student and teacher populations across multiple sites, emphasizing cross-school collaborations.

Intuitively, we recognize how students benefit from cross-school collaborative inquiry through idea sharing, multiple perspective taking, and heightened creativity [72]; however, given the implementation complexities inherent in these types of projects, as highlighted in this study, we need to empiricize the cognitive, affective, and social factors influenced by this type of teaching and learning. Additionally, as Akuma and Callaghan [73] and Harris and Rooks [74] suggest, the systemic and structural impediments in schools that limit or inhibit effective, collaborative inquiry-based learning need to be further explored in order to scale this pedagogical approach more broadly. Moreover, since this project took place prior to the COVID-19 pandemic, the challenges students experienced regarding remote cross-school collaboration may have shifted due to the growing fluency of students and teachers in navigating learning through online, remote environments. A research agenda that addresses this shift would deepen our understanding of inquiry-based learning through cross-school collaborations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci12060412/s1, Researcher-Designed Science Content Knowledge Test; Student Semi-Structured Focus Group Questions.

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References

1. National Research Council. *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academy Press: Washington, DC, USA, 2011.
2. U.S. Department of Education, Office of Innovation and Improvement. STEM 2026: A Vision for Innovation in STEM Education. 2016. Available online: https://oese.ed.gov/files/2016/09/AIR-STEM2026_Report_2016.pdf (accessed on 17 September 2021).
3. Wilhelm, J.; Wilhelm, R.; Cole, M. What Is a Project-Based STEM Environment? In *Creating Project-Based STEM Environments*; Springer: Cham, Switzerland, 2019; pp. 3–5.
4. National Research Council. *National Science Education Standards*; National Academy Press: Washington, DC, USA, 1996.
5. Schneider, R.M.; Krajcik, J.; Marx, R.W.; Soloway, E. Performance of students in project-based science classrooms on a national measure of science achievement. *J. Res. Sci. Teach.* **2002**, *39*, 410–422. [CrossRef]
6. NGSS Lead States. *Appendix F of the Next Generation Science Standards: For States, by States*; National Academies Press: Washington, DC, USA, 2013.
7. Bruner, J.S. The act of discovery. *Harv. Educ. Rev.* **1961**, *31*, 21–32.
8. Freire, P. *Pedagogy of the Oppressed*; The Continuum International Publishing Group: New York, NY, USA, 1984.
9. Piaget, J. *The Psychology of the Child*; Basic Books: New York, NY, USA, 1972.
10. Bachtold, M. What do students construct according to constructivism in science education? *Res. Sci. Educ.* **2013**, *43*, 2477–2496. [CrossRef]
11. Dewey, J. *Interest and Effort in Education*; Houghton Mifflin Company: Boston, MA, USA, 1913.
12. Dewey, J. *How We Think*; D.C. Heath and Company: Lexington, MA, USA, 1910.
13. Barrow, L.H. A brief history of inquiry: From Dewey to standards. *J. Sci. Teach. Educ.* **2006**, *17*, 265–278. [CrossRef]
14. National Research Council. *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*; National Academy Press: Washington, DC, USA, 2000.
15. Pedaste, M.; Mäeots, M.; Leijen, Ä.; Sarapuu, S. Improving students' inquiry skills through reflection and self-regulation scaffolds. *Technol. Instr. Cogn. Learn.* **2012**, *9*, 81–95.
16. Krajcik, J.; Blumenfeld, P.C. Project-based learning. In *The Cambridge Handbook of the Learning Sciences*; Sawyer, R.K., Ed.; Cambridge University Press: New York, NY, USA, 2005; pp. 317–333.
17. Duran, L.; Duran, E. The 5E instructional model: A learning cycle approach for inquiry-based science teaching. *Sci. Educ. Rev.* **2004**, *3*, 49–58.

18. Chu, S.K.W.; Reynolds, R.B.; Tavares, N.J.; Notari, M.; Lee, C.W.Y. Twenty-first century skills and global education roadmaps. In *21st Century Skills Development through Inquiry-Based Learning*; Springer: Singapore, 2017; pp. 17–32.
19. Keselman, A. Supporting inquiry learning by promoting normative understanding of multivariable causality. *J. Res. Sci. Teach.* **2003**, *40*, 898–921. [CrossRef]
20. Minner, D.D.; Levy, A.J.; Century, J. Inquiry-based science instruction—what is it and does it matter? *Results from a research synthesis years 1984 to 2002. J. Res. Sci. Teach.* **2010**, *47*, 474–496.
21. Alfieri, L.; Brooks, P.J.; Aldrich, N.J.; Tenenbaum, H.R. Does discovery-based instruction enhance learning? *J. Educ. Psychol.* **2011**, *103*, 1–18. [CrossRef]
22. Furtak, E.; Seidel, T.; Iverson, H.; Briggs, D. Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *J. Educ. Psychol.* **2012**, *82*, 300–329. [CrossRef]
23. Hogan, K.; Pressley, M. Scaffolding scientific competencies within classroom communities of inquiry. In *Scaffolding Student Learning: Instructional Approaches and Issues*; Hogan, K., Pressley, M., Eds.; Brookline Books: Cambridge, MA, USA, 1997; pp. 74–107.
24. Vygotsky, L.S. *Mind in Society: The Development of Higher Psychological Processes*; Harvard University Press: Cambridge, MA, USA, 1978.
25. Spires, H.A.; Himes, M.; Medlock Paul, C.; Kerkhoff, S. Going global with project-based inquiry: Cosmopolitan literacies in practice. *J. Adolesc. Adult Lit.* **2019**, *63*, 51–64. [CrossRef]
26. Buck Institute for Education. PBLWorks. 2021. Available online: http://pblworks.org (accessed on 23 June 2021).
27. Krajcik, J.S.; Czerniak, C.M. *Teaching Science in Elementary and Middle School: A Project-Based Approach*; Routledge: New York, NY, USA, 2014.
28. Marx, R.W.; Blumenfeld, P.C.; Krajcik, J.S.; Fishman, B.; Soloway, E.; Geier, R.; Tal, R.T. Inquiry based science in the middle grades: Assessment of learning in urban systemic reform. *J. Res. Sci. Teach.* **2004**, *41*, 1063–1080. [CrossRef]
29. Blumenfeld, P.C.; Soloway, E.; Marx, R.W.; Krajcik, J.S.; Guzdial, M.; Palincsar, A. Motivating project-based learning: Sustaining the doing, supporting the learning. *Educ. Psychol.* **1991**, *26*, 369–398. [CrossRef]
30. Capraro, M.M.; Jones, M. Interdisciplinary STEM project-based learning. In *STEM Project-Based Learning*; Sense Publishers: Rotterdam, The Netherlands, 2013; pp. 51–58.
31. LaForce, M.; Noble, E.; Blackwell, C. Problem-Based Learning (PBL) and Student Interest in STEM Careers: The Roles of Motivation and Ability Beliefs. *Educ. Sci.* **2017**, *7*, 92. [CrossRef]
32. Price, C.; Mohammed, S.; Rabbit, B. BetterLesson and PBLWorks Professional Learning at LUSD: Effects on Instructional Behaviors and Learning Outcomes. The Learning Accelerator. 2019. Available online: https://www.hsredesign.org/wp-content/uploads/2020/09/PBLWorks-LindsayUSD-research-report_2019-November.pdf (accessed on 17 September 2021).
33. Duke, N.; Halvorsen, A.; Strachan, S.; Kim, J.; Konstantopoulos, S. Putting PjBL to the test: The impact of project-based learning on second graders' social studies and literacy learning and motivation in low-SES school settings. *Am. Educ. Res. J.* **2021**, *58*, 160–200. [CrossRef]
34. Craig, T.T.; Marshall, J. Effect of project-based learning on high school students' state-mandated, standardized math and science exam performance. *J. Res. Sci. Teach.* **2019**, *56*, 1461–1488. [CrossRef]
35. Bybee, R.W.; Landes, N.M. Science for Life and Living: An elementary school science program from Biological Sciences Curriculum Study (BSCS). *Am. Biol. Teach.* **1990**, *52*, 92–98. [CrossRef]
36. Grant, S.G.; Swan, K.; Lee, J. *Inquiry-Based Practice in Social Studies Education: Understanding the Inquiry Design Model*; Routledge: New York, NY, USA, 2017.
37. Li, N. *Approaches to Learning: Literature Review*; International Baccalaureate Organization, 2012; Available online: https://ibo.org/research/curriculum-research/cross-programme/approaches-to-learning-literature-review-2012/ (accessed on 17 September 2021).
38. United Nations Department of Economic and Social Affairs. Sustainable Development Goals. 2015. Available online: https://sdgs.un.org/goals (accessed on 17 September 2021).
39. United Nations. Sustainable Development Goals Report. 2018. Available online: https://unstats.un.org/sdgs/files/report/2018/TheSustainableDevelopmentGoalsReport2018-EN.pdf (accessed on 17 September 2021).
40. Spires, H.A.; Hervey, L.G.; Morris, G.; Stelpflug, C. Energizing project-based inquiry: Middle-grade students read, write, and create videos. *J. Adolesc. Adult Lit.* **2012**, *55*, 483–493. [CrossRef]
41. Spires, H.A.; Himes, M.; Lee, C.; Gambino, A. "We Are the future": Embracing the potential for critical literacy and social action. *J. Lit. Res.* **2021**, *53*, 219–241. [CrossRef]
42. Spires, H.A.; Kerkhoff, S.; Fortune, N. Educational cosmopolitanism and collaborative inquiry with Chinese and US teachers. *Teach. Educ.* **2018**, *30*, 437–454. [CrossRef]
43. Spires, H.A.; Medlock Paul, C.; Himes, H.; Yuan, C. Cross-cultural collaborative inquiry: A collective case study with students from China and the US. *Int. J. Educ. Res.* **2018**, *91*, 28–40. [CrossRef]
44. Wahlström, N. Toward a conceptual framework for understanding cosmopolitanism on the ground. *Curric. Inq.* **2014**, *44*, 113–132. [CrossRef]
45. Kerkhoff, S.; Spires, H.A.; Wanyonyi, P. Teaching new literacies and inquiry: A grassroots effort to bring about educational change in Kenya. J. Adolesc. Adult Lit. *J. Adolesc. Adult Lit.* **2020**, *64*, 145–156. [CrossRef]

46. Creswell, J.; Plano Clark, V. *Designing and Conducting Mixed Methods Research*; SAGE Publishing: Thousand Oaks, CA, USA, 2018.
47. National Assessment of Educational Progress (NAEP) Questions Tool. National Center for Education Statistics. 2018. Available online: https://nces.ed.gov/nationsreportcard/nqt (accessed on 8 August 2019).
48. American Association for the Advancement of Science (AAAS) Project 2061 Science Assessment Item Bank. 2018. Available online: http://assessment.aaas.org (accessed on 8 August 2019).
49. Nunnally, J.C. *Psychometric Theory*, 2nd ed.; McGraw-Hill: New York, NY, USA, 1978.
50. Jones, B.D. Motivating students to engage in learning: The MUSIC Model of Academic Motivation. *International. J. Teach. Learn. High. Educ.* **2009**, *21*, 272–285.
51. Jones, B.D. User Guide for Assessing the Components of the MUSIC®Model of Motivation. 2017. Available online: http://www.theMUSICmodel.com (accessed on 8 August 2019).
52. Chittum, J.; Jones, B.D. Identifying pre-high school students' science class motivation profiles to increase their science identification and persistence. *J. Educ. Psychol.* **2017**, *109*, 1163–1187. [CrossRef]
53. Jones, B.D.; Sahbaz, S.; Schram, A.B.; Chittum, J.R. Using psychological constructs from the MUSIC Model of Motivation to predict students' science identification and career goals: Results from the US and Iceland. *Int. J. Sci. Educ.* **2017**, *39*, 1089–1108. [CrossRef]
54. Parkes, K.; Jones, B.D.; Wilkins, J. Assessing music students' motivation using the MUSIC Model of Academic Motivation Inventory. *Appl. Res. Music Educ.* **2017**, *35*, 16–22. [CrossRef]
55. Schram, A.B.; Jones, B.D. A cross-cultural adaptation and validation of the Icelandic version of the MUSIC Model of Academic Motivation Inventory. *Icel. J. Educ.* **2016**, *25*, 159–181.
56. Saldaña, J. *The Coding Manual for Qualitative Researchers*; SAGE Publications: Thousand Oaks, CA, USA, 2009.
57. Strauss, A.; Corbin, J. *Basics of Qualitative Research*; SAGE Publications: Thousand Oaks, CA, USA, 1990.
58. Cooper, B. *Empathy in Education: Engagement, Values and Achievement*; Bloomsbury Publishing: New York, NY, USA, 2011.
59. Noddings, N. *Caring: A Feminine Approach to Ethics and Moral Education*; University of California Press: Berkeley, CA, USA, 1986.
60. Brown, L. (Ed.) *New Oxford English Dictionary*; Oxford University Press: Oxford, UK, 1993; p. 803.
61. Zeyer, A.; Dillon, J. The role of empathy for learning in complex Science | Environment | Health contexts. *Int. J. Sci. Educ.* **2019**, *41*, 297–315. [CrossRef]
62. Mirra, N. *Educating for Empathy: Literacy Learning and Civic Engagement*; Teachers College Press: New York, NY, USA, 2018; p. 3.
63. Breithaupt, F. *Why Empathy Is Not the Best Basis for Humanitarianism*; Centre for Global Cooperation Research: Duisburg, Germany, 2015. [CrossRef]
64. Gallay, E.; Marckini-Polk, L.; Schroeder, B.; Flanagan, C. Place-based stewardship education: Nurturing aspirations to protect the rural commons. *Peabody J. Educ.* **2016**, *91*, 155–175. [CrossRef]
65. Krasny Marianne, E.; Tidball Keith, G. Community gardens as contexts for science, stewardship, and civic action learning. *Cities Environ. (CATE)* **2009**, *2*, 1–18. [CrossRef]
66. Dole, S.; Bloom, L.; Kowalske, K. Transforming pedagogy: Changing perspectives from teacher-centered to learner-centered. Interdiscip. *J. Probl.-Based Learn.* **2016**, *10*, 1. [CrossRef]
67. Frenzel, A.C.; Becker-Kurz, B.; Pekrun, R.; Goetz, T.; Lüdtke, O. Emotion transmission in the classroom revisited: A reciprocal effects model of teacher and student enjoyment. *J. Educ. Psychol.* **2018**, *110*, 628–639. [CrossRef]
68. Love, N. *Using Data to Improve Learning for All: A Collaborative Inquiry Approach*; Corwin Press: Thousand Oaks, CA, USA, 2009.
69. Fitzgerald, M.; Danaia, L.; McKinnon, D.H. Barriers inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters. *Res. Sci. Educ.* **2019**, *49*, 543–566. [CrossRef]
70. Asghar, A.; Ellington, R.; Rice, E.; Johnson, F.; Prime, G.M. Supporting STEM Education in Secondary Science Contexts. Interdiscip. *J. Probl.-Based Learn.* **2012**, *6*, 4.
71. Bando, R.; Näslund-Hadley, E.; Gertler, P. *Effect of Inquiry and Problem Based Pedagogy on Learning: Evidence from 10 Field Experiments in Four Countries*; National Bureau of Economic Research: Cambridge, MA, USA, 2019; p. 26280. [CrossRef]
72. Haycock, K. Collaboration: Critical success factors for student learning. *Sch. Libr. Worldw.* **2007**, *13*, 25–35. [CrossRef]
73. Akuma, F.V.; Callaghan, R. A systematic review characterizing and clarifying intrinsic teaching challenges linked to inquiry-based practical work. *J. Res. Sci. Teach.* **2019**, *56*, 619–648. [CrossRef]
74. Harris, C.J.; Rooks, D.L. Managing inquiry-based science: Challenges in enacting complex science instruction in elementary and middle school classrooms. *J. Sci. Teach. Educ.* **2010**, *21*, 227–240. [CrossRef]