education sciences

Article

STEM Project-Based Instruction: An Analysis of Teacher-Developed Integrated STEM PBI Curriculum Units

Jeanna R. Wieselmann [1,*], Marc T. Sager [2] and Brynn C. Price [2]

[1] Department of Teaching & Learning, Southern Methodist University, Dallas, TX 75275, USA
[2] Simmons School of Education & Human Development, Southern Methodist University, Dallas, TX 75275, USA
* Correspondence: jwieselmann@smu.edu

Abstract: Integrated science, technology, engineering, and mathematics (STEM) and project-based instruction (PBI) have both received increased attention as instructional approaches that allow for deep, authentic student learning. However, there has been little research that explores the overlap of these two related yet distinct approaches. In this case study, eight teacher-developed STEM PBI curriculum units for grades 1–8 were analyzed using content analysis methods. Each unit was scored for integrated STEM and PBI quality. Findings highlight strengths related to an authentic context for learning, opportunities for communication, and the development of a final product that is shared publicly. However, weaknesses were also apparent related to STEM content integration and learning goals, student voice and choice, assessment, and organization. Notably, the content analysis also illustrated that the units developed for elementary grades (1 and 5) were generally stronger than those units developed for middle-school grades (7 and 8). Implications for practice and future research are discussed.

Keywords: integrated STEM education; project-based instruction (PBI); curriculum design

Citation: Wieselmann, J.R.; Sager, M.T.; Price, B.C. STEM Project-Based Instruction: An Analysis of Teacher-Developed Integrated STEM PBI Curriculum Units. *Educ. Sci.* **2022**, *12*, 626. https://doi.org/10.3390/educsci12090626

Academic Editors: Jennifer Wilhelm, Rebecca Krall and Merryn Cole

Received: 23 August 2022
Accepted: 13 September 2022
Published: 16 September 2022

1. Introduction

With an increasing demand for science, technology, engineering, and mathematics (STEM) expertise, the quality of STEM education is of ongoing concern in the United States and around the world. Recent U.S. educational reforms reflect this concern and call for integrated STEM education. For example, *A Framework for K-12 Science Education* [1] and the Next Generation Science Standards [2] emphasize science and engineering practices supported by technology and mathematics. STEM integration is promoted as a means of increasing student interest and engagement in STEM [3], and a variety of studies have demonstrated positive outcomes for students. For example, Guzey et al. [4] found that students who were taught using an engineering design-based science curriculum showed improved attitudes toward STEM. However, a number of different approaches to STEM integration exist [5], resulting in a lack of consensus about how quality STEM instruction is enacted.

Project-based instruction (PBI) has been utilized in the U.S. for decades and has recently been advanced in conjunction with integrated STEM as a way to deepen student engagement and learning while preparing them for success in the 21st century (e.g., [6–8]). While a number of design principles and best practices in PBI have been identified, both teachers and students encounter challenges with PBI (e.g., [9,10]). The integration of STEM and PBI approaches has also been less studied than either approach in isolation. This manuscript seeks to fill a gap in the literature by considering teacher-developed integrated STEM PBI curricula using two distinct but overlapping lenses: integrated STEM and PBI. We address the research question: What are the strengths and weaknesses of teacher-developed elementary and middle-school STEM PBI curriculum units in terms of (a) STEM integration and (b) PBI design?

2. Literature Review

2.1. STEM Integration

STEM disciplines are often taught as distinct subject areas in formal educational contexts, but STEM careers frequently require a blending of content knowledge from different disciplines [3]. STEM integration merges the disciplines through authentic contexts in order to increase engagement and interest in STEM for all students, regardless of whether they eventually pursue STEM careers [3,11]. While teachers generally value STEM education [12], they hold a range of conceptions of integrated STEM [13,14], and these conceptions are reflected in the curriculum materials they develop [15]. Further, a number of different approaches to content integration exist [16], ranging from superficial connections to interdisciplinary integration that meaningfully connects domains in order to simultaneously serve the goals of each discipline [5]. Thus, there is no single approach to integrated STEM education that has translated to curriculum design and instructional practices.

Quality science instruction is largely recognized as shifting away from memorization of discrete facts to using and applying scientific concepts through authentic practices. *A Framework for K-12 Science Education* [1] and the Next Generation Science Standards [2] highlight a range of science and engineering practices that should be fostered among students, including: asking questions (for science) and defining problems (for engineering); developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations (for science) and designing solutions (for engineering); engaging in argument from evidence; and obtaining, evaluating, and communicating information. With engineering practices as well as explicit attention to the use of mathematics in the Next Generation Science Standards, integrated STEM instruction is often enacted within science classrooms.

Despite growing attention to STEM integration, a number of challenges have been documented in relation to integrated STEM curriculum and instruction. For example, Hutner et al. [17] found that teachers who were implementing STEM design challenges experienced goal conflicts related to pacing and mandated testing. Similarly, Marshall et al. [18] found that curricula designed to emphasize conceptual development, con-construction of knowledge, and student autonomy were seen to be in tension with teacher goals related to assessment, including vocabulary knowledge, individual student accountability, and efficient use of time. Further, teachers often feel underprepared to implement integrated STEM instruction [19,20] and are faced with inadequate time for both preparation and instruction of integrated STEM activities and units [20]. Thus, although the research literature strongly supports instruction that focuses on deep conceptual development, teachers continue to feel as though this approach may come at the cost of student performance on standardized tests and are faced with the challenge of finding time for integrated STEM instruction.

2.2. Project-Based Instruction

Over the past 20 years, the research literature has supported the use of PBI as a tool for purposeful instruction [21–24]. Although there is no one definition of PBI, there is consensus around several elements that must be present for quality PBI: a driving question or problem to anchor student learning; a focus on learning goals; student participation in disciplinary practices; collaboration; scaffolding to support students; use of technology to enhance understanding; opportunities for students to receive and utilize feedback; and a tangible final product or artifact [9,25–32]. Scholars also advocate for project authenticity and student-centered instruction as key elements of quality PBI [21,22,24] and point to the need for students to develop sub-driving questions to shape their own learning trajectories [32]. Further, the final product or artifact should build from milestones that students reach throughout the PBI process [33], be made public and presented to an audience [32,34], and utilize experts as collaborators [35].

Studies of PBI have considered whether PBI is effective in improving student outcomes. Condliffe et al. [34] literature review suggested that PBI is a promising strategy, but is not fully proven because of issues with the quality of research design and instrumentation.

Chen and Yang [36] conducted a meta-analysis of 30 journal articles and concluded that PBI was associated with positive student achievement outcomes compared to traditional instruction; however, the positive effects were stronger in the social sciences than they were in science and mathematics. Notably, the positive results associated with PBI include a range of outcomes, including improved content knowledge [37,38], science and technology self-efficacy [39], behavioral and cognitive engagement [40], and perceptions of STEM [41].

Despite these promising results related to PBI, teachers encounter a range of challenges in implementing quality PBI [32,42]. They often struggle to develop and implement questions that adequately drive the unit and to grant autonomy to students to develop their own learning goals and questions [29]. Teachers often conflate PBI with hands-on activities [43], and the final artifacts that result from PBI in science classrooms rarely serve a real purpose, which reduces their authenticity [25]. In addition, time and project management are significant obstacles [44]. Further, the use of PBI within integrated STEM contexts requires additional considerations for supporting student learning across multiple disciplines, including benchmark lessons that ensure opportunities to learn key content [32]. Adequate professional development (PD) in PBI is necessary for successful implementation [45,46], and it may take 2–3 years for positive outcomes to result with PBI [43]. Thus, the complexities of PBI continue to pose challenges related to PBI curriculum design and implementation.

2.3. Teachers as Curriculum Designers

Curriculum design is complex, but teachers who engage in this work have opportunities to experience professional growth [47] through analysis, reflection, and development of curriculum materials [48]. When the curriculum design process is collaborative in nature, teachers have further opportunities to learn from other educators as they build from their unique experiences [49,50]. However, many teachers do not have expertise in curriculum development, leading to mixed quality of teacher-developed curriculum materials [51].

While there is a need for further research on teacher-developed STEM PBI curricula [52,53], the challenges with STEM PBI curriculum development have been documented in several studies. Teachers in Slavit et al. [54] case study of a new STEM school were provided with time to collaborate on integrated STEM project planning during the summer and each week of the school year; even with this time clearly allocated for curriculum development, however, few projects were fully developed to be implemented in the classroom. In an analysis of teacher-developed integrated STEM curriculum units, Guzey et al. [4] found that they ranged in quality, with many rated low to medium quality. Roehrig et al. [55] found that teacher-developed integrated STEM units often lacked coherence, particularly for curricula focused on Earth and life science topics. Teachers may struggle to address academic standards and maintain high cognitive demand through projects [54], and these challenges with curriculum design extend to implementation of teacher-developed science PBI units, with key characteristics (e.g., driving questions, sustained inquiry, student voice and choice, content learning, and critique and revision) more challenging to implement [29,53]. Thus, PD specifically tailored to meet curriculum design needs is necessary before teachers can be expected to engage successfully in design tasks [42,48].

3. Theoretical Framework

This study is grounded in two key frameworks. First, Moore et al. [56] framework for integrated STEM instruction provides a set of six key tenets for developing and assessing integrated STEM curricula. These tenets include: (1) a motivating and engaging context; (2) an engineering design challenge; (3) opportunity to learn from failure through redesign; (4) inclusion of mathematics and/or science content; (5) student-centered pedagogies; and (6) an emphasis on teamwork and communication. These six tenets were used to define quality integrated STEM curricula for the purpose of this study.

Second, the PBLWorks Gold Standard Project Based Learning framework [57] outlines seven essential elements of quality project-based learning (PBL) or PBI projects: (1) a challenging problem or question; (2) sustained inquiry; (3) authenticity; (4) student voice and choice; (5) reflection; (6) critique and revision; and (7) a public product. Notably, there is considerable overlap and joint goals across these two frameworks. For example, the motivating and engaging context tenet of quality STEM integration coincides with a challenging problem or question and authenticity in the PBI framework. Both frameworks also emphasize the importance of iteration and revision. Thus, while these frameworks are distinct, they can work in concert within a single curriculum unit.

4. Context and Research Design

This study utilized a multiple case study design [58] to analyze eight teacher-developed integrated STEM PBI units. These curriculum units were developed in anticipation of implementing the units in a new PreK-Grade 8 STEM school in the coming years. The STEM school was located in the Southwest U.S. in a state that had not adopted the Next Generation Science Standards [2] or Common Core State Standards [59]. A summer PD series led by university-based staff introduced participating teachers to PBI and STEM integration. Five initial days of PD workshops focused on curriculum development and academic standards analysis. These workshops were followed by two curriculum development cycles. Each cycle lasted approximately 3–4 weeks and included opportunities for teams of teachers to develop their ideas, receive feedback from other teachers and the PD facilitator, and revise their curriculum units before the end of the cycle. Twelve teachers worked in teams of three to write the units, and each team wrote two units over the course of the summer. Teachers had a range of teaching experience both within and beyond the district of the STEM school, and none were affiliated with the STEM school beyond their curriculum design work. Teams were provided with a PBI design checklist and a PBI mapping document. None of the authors of this paper were involved in the summer PD or in the development of the units. An overview of the resulting units is shown in Table 1.

Table 1. STEM PBI Curriculum Units.

Grade	Unit Title	Disciplines	Driving Question	Culminating Project
1	Grow Your Own Veggies!	Science Math ELAR Social Studies	How can we, as gardeners, bring fresh fruits and vegetables to our community?	Students design a container garden and host a community workshop describing their designs and the type of soil that is best to grow plants in their backyards to give everyone the capability to create fresh food sources.
1	We Depend on Each Other	Science Math ELAR	How can we, as conservation activists, create awareness of the need to preserve the prairie ecosystem along the local river?	Students create an informational display and trail markings to present their findings to community members.
5	Flooding on the Local River	Science Math ELAR Social Studies	How can we, as stormwater operations managers, inform the city council about the impact of flooding using a website to improve the existing flood prevention system in our community?	Students present a website to the city council members to inform them of the flood risk in their community and implore them to continue construction on a floodway extension project while emphasizing the impact to the community if levees extensions are not built.
5	What's the "Matter" with our Water?	Science Math ELAR Social Studies	How can we, as chemical engineers, persuade the city council to improve water quality at the local lake?	Students write and present a proposal and filtration model with the intent to persuade the city council about the importance of improving water quality at the lake.
7	Campaign Against Catastrophe	Science Math ELAR Social Studies	How might we prepare ourselves and our community for a catastrophic event?	Students present media campaigns to promote individual and community preparedness for a chosen catastrophic event (floods, tornados, hurricanes).
7	Community Wellness Initiative	Science Math ELAR	How might we promote wellness on our campus?	Students create booths to advertise and advocate for their campus wellness initiative for a predetermined STEM school Wellness Night. Individually, they develop a written proposal to accompany their oral presentation of the initiative and their booth artifact.

Table 1. *Cont.*

Grade	Unit Title	Disciplines	Driving Question	Culminating Project
8	Why Chemistry Really "Matters" in the Community	Science Math ELAR Social Studies	How can we, as filmmakers, document the chemical hazards present in the community to raise awareness and propose solutions to reduce the environmental impact of these hazards?	Students create a documentary challenging the status quo of environmental injustice caused by disproportionate chemical hazards found in the community.
8	Gentrification and Environmental Injustice in Our Community	Science Math ELAR Social Studies	What can the city, school district, and residents of the community do to address the effects of gentrification and environmental injustice that have taken place in the community?	Students craft a joint memo addressed to both city leaders and residents of the community outlining the effects of gentrification and environmental injustice in the community. They also present recommendations on how to mitigate these effects.

Instruments and Data Analysis

We conducted content analysis to analyze textual data and explore the information conveyed by the eight curriculum units [60,61]. Because our analysis was based on existing models and theories related to quality STEM integration and PBI, we utilized a directed or deductive approach to our content analysis [62].

Building from our theoretical frameworks, we selected two existing instruments to evaluate the quality of the units. First, the STEM Integration Curriculum Assessment (STEM-ICA) is a rubric developed to evaluate the quality of STEM integration of a curriculum unit [4]. The rubric consists of nine elements of quality based on Moore et al. [56] framework for integrated STEM: a motivating and engaging context, engineering design challenge, integration of science content, integration of mathematics content, instructional strategies, teamwork, communication, performance and formative assessment, and organization. Because the curricula developed as part of this project also included English language arts and reading (ELAR) and social studies integration, we added two additional elements, mirroring the rubric criteria for science and mathematics integration. Each item is scored on a five-point scale, with possible scores including 0 (not present), 1 (weak), 2 (adequate), 3 (good), and 4 (excellent). In considering which score is most appropriate for the item, scorers consider a number of yes/no questions about specific elements of the unit in relation to the item, then provide evidence for the score that is selected [4]. For example, the item focused on a motivating and engaging context includes six yes/no questions that capture a range of elements, including students drawing upon personal knowledge and experiences, motivating students from different backgrounds, including current events or issues, and including global, economic, environmental, or societal concerns [4]. Thus, in reaching a score for the single item, all of these factors are considered. Units also receive an overall rating that summarizes their effectiveness in supporting student learning.

Second, the existing PBI design rubric [63] was established by the Buck Institute for Education to evaluate projects as they align to the PBLWorks Gold Standard framework [57]. The rubric consists of eight dimensions: key knowledge, understanding and success, challenging problem or question, sustained inquiry, authenticity, student voice and choice, reflection, critique and revision, and public product. Each item is scored on a three-point scale, including 1 (lacks features of effective PBI), 2 (needs further development), and 3 (includes features of effective PBI).

Scoring was first completed independently by three researchers. Following independent scoring of each unit, the researchers met to debrief and discuss each item until they reached consensus on the score. Throughout this process, they continued to iteratively refine their scoring guides to provide clear criteria and examples. Constant comparative analysis strategies [64] were used to identify consistencies and differences across curriculum units and ensure the scoring criteria were applied consistently.

5. Findings

5.1. STEM-ICA

In addition to the 11 items we used from the STEM-ICA rubric, each unit was given an overall score to indicate its quality of STEM integration [4]. Across the eight units included in this study, the overall STEM-ICA scores consisted of three scores of 1 (weak), four scores of 2 (adequate), and one score of 3 (good). The strongest unit was the fifth-grade unit *What's the "Matter" with our Water?*, which addressed the water quality of a nearby lake. There was a distinct difference between the quality of the elementary units and the middle-school units. The elementary units were all adequate, with the strongest unit rated as good. In contrast, the middle-school units were mostly weak, with all three of the 1s coming from these units and only one being deemed adequate. Table 2 includes each unit's scores for the 11 individual items and the overall rating on the STEM-ICA rubric.

5.1.1. Motivating and Engaging Context

Across the eight units, the context for learning was generally motivating and engaging to students. All units were scored as either 2 (adequate) or 3 (good) on this criterion. Common strengths included situating the learning within local community contexts and considering contemporary environmental and societal issues. For example, the fifth-grade unit *Flooding on the Local River* emphasized local flooding issues on a river in close proximity to the STEM school. The eighth-grade unit *Why Chemistry Really "Matters" in the Community* focused on environmental toxins and identifying the lasting environmental and health effects of a local lead smelting plant and other companies that generated hazardous waste. With real-world implications local to students' own communities, these contexts provided rich motivation for learning. However, in many cases, the units did not make explicit attempts to draw upon students' prior knowledge and experiences. Such efforts would strengthen the units and help ensure that the units would motivate and engage students from differing backgrounds.

5.1.2. Engineering Design Challenge

The units demonstrated a range of quality on the engineering design challenge criterion, with five units scoring a 1 (weak), two units scoring a 2 (adequate), and one unit scoring a 3 (good). Notably, the middle-school units all received scores of 1, whereas there was more variety in the scores of elementary units. The strongest unit, *What's the "Matter" with our Water?* was designed for the fifth grade and focused on evaluating water quality in a lake just outside the STEM school and proposing solutions for improving the water quality. The unit included explicit instruction on the engineering design process and provided students with an opportunity to design a water filtration system, giving them a chance to engage in many engineering practices. However, they had limited opportunities to learn from failure and incorporate their learning into a redesign, so the engineering in this unit could have been strengthened. Common shortcomings across units included the need for clear criteria and constraints to guide students' design work and connections to the field of engineering to promote a greater understanding of the profession. Among the units that received lower scores, an explicit engineering design challenge was not present, but there were some embedded opportunities to engage in engineering habits of mind, such as systems thinking, creativity, and perseverance. Additional opportunities to engage in engineering design would be beneficial across the majority of the units.

Table 2. STEM-ICA Rating by Unit.

Grade	Unit Title	Motivating and Engaging Context	Engineering Design	Science Content	Math Content	ELAR Content	Social Studies Content	Instructional Strategies	Teamwork	Communication	Assessment	Organization	Overall Rating
1	Grow Your Own Veggies!	3	2	2	1	3	2	2	2	3	1	1	2
1	We Depend on Each Other	2	1	2	2	4	0	2	1	3	1	1	2
5	Flooding on the Local River	3	2	2	1	3	2	1	1	3	2	2	2
5	What's the "Matter" with our Water?	3	3	3	3	4	2	2	3	4	3	2	3
7	Campaign Against Catastrophe	3	1	2	2	2	2	2	2	3	1	1	2
7	Community Wellness Initiative	2	1	2	2	1	0	2	2	3	1	1	1
8	Why Chemistry Really "Matters" in the Community	2	1	2	1	2	1	2	2	3	1	1	1
8	Gentrification and Environmental Injustice in Our Community	2	1	1	2	3	1	2	2	3	1	1	1

5.1.3. Integration of Science Content

In general, the curriculum units integrated science content to an adequate level (score of 2), with only two of the units receiving scores other than 2. With a range of issues present across units, there were no consistent strengths related to science content integration. Aside from the six units receiving scores of 2 (adequate), one unit received a 1 (weak) for integration of science content. This unit, *Gentrification and Environmental Injustice in Our Community*, was an eighth-grade unit that was rated as having weak science integration for a number of reasons. For example, none of the science academic standards selected for the unit (e.g., considering how organisms and populations in an ecosystem utilize and compete for biotic and abiotic resources) were fully addressed, and very few components were explicitly addressed at all. Further, there were no hands-on science investigations that allowed students to engage in science practices, and the bulk of the activities focused on reading informational texts. A lack of opportunities to engage in science investigations was a common issue across most of the units, which often relied heavily on informational texts, videos, and in some cases confirmation labs where students followed a prescribed set of steps.

Only one unit, *What's the "Matter" with our Water?*, designed for the fifth grade, received a score of 3 (good) for science content integration. This unit included strong connections to science standards through a number of activities and also provided students with opportunities to engage in hands-on science investigations where they utilized a greater range of science practices. However, this unit still showed room for improvement in making connections across science activities to help students develop a coherent understanding of the science concepts. Issues with the coherence of science integration were common across all of the units, with the activities that explicitly addressed science standards often disconnected from the project and seemingly added in for the sole purpose of addressing a standard.

5.1.4. Integration of Mathematics Content

The integration of mathematics content for the eight units varied, with three units scoring a 1 (weak), three units scoring a 2 (adequate), and one unit scoring a 3 (good). Similar to the engineering design challenge and integration of science content criterion, the strongest unit was the fifth-grade *What's the "Matter" with our Water?* unit, which included explicit instruction of measurement (mass and volume) in station activities, using scale models, and ordering decimals. These activities were tightly linked to the unit context, demonstrating authenticity and coherence with the other activities. In contrast, most other units included inauthentic mathematics lessons that did not meaningfully contribute to the culminating project. Most of these lessons were written to address a standard rather than promoting a deeper understanding of the phenomenon under study. To strengthen the quality of mathematics integration, mathematics activities and lessons need to more closely align with the context and learning goals of the project and promote a coherent understanding of mathematical thinking.

5.1.5. Integration of English Language Arts and Reading Content

The effectiveness of ELAR integration ranged across units, though patterns emerged in the scoring of this criterion. While the first- and fifth-grade units regularly exhibited strong ELAR integration, the seventh- and eighth-grade units did not. The curriculum for younger classrooms earned two scores of 3 (good) and two of 4 (excellent); with the shift to middle school, however, came two scores of 2 (adequate), one of 1 (weak), and only one score of 3 (good). This disparity in scores revealed common strengths and weaknesses that often foretold if a unit would score high or low for this criterion. For instance, the most impactful units for this content area embedded ELAR instruction that was both explicit and consistent within the context of the unit and the problem being addressed by the design challenge. In doing so, these units promoted a sense of coherence, in terms of both the disciplinary practices of ELAR and of the unit as a whole. The first-grade *We Depend on*

Each Other unit provided an "excellent" example of ELAR integration, with the inclusion of several writing workshops aligned with the scientific process of research, as well as with the unit's milestone tasks and final artifact. The one "good" eighth-grade unit, *Gentrification and Environmental Injustice in Our Community*, also included some explicit ELAR instruction with writing workshops and opportunities for students to listen, speak, and write; even so, the unit failed to address all state standards designated as being taught within the unit. In contrast, units earning lower scores suffered from a lack of frequent and explicit ELAR instruction, creating an absence of coherence. The seventh-grade unit *Community Wellness Initiative*, a "weak" instance of ELAR integration, did not include explicit instruction and demonstrated a merely implicit connection to standards, which was another common weakness of low-scoring units. Underperforming curriculum units would be strengthened with the incorporation of explicit, consistent ELAR instruction that meaningfully ties to both state standards and to the unit itself. Effective ELAR integration, as modeled by *We Depend on Each Other*, demonstrated the ability to reinforce the acquisition of relevant STEM knowledge applicable to the engineering design challenge, while also stimulating the development of valuable reading and writing skills.

5.1.6. Integration of Social Studies Content

Across the units, the integration of social studies content was lackluster and a missed opportunity for further cross-disciplinary connections, with two units scoring a 0 (not present), two units scoring a 1 (weak), and three units scoring a 2 (adequate). One of the weakest units for this construct was designed for the seventh-grade *Community Wellness Initiative* unit, which encompassed mental health, exercise, and nutrition. This unit completely omitted any state standards relating to social studies despite various standards offering opportunities for social studies integration. For example, relevant social studies standards relating to the economic concepts of supply and demand, commerce, and agriculture production could have been incorporated. Additionally, this unit did not address the pertinent contextual issue of urbanization and the consequences of related policies, such as the existence of food deserts in the local community. Among the other units, it was common to see social studies standards present, but they were not covered in depth, nor did they promote a coherent understanding of the concepts. Additional information and support for fully implementing the standards to promote a clear and coherent understanding of the social studies content and its connections to the broader problem are needed across many of the units.

5.1.7. Instructional Strategies

Across the eight units, there was relative consistency in regards to instructional strategies present, with one unit scoring a 1 (weak) and the remaining seven units scoring a 2 (adequate). For example, in the weakest unit, the fifth-grade *Flooding on the Local River*, the instructional strategies were usually hands-on (cookbook labs) or minds-on (reading), but not both. This unit had few opportunities for student choice and also did not provide adequate guidance for teachers to understand how to best implement the activities. Across the units, there was a mix of student-centered activities and teacher-directed activities, but most of the standards were addressed through traditional teacher-directed activities. The lessons and activities within the unit were often poorly connected to the overall problem and context, creating issues related to student understanding of why each lesson and activity was important. There was also a need for more explicit opportunities for argumentation to support students in developing skills for advancing and evaluating a variety of ideas.

5.1.8. Teamwork

All eight units included opportunities for students to work with peers in small group activities. However, the frequency and quality of these collaborative opportunities varied greatly. Five of the units were rated as adequate (score of 2), two were rated as weak (score of 1), and only one was rated as good (score of 3). Notably, this variation in the quality of teamwork was only present in the elementary units, whereas the middle-school units were all rated as adequate. The two units receiving weak ratings were the first-grade *We Depend on Each Other* unit that focused on interdependence among organisms in a nearby river and the fifth-grade *Flooding on the Local River* unit. Both of these units included primarily individual activities that were brought together in a final group product. However, there was no process for integrating disparate individual work into a cohesive group product that would include mutual accountability, and it would be possible for a single student's work to be turned in as the group product. These issues with clear purposes and processes for collaboration that maintained individual responsibility were common across units.

The unit that was rated as good was the fifth-grade *What's the "Matter" with our Water?* unit. Unique strengths of this unit included clear roles and expectations for teamwork, including rubrics for use by both students and the teacher, and a consistent approach to teamwork that provided students with time every day to work in groups. The presence of instructional strategies to support positive teamwork was noteworthy in comparison to the other units and helped ensure that students would be able to productively engage as small groups.

5.1.9. Communication

Communication emerged as the most consistently strong criterion of effective STEM integration among the eight units. Seven of the eight units scored a 3 (good), and the other scored a 4 (excellent). Units exhibited the common strength of including multiple opportunities for students to develop their oral and written communication skills while engaging with the curriculum material. For example, in *Campaign Against Catastrophe*, a seventh-grade unit with a score of 3, students were required to communicate science concepts in both formal and informal contexts, and each performance task targeted the development of effective communication skills. Designed for fifth-grade, *What's the "Matter" with our Water?*, the only unit to score a 4, demonstrated similar strengths; however, this unit also required students to communicate engineering thinking and solutions to an authentic audience. Further, this successful unit did not succumb to a common weakness among units: the absence of explicit argumentation requirements, and/or infrequent or weak opportunities to use argumentation strategies. For example, *We Depend on Each Other*, a first-grade unit, included opportunities for communication but failed to include explicit prompts for students to use argumentation as a tool for communicating their learning to an audience. Nevertheless, the inclusion of an argumentation requirement did not dispel all weaknesses of a curriculum unit, as the requirement must be present alongside impactful curriculum design and implementation. For instance, the eighth-grade unit *Gentrification and Environmental Injustice in Our Community* did include argumentation, but as was the case with *Campaign Against Catastrophe*, it did not fully require students to communicate engineering thinking and solutions to an audience. Additionally, the fifth-grade unit *Flooding on the Local River* included requirements for argumentation but did so to a limited extent. Therefore, while all units earned high scores for this criterion, intentional, explicit requirements for argumentation strategies and engineering communication would further strengthen their potential impact on student learning and skill development.

5.1.10. Performance and Formative Assessment

All but two of the curriculum units earned a score of 1 (weak) for their efforts to incorporate assessments that effectively measured students' knowledge and skill acquisition. Common weaknesses included issues with rubrics (including inconsistent usage of rubrics, broad rubrics not tailored to the context of the unit, and the absence of rubrics entirely); a lack of teacher guidance for the implementation of the unit assessments, partially resulting from the absence of functional rubrics; assessments that did not tie meaningfully to state standards and did not clearly address content or skill learning; and, generally, a lack of clarity as to how students would be assessed. *Grow Your Own Veggies!*, a first-grade unit with a score of 1, exhibited a number of these weaknesses. For instance, while the unit outline mentioned the introductions of rubrics at the start of the unit, these rubrics were not provided to readers of the curriculum and were not referenced again at any point in the unit. Further, the unit did not prompt substantial formative assessment on the part of the teacher, instead relying primarily upon peer feedback. This peer feedback actually emerged as one of the few strengths among units. Many units required students to provide feedback to classmates, though not always in a structured format.

What's the "Matter" with our Water?, a fifth-grade unit with a score of 3, demonstrated this strength and was unique compared to other units in that it provided clear structures for peer feedback. Unlike weaker units, this unit also included specific criteria that needed to be addressed by students in each performance task; further, it frequently referenced relevant rubrics, included a number of them, and prompted instructors to explain the rubrics in relation to the unit's products on only the second day of the unit. Similarly, fifth-grade teachers of the *Flooding on the Local River* unit (which scored a 2) were prompted to introduce project rubrics in the early stages; though unlike *What's the "Matter" with our Water?*, examples of rubrics for instructors were absent. Therefore, curriculum units would be strengthened by the development of rubrics that clearly relate to both the context of the unit and its associated standards, a balance between structured teacher and peer formative assessment, and supports for teachers that allow them to assess student learning and development efficiently. Further, with all units including some small group elements, there was an additional need for greater distinction between individual and group assessments, including support for teachers in carrying out these assessments.

5.1.11. Organization

Six of the eight curriculum units scored a 1 (weak) for this criterion, while the others—both fifth-grade units—scored a 2 (adequate). All units failed to include an instructional calendar to outline the implementation of the curriculum on a daily basis, thereby withholding necessary teacher supports along with any assurance of feasibility. The curricula also lacked teacher guidance with the absence of essential details about central tasks within the units. For example, *We Depend on Each Other* required first-grade students to engage in research that would be incorporated into performance tasks, yet the unit did not include information about how students would acquire such data. Additionally, many units failed to include activities and lessons that flowed in a logical and sequential order. Occasionally, broad themes provided some clarity on the intended flow of the unit, and other times, a select portion of a unit's activities connected fairly well to one another; rarely, however, did a unit flow coherently from the beginning to its end. Other weaknesses included the absence of learning objectives and goals and a lack of explicit connections between instructional material and associated state standards, which could lead to important content not being taught or emphasized to students. Though these weaknesses largely overshadowed any strengths, a number of strengths did emerge. For instance, *Flooding on the Local River*, with a score of 2, included sub-headings throughout the unit document to summarize the primary focus and intention behind a group of lessons or activities; further, the unit's performance tasks built upon each other. Even so, the presence of strengths did not guarantee a higher score, as *Community Wellness Initiative* also included sub-headings in its instructional pathway, but its weak organizational structure rendered the benefit from this strength negligible. While the organization of the units was weak, the inclusion of instructional calendars, more detail about lessons and activities, and explicit connections from lessons and activities to the broader context of the unit would substantially alleviate these structural shortcomings.

5.2. Gold Standard PBI

Unlike the STEM-ICA, the rubric for Gold Standard PBI does not include an overall score of the unit's quality. Thus, in the following sections, we describe patterns in scores for each individual item, scored on a three-point scale from 1 (lacks features of effective PBI) to 3 (includes features of effective PBI). Table 3 includes each unit's scores for the eight items.

Table 3. PBI Rating by Unit.

Grade	Unit Title	Student Learning Goals	Challenging Problem or Question	Sustained Inquiry	Authenticity	Student Voice & Choice	Reflection	Critique & Revision	Public Product
1	Grow Your Own Veggies!	1	1	2	2	2	1	1	3
1	We Depend on Each Other	2	1	2	2	2	2	2	3
5	Flooding on the Local River	2	2	2	2	2	2	2	3
5	What's the "Matter" with our Water?	2	2	2	2	1	2	3	3
7	Campaign Against Catastrophe	1	2	1	2	2	2	2	3
7	Community Wellness Initiative	1	2	2	2	2	2	2	3
8	Why Chemistry Really "Matters" in the Community	1	1	2	2	2	1	2	3
8	Gentrification and Environmental Injustice in Our Community	1	1	2	2	1	1	2	3

5.2.1. Student Learning Goals

Five of the eight units lacked features of effective PBI (score of 1) for student learning goals because they did not provide any specifics about learning goals beyond listing academic standards. Without breaking down standards into clear and specific learning goals and indicating which learning goals would be addressed in each activity, it was difficult to ascertain the extent to which students would complete meaningful learning each day. Further, these units listed a variety of success skills that would be targeted (e.g., inquiry, problem-solving, advocacy), but offered no pathways for teaching and assessing these skills.

Only three of the units (first-grade *We Depend on Each Other*, fifth-grade *Flooding on the Local River*, and fifth-grade *What's the "Matter" with our Water?*) included student learning goals and received a score of 2 (needs further development). Notably, all three of these units were developed for elementary grades. Despite including learning goals, these goals were often focused on basic recall-level knowledge. Further, they included a number of sub-components that would be difficult to achieve in a single day and that diluted the focus of the activity. For example, one of the *Flooding on the Local River* unit learning goals was: "Students will present and summarize their inferences and synthesize findings to describe how and why people modified their environment by using flood prevention strategies that allow organisms to live and survive in their environment, including collecting, organizing, displaying, and interpreting data." While each element of this learning goal is important, distinct learning goals that focus first on data collection, organization, display, and interpretation followed by summarizing and presenting those findings would be more effective at guiding both teachers and students.

5.2.2. Challenging Problem or Question

Across the eight units, there was an even distribution of those lacking effective PBI features (four units with a score of 1) and those needing further development (four units with a score of 2). There was no difference between elementary- and middle-school units on this criterion. In general, the units had interesting problems with the potential for meaningful learning. However, in some cases, the driving question focused students on a single approach to solving the problem, limiting the level of challenge students would face in exploring the problem. For example, the fifth-grade *Flooding on the Local River* unit centered on the driving question: How can we, as stormwater operations managers, inform the city council about the impact of flooding using a website to improve the existing flood prevention system in our local neighborhood? While the flooding context was meaningful, rather than allowing for a more open-ended exploration of the issue, this question guided all students to use a website to advocate to the city council. While some of the driving questions were more open-ended in nature and seemed to allow for multiple solutions, the instructional activities did not support the pursuit of different solutions, again funneling students toward a single solution or solution pathway. Some of the driving questions were not understandable to students. For example, the first-grade *We Depend on Each Other* driving question was: How can we, as conservation activists, create awareness of the need to preserve the prairie ecosystem along the Local River? With a number of complex academic vocabulary terms, this question would not allow first-graders to engage from the outset of the unit. Some of the units further struggled to maintain consistent links to the driving question throughout the unit, instead seeming like a series of tasks only somewhat related to one another.

5.2.3. Sustained Inquiry

Seven of the eight units received a score of 2 (needs further development) in relation to the sustained inquiry criterion. One unit, the seventh-grade *Campaign Against Catastrophe* unit, was distinct in that it received a score of 1 (lacks effective PBI features). This unit was composed of a series of tasks that did not clearly relate to a single focus for the inquiry. For example, students read about catastrophic events; then did a science lab on conduction, convection, and radiation; then visited an environmental center to learn about ecosystems. While these activities could have been meaningfully linked to one another, no attempts were made to do so, likely leaving students with the impression that they were disconnected. Further, the unit did not include opportunities for students to generate questions to guide inquiry or affect the path of the project; this shortcoming was common across most of the other units as well. While some of the units included a chance for students to identify what they already knew and what they needed to know, these ideas did not substantively shape the path of inquiry. Many of the units also focused on information-gathering rather than engaging students in deeper inquiry into topics of interest.

5.2.4. Authenticity

Authenticity was consistent across the units, as all eight scored a 2 (needs further development). Each unit centered on a real-world problem and was often situated in the local community. For example, the first-grade *Grow Your Own Veggies!* unit had students explore ways to improve food access by creating a community garden and included opportunities for students to engage in real-world tasks using authentic tools and materials. However, despite strong real-world contexts, the units often lacked explicit connections to students' personal concerns, interests, and identities. Across the units, there were few opportunities for students to share their own experiences in relation to the topic of interest, and even brief connections to students as individuals would have strengthened the authenticity of the units.

5.2.5. Student Voice and Choice

A majority of the curriculum units earned a score of 2 (needs further development) for this criterion, meaning that learners were typically given limited opportunities to express their voice and make choices throughout the unit. Two units, one designed for fifth-grade and the other for eighth-grade, scored a 1 (lacks features of effective PBI). Every unit demonstrated the need for more student independence; however, a number of units—particularly the units with a score of 1—also exhibited a need for increased teacher guidance before students assumed independence in completing activities. For example, the fifth-grade *What's the "Matter" with our Water?* lacked the potential of multiple solutions to the engineering challenge and also involved intense direct instruction on specific topics, including a number of slide presentations given by the teacher on key science concepts. In contrast, the unit later expected students to build a scale model of a nearby lake and its pollutants, guided primarily by a generic lesson plan on model-building pulled from a website and other "online resources." These resources were insufficient in helping teachers guide students to success in their independent modeling work. In other units, student choice was often limited to unimportant matters that did not meaningfully impact their final products. Curriculum units would therefore benefit from intentional and systematic incorporation of student voice, as well as a functional balance between student freedom and teacher guidance that prepares students to work independently.

5.2.6. Reflection

Reflection was inconsistent throughout the units, with three scoring a 1 (lacks features of effective PBI) and the remaining five scoring a 2 (needs further development). The reflection that was present in the units was only surface-level and after a single activity or lesson. For example, in the fifth-grade *Flooding on the Local River* unit, the only opportunity for students to reflect was after a flooding simulation lab, and the reflective questions did not prompt a deeper understanding of students' developing knowledge. To further strengthen reflection in the units, consistent opportunities throughout the unit, as well as an overall reflection after the culmination of the unit, should be present. Further, students should be prompted to reflect on how their skills and understanding have developed and how their projects could be enacted outside of the classroom.

5.2.7. Critique and Revision

All but two units demonstrated a need for further development in relation to this criterion of PBI design. One unit, the first-grade *Grow Your Own Veggies!* unit, lacked features of effective PBI and therefore earned the lowest score of 1. The fifth-grade *What's the "Matter" with our Water?* unit included features of effective PBI and consequently earned the highest score of 3. Every unit included the opportunity for students to give and receive peer feedback, though these opportunities were rarely structured, lacking rubrics and clear criteria for commentary. Therefore, it was unclear whether these critiques would strengthen the quality of students' work. Additionally, a number of units, such as the first-grade *Grow Your Own Veggies!* unit, relied too heavily on peer feedback; as a result, the unit lacked features of effective PBI because it did not balance peer and teacher feedback as valuable forms of critique. Further, the unit displayed another common weakness for this criterion, with an unclear process for student revisions and the incorporation of feedback into any such revisions. The other first-grade unit, *We Depend on Each Other*, displayed similar weaknesses, but unlike its counterpart, it included feedback processes that involved peers, the teacher, and an expert working in a field relevant to the unit. However, it still needed further development for this aspect of PBI design, as the peer feedback outweighed other forms of critique, and the revision process was weak. Designed for fifth-grade, *What's the "Matter" with our Water?* emerged as the strongest unit for its high-quality and consistent critique and revision processes. Not only was feedback structured with the inclusion of rubrics, but this feedback was used to revise student work. Curriculum units would be further strengthened by frequent, structured opportunities for feedback from peers, the teacher, and experts. Further, this feedback should be targeted toward both content knowledge and the project's context, and students should be required to use the feedback as part of an iterative revision process that is present throughout the unit's duration.

5.2.8. Public Product

For this criterion of producing public products, the units consistently received high scores, with all eight scoring a 3 (includes features of effective PBI). For example, in the eighth-grade *Why Chemistry Really "Matters" in Our Community* unit, students were tasked with researching potential chemical hazards within their community and their harmful effects on both people and the environment. The culminating project consisted of having groups present their findings in the form of a documentary at a film festival for city leaders, environmental working groups, and community advocates to raise awareness and propose possible solutions for mitigating further adverse effects. For curriculum units to score high on this criterion, student work must be made public and presented beyond the classroom. Additionally, curriculum units need to have students explain the reasoning behind their choices, their inquiry process, how they worked, and what they learned. All eight of the units demonstrated these features.

6. Discussion

This study begins to address a gap in the literature around teacher-developed STEM PBI curricula [52,53] and highlights key strengths and weaknesses of the eight curriculum units that were analyzed. Previous research on integrated STEM units revealed that teacher-developed units were generally rated as low to medium quality [4], and that holds true in this study. Only one unit received an overall score of "good" STEM integration, with all others rated as adequate or weak. While there was no overall score for PBI quality, none of the units received the highest rating for more than two of the eight PBI criteria.

Although the units generally did not illustrate exemplary STEM PBI instruction, it is important to consider the possible causes for these weaknesses. With time frequently cited by teachers as a barrier to curriculum development and STEM PBI instruction (e.g., [17,18,54]), it is likely that time was also a significant factor in this study. Similar to findings from Slavit et al. [54] study, even with dedicated time for curriculum development, these units were not ready for full classroom implementation. They lacked detailed daily instructional pathways and often did not include resources like worksheets. Thus, it is possible that with more time, these units would have been further strengthened by the teachers who wrote them.

Despite weaknesses in overall unit quality, the units generally utilized motivating real-world contexts with elements of authenticity to engage students in learning, highlighting strengths in both STEM integration and PBI. Similarly, Guzey et al. [4] identified the context for learning as one of the strengths of teacher-developed integrated STEM curricula. By establishing a clear reason for learning through the real-world context, students have both a frame for understanding and a "need to know" the content that follows. Other researchers (e.g., [65]) have highlighted the significance of this drive to learn, which enables the development of understanding that can be applied in new contexts; therefore, this key strength of the units should not be overlooked. However, the units sometimes did not take full advantage of opportunities for even stronger contexts for learning. In particular, they often lacked explicit connections to students' identities and lived experiences, which are key in promoting positive STEM identity and ongoing engagement with STEM [66].

Related to the context for learning, driving questions for a STEM PBI unit should be feasible for students to explore, contextualized in real-world issues, and complex enough to allow students to identify sub-questions to explore over time [27,32]. Previous studies have found that teachers struggle to implement effective driving questions to guide a project [29], and despite having strong real-world contexts, the driving questions in this study presented issues as well. A number of the questions directed students toward a single approach to investigating or solving the real-world problem. Other driving questions appeared open-ended initially; even so, the instructional pathway limited the approaches students were able to take in addressing the problem, thereby limiting the authenticity of the final products students developed. Other studies of PBI have also found that teachers find it difficult to meaningfully incorporate student autonomy and choice [29] and build toward authentic final products [25]. It is noteworthy that these challenges are evident not just in implementation, but also in curriculum and planning documents.

Some of the challenges in engaging students in sustained inquiry [53] seem to derive from the tension between STEM PBI instruction and instruction focused on preparation for standardized assessments. Other studies [17,18] have documented tensions between integrated STEM and mandated testing, vocabulary practice, and student accountability. Similarly, studies of PBI have highlighted challenges related to academic standards, cognitive demand, and ensuring that key content is addressed [29,54]. The weaknesses of the teacher-developed units in the current study suggest these same tensions may be at play. While the units had strong overall contexts, these contexts did not consistently emerge throughout the duration of the unit. In particular, the performance tasks tended to be authentic to solving the problem, but the activities and lessons preceding a given performance task did not share the same authentic focus. Rather, the material attended to state academic standards, often utilizing lecture-based instruction. Although benchmark lessons that provide opportunities for students to learn key content ideas are a key part of PBI instruction, the content should be integral to the overall project [32]. In this study, many of the content-focused lessons were weakly connected to the context and project, often appearing to be inserted solely due to a tangential connection between the unit context and an academic standard; this significantly disrupted the flow and authenticity of the units. Further, similar to the findings of Roehrig et al. [55], the units in this study—largely focused on life and Earth science concepts—demonstrated issues with coherence across each unit. This fragmented structure of knowledge building does not lead to meaningful and deep understanding of STEM concepts [3].

With inconsistent connections between STEM PBI contexts and key content ideas, it is perhaps unsurprising that these units generally received low scores for science content integration (on the STEM-ICA rubric) and student learning goals (on the PBI rubric). Although content-focused lessons were included in the units as previously described, these lessons often lacked explicit learning goals, and the science-focused instruction often utilized direct, lecture-based instruction. This lack of student-centered pedagogies in the content-focused lessons is problematic because it suggests that teachers may view lecture-based instruction as the most efficient or effective means of helping students understand science concepts. While the curriculum units in Guzey et al. [4] original study of the STEM-ICA instrument generally received scores of 2–3 (with a maximum of 4) for pedagogy, the units in the present study almost exclusively received scores of 2, with one unit even scoring a 1. The units often focused on information-gathering and reading about science, sometimes including prescriptive, step-by-step science labs rather than allowing for student-led scientific inquiry.

This lack of effective pedagogical strategies and science content integration also hindered the potential effectiveness of communication opportunities in the units. Like the units in Guzey et al. [4] study, the units in the current study generally received high scores for communication. They all required students to share their final products with an audience that extended beyond the classroom, a key element of quality PBI [32,34]. However, they often lacked explicit requirements for scientific reasoning and argumentation, which are key to deep conceptual understanding [1,2,67]. Thus, despite generally strong opportunities for student communication, reasoning and argumentation emerged as a weakness among these units.

In addition to patterns of strengths and weaknesses across all eight of the units, this study also revealed interesting points of contrast across elementary (grades 1 and 5) and middle-school (grades 7 and 8) curriculum units, as the elementary units generally received higher scores than the middle-school units. Surprisingly, this was even the case for science content integration, despite the fact that the middle-school teachers were science specialists, whereas the elementary teachers were generalists responsible for teaching multiple subjects. While studies have documented that elementary teachers are often underprepared to teach STEM content [19], it is notable that the elementary units generally scored higher than the middle-school units for science content integration. A number of factors that could relate to this difference in quality across elementary and middle-school units are worth considering. First, it is possible that the elementary teachers who participated in the curriculum-writing activities were more experienced with curriculum writing, either because of the nature of their positions or because of prior PD experiences. For example, middle-school teachers may face increased pressure associated with standardized assessments, leaving them with less autonomy to develop their own curricula in their everyday teaching practice. Second, elementary teachers may already be utilizing instruction that is more closely aligned with STEM PBI practices, making the STEM PBI focus of the curriculum more familiar to them. Finally, it is also possible that elementary STEM PBI curricula are easier to write or that the lower academic rigor at these grades better lends itself to STEM PBI instruction. There is a need for further research into factors that influence the development process and quality of teacher-developed curricula across grade levels.

7. Limitations

While this study provides useful information about the quality of STEM integration and PBI within teacher-developed curriculum units, several limitations must be considered. First, content analysis can only reveal what is documented [68], in this case, what was written in the unit plans. The teachers who developed the units included in this study were provided with a particular curriculum-planning template, and thus may have felt constrained by what was included or excluded from the template. It is possible that the teacher-authors of these units had different visions for how the curricula would be enacted and would have had different interpretations than the researchers. However, given that the units were designed with the intent of being used across teachers, it cannot be assumed that implicit intentions would be implemented by all teachers using the curriculum units.

Second, these teacher-developed STEM PBI units were developed within a particular context, and as such, caution must be taken in generalizing these findings. The teachers who developed these units had a particular set of background and PD experiences, aimed to address state-specific academic standards, and completed all PD and collaborative activities online because of COVID-19. Thus, it is possible that a different PD program, a focus on different academic standards, or a different approach to collaboration (i.e., in-person) would have resulted in curriculum units with different strengths and weaknesses from those observed in this study. Additional research is warranted in this area.

Finally, the curriculum unit analysis was conducted using two existing instruments, introducing additional limitations based on these tools. One key consideration is that the STEM-ICA [4] places central importance on engineering design, which was not a major emphasis in the curriculum development process of the current study. Therefore, it is unsurprising that the units generally received low scores on the engineering-focused criterion. The instruments also utilize different rating scales, with the STEM-ICA [4] using a five-point scale, and the PBI design rubric [63] only including three distinct performance levels. Additionally, the PBI rubric does not include an overall rating of PBI design effectiveness or guidance on how to consider the overall quality of the unit. Further, many of the units scored in the middle category of this rubric, making it difficult to distinguish between lower- and higher-quality units using this instrument. While the five-point scale of the STEM-ICA allowed for greater detection of quality differences across units, very few scores of 4 (the highest rating) were given, and none were given for the overall unit. Similarly, Guzey et al. [4] also found that none of the curriculum units in their study were given an overall score of 4.

8. Implications and Future Research

This study builds on and extends the existing literature by considering the quality of teacher-developed curriculum units using two distinct but overlapping lenses: integrated STEM and PBI. Implications for both research and practice can be drawn from this study. In general, the curriculum units analyzed in this study were of relatively weak quality in terms of both STEM and PBI. Curriculum development is a challenging and time-consuming process, and this study further highlights the need for ample PD and time to support teachers developing new STEM PBI curricula. Teachers should also be supported in developing a critical lens for analyzing existing curriculum materials so that they can be adapted and strengthened, rather than having to start from scratch when developing a new curriculum unit; this may help ease some of the time-related burdens of curriculum development. Curriculum-related PD opportunities should also have an explicit focus on creating and maintaining a unit storyline both within and across lessons, with each instructional element building upon the previous to ensure a coherent unit.

This study also highlighted the tension between academic standards and STEM PBI instruction. While other studies have illustrated this tension in practice and implementation of STEM PBI units, this study offers new insights into how that tension is also reflected in instructional planning and design. Notably, this study occurred in a state that had not adopted the Next Generation Science Standards [2] or Common Core State Standards [59]. Thus, further research should explore the extent to which a state's academic standards relate to the quality of STEM PBI curriculum materials that teachers develop.

With findings revealing that elementary curriculum units were generally stronger than middle-school units, it is important to consider whether elementary and middle-school teachers may have distinct needs for support in relation to curriculum development. PD programs should carefully consider the audience of teachers and their unique strengths and needs. Further research is also needed in this area to better understand the factors that relate to the differing quality of teacher-developed curricula.

Moreover, subsequent research should explore the implementation of teacher-developed curricula, both by the teacher-authors and by other teachers not part of the development process. This would provide further insight into planned versus enacted curricula and highlight key considerations for teachers developing units to be used by others. As integrated STEM and PBI each provide strong contexts for student engagement and deep learning, additional research into curricula that combine these frameworks will have important implications for practice in the years to come.

Author Contributions: Conceptualization, J.R.W.; methodology, J.R.W.; formal analysis, J.R.W., M.T.S. and B.C.P.; writing—original draft preparation, J.R.W., M.T.S. and B.C.P.; writing—review and editing, J.R.W., M.T.S. and B.C.P.; supervision, J.R.W. All authors have read and agreed to the published version of the manuscript.

Funding: This material is based upon work supported by the Toyota USA Foundation under grant numbers G001740 and G002017. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Toyota USA Foundation.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academies Press: Washington, DC, USA, 2012. [CrossRef]
2. NGSS Lead States. *Next Generation Science Standards: For States, by States*; National Academies Press: Washington, DC, USA, 2013. [CrossRef]
3. National Research Council. *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*; National Academies Press: Washington, DC, USA, 2014. [CrossRef]
4. Guzey, S.S.; Moore, T.J.; Harwell, M. Building up STEM: An analysis of teacher-developed engineering design-based STEM integration curricular materials. *J. Pre-Coll. Eng. Educ. Res.* **2016**, *6*, 11–29. [CrossRef]
5. National Academies of Sciences, Engineering, and Medicine. *Science and Engineering in Preschool through Elementary Trades: The Brilliance of Children and the Strengths of Educators*; National Academies Press: Washington, DC, USA, 2022. [CrossRef]
6. Bell, S. Project-based learning for the 21st century: Skills for the future. *Clear. House* **2010**, *83*, 39–43. [CrossRef]
7. Kanter, D.E.; Konstantopoulos, S. The impact of a project-based science curriculum on minority student achievement, attitudes, and careers: The effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Sci. Educ.* **2010**, *94*, 855–887. [CrossRef]
8. Krajcik, J.; Schneider, B.; Miller, E.; Chen, I.-C.; Bradford, L.; Bartz, K.; Baker, Q.; Palinscar, A.; Peek-Brown, D.; Codere, S. Assessing the Effect of Project-Based Learning on Science Learning in Elementary Schools. Available online: https://mlpbl.open3d.science/techreport (accessed on 8 July 2022).
9. Barron, B.J.S.; Schwartz, D.L.; Vye, N.J.; Moore, A.; Petrosino, A.; Zech, L.; Bransford, J.D.; The Cognition and Technology Group at Vanderbilt. Doing with understanding: Lessons from Research on Problem- and Project-Based Learning. *J. Learn. Sci.* **1998**, *7*, 271–311. [CrossRef]
10. 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]
11. Stohlmann, M.; Moore, T.J.; Roehrig, G.H. Considerations for teaching integrated STEM education. *J. Pre-Coll. Eng. Educ. Res.* **2012**, *2*, 28–34. [CrossRef]
12. Margot, K.C.; Kettler, T. Teachers' perception of STEM integration and education: A systematic literature review. *Int. J. STEM Educ.* **2019**, *6*, 2. [CrossRef]
13. Kloser, M.; Wilsey, M.; Twohy, K.E.; Immonen, A.D.; Navotas, A.C. "We do STEM": Unsettled conceptions of STEM education in middle school S.T.E.M. classrooms. *Sch. Sci. Math.* **2018**, *118*, 335–347. [CrossRef]
14. Ring, E.A.; Dare, E.A.; Crotty, E.A.; Roehrig, G.H. The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *J. Sci. Teach. Educ.* **2017**, *28*, 444–467. [CrossRef]
15. Ring-Whalen, E.; Dare, E.; Roehrig, G.; Titu, P.; Crotty, E. From conception to curricula: The role of science, technology, engineering, and mathematics in integrated STEM units. *Int. J. Educ. Math. Sci. Technol.* **2018**, *6*, 343–362. [CrossRef]
16. Moore, T.J.; Johnston, A.C.; Glancy, A.W. STEM integration: A synthesis of conceptual frameworks and definitions. In *Handbook of Research on STEM Education*; Johnson, C.C., Mohr-Schroeder, M.J., Moore, T.J., English, L.D., Eds.; Routledge: New York, NY, USA, 2020; pp. 3–16. [CrossRef]
17. Hutner, T.L.; Sampson, V.; Chu, L.; Baze, C.L.; Crawford, R.H. A case study of science teachers' goal conflicts arising when integrating engineering into science classes. *Sci. Educ.* **2022**, *106*, 88–118. [CrossRef]
18. Marshall, S.L.; Nazar, C.R.; Ibourk, A.; McElhaney, K.W. The role of collective sensemaking and science curriculum development within a research-practice partnership. *Sci. Educ.* **2021**, *105*, 1202–1228. [CrossRef]

19. Banilower, E.R.; Smith, P.S.; Malzahn, K.A.; Plumley, C.L.; Gordon, E.M.; Hayes, M.L. *Report of the 2018 NSSME+*; Horizon Research: Chapel Hill, NC, USA, 2018.
20. Shernoff, D.J.; Sinha, S.; Bressler, D.M.; Ginsburg, L. Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *Int. J. STEM Educ.* **2017**, *4*, 4. [CrossRef] [PubMed]
21. Blumenfeld, P.; Fishman, B.J.; Krajcik, J.; Marx, R.W.; Soloway, E. Creating usable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. *Educ. Psychol.* **2020**, *35*, 149–164. [CrossRef]
22. Kokotsaki, D.; Menzies, V.; Wiggins, A. Project-based learning: A review of the literature. *Improv. Sch.* **2016**, *19*, 267–277. [CrossRef]
23. Morrison, J.; Frost, J.; Gotch, C.; McDuffie, A.R.; Austin, B.; French, B. Teachers' role in students' learning at a project-based STEM high school: Implications for teacher education. *Int. J. Sci. Math. Educ.* **2021**, *19*, 1103–1123. [CrossRef]
24. Thomas, J.W. *A Review of Research on Project-Based Learning*; The Autodesk Foundation: San Rafael, CA, USA, 2000.
25. Hasni, A.; Bousadra, F.; Belletête, V.; Benabdallah, A.; Nicole, M.-C.; Dumais, N. Trends in research on project-based science and technology teaching and learning at K–12 levels: A systematic review. *Stud. Sci. Educ.* **2016**, *52*, 199–231. [CrossRef]
26. Krajcik, J.; Blumenfeld, P.C.; Marx, R.W.; Bass, K.M.; Fredricks, J.; Soloway, E. Inquiry in project-based science classrooms: Initial attempts by middle school students. *J. Learn. Sci.* **1998**, *7*, 313–350. [CrossRef]
27. Krajcik, J.S.; Czerniak, C.M. *Teaching Science in Elementary and Middle School: A Project-Based Learning Approach*, 5th ed.; Routledge: New York, NY, USA, 2018.
28. Krajcik, J.S.; Shin, N. Project-based learning. In *The Cambridge Handbook of Learning Sciences*, 2nd ed.; Sawyer, R.K., Ed.; Cambridge University Press: Cambridge, UK, 2014; pp. 275–297.
29. Markula, A.; Aksela, M. The key characteristics of project-based learning: How teachers implement projects in K-12 science education. *Discip. Interdiscip. Sci. Educ. Res.* **2022**, *4*, 2. [CrossRef]
30. Marshall, J.; Petrosino, A.; Martin, T. Preservice teachers' conceptions and enactments of project-based instruction. *J. Sci. Educ. Technol.* **2010**, *19*, 370–386. [CrossRef]
31. Novak, A.M.; Krajcik, J.S. A case study of project-based learning of middle school students exploring water quality. In *The Wiley Handbook of Problem-Based Learning*; Moallem, M., Hung, W., Dabbagh, N., Eds.; Wiley: Hoboken, NJ, USA, 2019; pp. 551–572. [CrossRef]
32. Wilhelm, J.; Wilhelm, R.; Cole, M. *Creating Project-Based STEM Environments: The Real Way*; Springer: Cham, Switzerland, 2019. [CrossRef]
33. Polman, J.L. *Designing Project-Based Science Connecting Learners through Guided Inquiry*; Teachers College Press: Williston, VT, USA, 2000; ISBN 978-080-773-912-9.
34. Condliffe, B.; Quint, J.; Visher, M.G.; Bangser, M.R.; Drohojowska, S.; Saco, L.; Nelson, E. *Project Based Learning: A Literature Review*; MDRC: New York, NY, USA, 2017.
35. Merricks, J.; Lankford, D. City planners at work: 4th graders research an ideal location for their garden. *Sci. Child.* **2019**, *56*, 56–63. [CrossRef]
36. Chen, C.-H.; Yang, Y.-C. Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. *Educ. Res. Rev.* **2019**, *26*, 71–81. [CrossRef]
37. Main, S. Project-Based Learning Versus Textbook/Lecture Learning in Middle School Science. Ph.D. Thesis, Northern Illinois University, DeKalb, IL, USA, 2015.
38. Wirkala, C.; Kuhn, D. Problem-based learning in K–12 education. *Am. Educ. Res. J.* **2011**, *48*, 1157–1186. [CrossRef]
39. Baker, T.R.; White, S.H. The Effects of G.I.S. on Students' Attitudes, Self-Efficacy, and Achievement in Middle School Science Classrooms. *J. Geogr.* **2003**, *102*, 243–254. [CrossRef]
40. Kreutz, D.L. Students' Engagement and Academic Achievement for High School Anatomy Students in a Project-Based Learning Environment: A Quantitative t-Test Repeated Measures Design Study. Ph.D. Thesis, Northcentral University, San Diego, CA, USA, 2019.
41. Thompson, K.R. Assessing the Effects of an Authentic Project-Based Intervention on Secondary Students' Understanding of Ecosystems and Their Attitudes toward and Interests in STEM. Ph.D. Thesis, University of Kentucky, Lexington, KY, USA, 2020.
42. Tamim, S.R.; Grant, M.M. Definitions and uses: Case study of teachers implementing project-based learning. *Interdiscip. J. Probl.-Based Learn.* **2013**, *7*, 72–101. [CrossRef]
43. Mentzer, G.A.; Czerniak, C.M.; Brooks, L. An examination of teacher understanding of project based science as a result of participating in an extended professional development program: Implications for implementation. *Sch. Sci. Math.* **2017**, *117*, 76–86. [CrossRef]
44. Viro, A.; Lehtonen, D.; Joutsenlahti, J.; Tahvanainen, V. Teachers' perspectives on project-based learning in mathematics and science. *Eur. J. Sci. Math. Educ.* **2020**, *8*, 12–31. [CrossRef]
45. Farrow, J.; Kavanagh, S.S.; Samudra, P. Exploring relationships between professional development and teachers' enactments of project-based learning. *Educ. Sci.* **2022**, *12*, 282. [CrossRef]
46. Lee, H.-C.; Blanchard, M.R. Why teach with PBL? Motivational factors underlying middle and high school teachers' use of problem-based learning. *Interdiscip. J. Probl.-Based Learn.* **2019**, *13*, 2. [CrossRef]
47. Clandinin, D.J.; Connelly, F.M. Teacher as curriculum maker. In *Handbook of Research on Curriculum*; Jackson, P.W., Ed.; Macmillan: New York, NY, USA, 1992; pp. 363–401.

48. Parke, H.M.; Coble, C.R. Teachers designing curriculum as professional development: A model for transformational science teaching. *J. Res. Sci. Teach.* **1997**, *34*, 773–789. [CrossRef]
49. Schneider, R.; Pickett, M. Bridging engineering and science teaching: A collaborative effort to design instruction for college students. *Sch. Sci. Math.* **2006**, *106*, 259–266. [CrossRef]
50. Voogt, J.; Westbroek, H.; Handelzalts, A.; Walraven, A.; McKenney, S.; Pieters, J.; De Vries, B. Teacher learning in collaborative curriculum design. *Teach. Teach. Educ.* **2011**, *27*, 1235–1244. [CrossRef]
51. Huizinga, T.; Handelzalts, A.; Nieveen, N.; Voogt, J.M. Teacher involvement in curriculum design: Need for support to enhance teachers' design expertise. *J. Curric. Stud.* **2014**, *46*, 33–57. [CrossRef]
52. Davis, E.A.; Janssen, F.J.J.M.; Van Driel, J.H. Teachers and science curriculum materials: Where we are and where we need to go. *Stud. Sci. Educ.* **2016**, *52*, 127–160. [CrossRef]
53. Lotter, C.; Carnes, N.; Marshall, J.C.; Hoppmann, R.; Kiernan, D.A.; Barth, S.G.; Smith, C. Teachers' content knowledge, beliefs, and practice after a project-based professional development program with ultrasound scanning. *J. Sci. Teach. Educ.* **2019**, *31*, 311–334. [CrossRef]
54. Slavit, D.; Nelson, T.H.; Lesseig, K. The teachers' role in developing, opening, and nurturing an inclusive STEM-focused school. *Int. J. STEM Educ.* **2016**, *3*, 7. [CrossRef]
55. Roehrig, G.H.; Dare, E.A.; Ring-Whalen, E.; Wieselmann, J.R. Understanding coherence and integration in integrated STEM curriculum. *Int. J. STEM Educ.* **2021**, *8*, 2. [CrossRef]
56. Moore, T.J.; Stohlmann, M.S.; Wang, H.-H.; Tank, K.M.; Glancy, A.W.; Roehrig, G.H. Implementation and integration of engineering in K–12 STEM education. In *Engineering in Pre-College Settings: Synthesizing Research, Policy and Practices*; Purzer, S., Strobel, J., Cardella, M., Eds.; Purdue University Press: West Lafayette, IN, USA, 2014; pp. 35–59.
57. Buck Institute for Education. Gold Standard PBL: Essential Project Design Elements. Available online: https://www.pblworks.org/what-is-pbl/gold-standard-project-design (accessed on 6 June 2022).
58. Yin, R.K. *Case Study Research: Design and Methods*, 5th ed.; Sage Publications: Thousand Oaks, CA, USA, 2014.
59. National Governors Association Center for Best Practices & Council of Chief State School Officers. Common Core State Standards. Available online: http://www.corestandards.org/ (accessed on 6 June 2022).
60. Cavanagh, S. Content analysis: Concepts, methods, and applications. *Nurse Res.* **1997**, *4*, 5–16. [CrossRef]
61. Krippendorff, K. *Content Analysis: An Introduction to Its Methodology*, 4th ed.; Sage Publications: Thousand Oaks, CA, USA, 2019.
62. Hsieh, H.-F.; Shannon, S.E. Three approaches to qualitative content analysis. *Qual. Health Res.* **2005**, *15*, 1277–1288. [CrossRef]
63. Buck Institute for Education. Project Design Rubric. Available online: https://my.pblworks.org/resource/document/project_design_rubric (accessed on 6 June 2022).
64. Corbin, J.; Strauss, A. *Basics of Qualitative Research*, 4th ed.; Sage Publications: Thousand Oaks, CA, USA, 2015.
65. Kanter, D.E. Doing the project and learning the content: Designing project-based science curricula for meaningful understanding. *Sci. Educ.* **2009**, *94*, 525–551. [CrossRef]
66. Van Horne, K.; Bell, P. Youth disciplinary identification during participation in contemporary project-based science investigations in school. *J. Learn. Sci.* **2017**, *26*, 437–476. [CrossRef]
67. Duschl, R.A.; Osborne, J. Supporting and promoting argumentation discourse in science education. *Stud. Sci. Educ.* **2002**, *38*, 39–72. [CrossRef]
68. Cohen, L.; Manion, L.; Morrison, K. *Research Methods in Education*, 8th ed.; Routledge: Abingdon, Oxfordshire, UK, 2017; ISBN 978-113-820-988-6.