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Establishing a PBL STEM Framework for Pre-Service Teachers

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Abstract: Research into pre-service teachers' (PSTs) ability to develop meaningful interdisciplinary, project-based curricula is lacking; at the same time, many young adolescents fail to see the connections between their schoolwork and the real world. As such, there is a need for new methods to prepare elementary and middle school teachers' abilities to integrate mathematics and science through authentic content. This article will examine how elementary and middle PSTs collaborated across their mathematics and science methods courses to design project-based learning (PBL) unit plans that integrate social justice and global awareness in a STEM context. The content analysis of 25 distinct PBL unit plans documented the levels at which PSTs could incorporate practical PBL design elements into their projects, integrate robust mathematical content, and identify connections to social justice and global awareness. Through this analysis, we will share the successes and challenges faced in guiding PSTs to create PBL STEM units and present a series of next steps that could be taken to further this cross-curricular endeavor.

Keywords: project-based learning; STEM; social justice; global awareness; mathematics conceptual understanding

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1. Introduction

Initiatives that aim to increase awareness of and develop competencies in science, technology, engineering, and mathematics, or STEM, have deepened as a response to the challenges of the 21st century [1]. *YOU Belong in STEM* is a current focus within the United States Department of Education, as expressed in the launching of a new initiative by which to enhance STEM education for all students. The initiative aims to raise the bar, investing in PK-higher education students so that they may reach higher levels of STEM learning through authentic and challenging experiences [2]. As researchers and educators, we define STEM education as a teaching and learning approach focused on the interdisciplinary integration of science, technology, engineering, and mathematics as a cohesive and interwoven unit. We believe that STEM disciplines "cannot and should not be taught in isolation, just as they do not exist in isolation in the real world or the workforce" [3].

This approach integrates rigorous STEM content standards with authentic and engaging contexts to further student development of workplace competencies such as teamwork, communication, problem-solving, critical thinking, and self-management [3–6]. An integrated STEM education can also develop students' global awareness competencies by promoting scientific and mathematical inquiry from global perspectives [5,7]. These workforce and global awareness competencies are also distinctive attributes of project-based learning (PBL), a pedagogical approach where students engage in authentic inquiry guided by driving questions as they work together to solve real-world problems by creating public products to answer the driving question [8–11].

1.1. PBL STEM Framework

A PBL STEM framework integrating global awareness requires a foundational understanding of two critical components—PBL design elements and integrated STEM instructional elements [12]. While PK-12 education practices may identify and focus on these foundations separately, the realization of an integrated approach encourages each content area to be equally emphasized in the teaching and learning of STEM, where content elements are interwoven throughout the project.

1.1.1. PBL Design Elements

According to McHugh [10], PBL is "a teaching and learning practice where students sustain exploration into an authentic question, challenge, or problem while engaging in academic content and developing critical success skills, such as communication, collaboration, and critical thinking" (p. 24). As a pedagogical approach, the benefits of PBL in improving student learning outcomes have been extensively researched; these benefits include the construction of cognitively demanding content knowledge [13–15], enhanced critical thinking and problem-solving skills [14,15] and the development of success skills such as time management and effective communication [10,14,16].

Designing a high-quality PBL unit involves attention to critical design elements, as outlined by PBLWorks [16], a leading organization in PBL professional development, research, and curricular materials. The learning goals are at the core of the design elements, which include grade-level standards and success skills. A **challenging problem or question** centers on a relevant problem or question that guides student learning and exploration [13]. **Sustained inquiry** refers to the cyclical nature of questioning, exploring, and applying new knowledge. **Authenticity** includes not only a real-world context or topic of interest directly connected to the lives of students but also the use of research methods and tools that align with those used by experts in that field of study [10,16]. **Student voice and choice** highlight students' pivotal role in a project, including providing students with opportunities to determine how they engage in the project and express their knowledge and creativity through the final product [13]. **Critique and revision** outline how students play a role as givers and receivers of feedback to improve project products and project management. **Reflection** centers on teachers and students reflecting upon growth in content understanding and success skills during and at the project's culmination. Lastly, **Public product** focuses on students as creators of a physical or digital product and presentation that is shared with people outside the classroom walls [10,16].

1.1.2. Integrated STEM Instructional Elements

Rather than teaching content in isolated classrooms, an integrated STEM education calls for combining the subject areas through relevant contexts to engage students and increase their understanding of and connection across each subject area [5,12,17,18]. Integrated STEM instruction can enhance student engagement [5], increase interest in STEM [12], and make learning more meaningful [18].

Designing integrated STEM curricular material can be conceptualized through six design elements [4]. The first element focuses on situating STEM integration in motivating and engaging contexts. These contexts, such as global, social, and environmental contexts, should allow students to use their prior knowledge to make sense of the context and provide a purpose for learning [17]. The second and third elements require students to engage in engineering design challenges with opportunities to learn from failure through redesign. The fourth element requires students to conceptually understand and apply scientific and mathematical concepts that align with grade-level standards. Student-centered pedagogies, which form the fifth element, allow students to participate actively in their learning [17]. The final element emphasizes teamwork and communication in which students collaboratively discuss scientific and mathematical concepts through multiple representations [17].

The PBL design elements lead directly to the goals of an integrated STEM curriculum. Jolly [19] tells educators that STEM is an interwoven, integrated practice that focuses "students on local, national, and global situations or problems, [that will] bring the classroom alive for students and deepen their learning" (p. 8). In STEM experiences, students apply knowledge to real-world situations by using tools or manipulating objects found in STEM careers while building social skills such as decision-making and collaborative problem-solving. As such, these integrated STEM elements align with several PBL design elements, as shown in Table 1 below.

Table 1. Alignment between an integrated STEM curriculum and PBL design elements.

Integrated STEM Instructional Elements	PBL Design Elements
Motivating and engaging contexts	Challenging problem or question authenticity
Science and mathematics concept	Learning goals sustained inquiry reflection
Student-centered pedagogies	Sustained inquiry critique and revision reflection
Teamwork and communication	Critique and revision public product

1.1.3. Focusing on the M (Mathematics) in STEM

Research has noted that mathematics often plays a secondary role in the integrated STEM classroom, which researchers call a "service role" or an "auxiliary discipline" to science, engineering, and technology concepts [20]. For example, Roehrig et al. [18] analyzed STEM curricula and found that mathematics concepts represented less than 10% of new learning, often being used as a tool for data analysis in service of science and engineering concepts. Roehrig et al. [18] further state that engaging in science and engineering practices inherently includes mathematical practices; however, in the curricular review, these practices are not made transparent but are implied, again leading to mathematics playing a service role in STEM curricula.

Therefore, national mathematics organizations have insisted that STEM educators make the M "transparent and explicit," recognizing that not all of our (K-12) students "will 'see' the mathematics that is involved in a particular problem" [21]. Furthermore, the mathematics used should move beyond procedural computations that a computer or calculator could quickly compute towards using and applying conceptual mathematical knowledge as an integral, intentional component of the STEM unit [18].

To assist with making mathematics visible in integrated STEM instruction, Guzey et al. [17] developed the STEM Integration Curriculum Assessment Tool (STEM-ICA). This tool consists of various rubric components related to high-quality integrated STEM curricular material, including several PBL design elements such as motivating and engaging questions, student-centered instructional strategies, implicit opportunities for teamwork and communication, and integrating science and mathematics content. Concerning the integration of mathematics content, the STEM-ICA tool operationally defines this integration as the alignment of the curricular material to appropriate grade-level mathematics standards and the incorporation of mathematical concepts so that students can "learn, understand, and use fundamental mathematics concepts" to "promote coherent understanding of mathematical thinking" [17] (p. 17).

These elements of mathematics integration in STEM are consistent with calls from national mathematics organizations highlighting the need for conceptual understanding and procedural fluency in the mathematics classroom. Conceptual understanding is operationally defined as "an integrated and functional grasp of mathematical ideas" so that students "know more than isolated facts and methods" [22] (p. 118). Conceptual understanding lays the foundation for procedural fluency, providing pathways for students to become flexible and efficient users of mathematics in real-world and mathematical problems [23].

1.1.4. Global Awareness in STEM Education

One way to realize the PBL design element of authenticity within an integrated STEM education is through a global awareness foundation. Global awareness has been defined as a "set of knowledge and skills to understand the world, comprehend current global problems and affairs, and devise solutions considering human dimensions as well as a positive attitude towards interacting peacefully, respectfully, and productively with people from diverse cultures" [24] (p. 1). Schools can and do play a critical role in developing globally aware students, providing classroom opportunities to examine local to global issues, engage in dialogue with people from diverse cultures, and analyze current issues impacting our global society [25].

For the most part, global awareness in STEM education naturally leads to the constructs of social justice, equity, and diversity across geographic levels, locally to globally [25,26]. According to Freire [27], educators should teach for social justice by fostering critical consciousness and empowering students to challenge and change oppressive structures in society. Social justice pedagogy includes facets of a caring classroom, where teachers and students learn together through dialogue about real-world issues and culturally relevant content, intending to develop students' critical consciousness [28]. Student empowerment, respect for diversity, and an emphasis on inclusion are central tenets of teaching and learning for social justice [27].

Specifically in STEM, social justice ensures that all students, regardless of their background, have equal access to and are represented within the curriculum. STEM educators must be responsive and welcoming to students' diverse backgrounds, including their culture, religion, sexual orientation, gender, and socio-economic backgrounds [29]. According to Mackenzie [30], social justice in STEM promotes academically rigorous content grounded in students' lives, democratic classrooms, safe havens, and promotion of activism. Mackenzie [30] suggests a range of topics that educators can use to infuse social justice in the science classroom. These topics in the literature are referred to as socioscientific issues or SSIs. SSIs are controversial, socially relevant, real-world problems informed by science that often include an ethical component [31]. Therefore, social justice in STEM from an SSI lens aligns with the PBL design elements of a challenging problem or question and student voice and choice.

Proponents of teaching science using SSIs have found that SSI-based instruction can promote the development of students' global awareness [32,33]. Therefore, global awareness and social justice aim to align directly with the PBL design elements of authenticity and public products. Both design elements center on students as agents of change when the public product aligns with awareness, advocacy, or action goals. Students can bring awareness to a critical topic, such as access to clean water, through a social media campaign. Students can then move towards advocacy by proposing a bill for the legislature to aid in access to clean water. Students can even move towards actionable change, such as assisting in water cleanup efforts or fundraising for clean water filters to give to families. These change agency products can also occur from a local to a global scale. For example, in a PBL STEM middle school classroom, students embodied the role of environmental engineers, where they designed "awareness campaigns to address environmentally destructive habits" at a local level, then translated individual human activities and lifestyle choices to realize the "global costs of these same activities at national or global levels" [34] (p. 73). Students then created "language-neutral posters that emphasize images over words [to] contextualize findings for a global audience" [34] (p. 73). This integrated PBL STEM unit exemplified students as local and global change agents, bringing awareness through campaigns. As students engage in awareness, advocacy, or action, they may move from sharing their ideas locally, such as the whole school, district, or community, to a national and global level through social media or fundraising efforts [10].

1.2. PST's Abilities to Produce PBL STEM Curricular Units

Much of the current research has highlighted the ability of in-service educators to integrate PBL and STEM [12,17]; however, research into pre-service teachers' (PSTs') ability to develop meaningful interdisciplinary, project-based STEM curricula is lacking. Research also suggests that teacher education programs fail to train PSTs for diverse classrooms or prepare them to integrate global awareness through social justice issues [25,35]. A gap exists between theory and classroom approaches related to integrating social justice theory with STEM practices [36]. As such, there is a need for new methods to prepare elementary and middle school teachers' abilities to integrate mathematics and science through authentic content. This content engagement should connect quality standards to real-world projects about students' interests.

Our study aimed to answer the overarching question: How does using an integrated PBL unit plan across undergraduate science and math methods courses support PSTs' abilities to produce meaningful PBL STEM units that increase students' global awareness and incorporate a social justice lens? To answer this question, we sought to answer the following questions:

- How do PSTs incorporate effective PBL design elements in a socioscientific PBL STEM unit?
- How do resulting PBL STEM units integrate concepts of global awareness and social justice?
- How do PSTs emphasize mathematics in PBL STEM units?

2. Methodology

2.1. Participants

A qualitative case study design was employed to provide an in-depth understanding of PST's use of a PBL STEM social justice framework. Specifically, the research methodology is a collective case study that includes the analysis of multiple unit plans developed by PSTs of senior status enrolled in a university Bachelor of Science Education degree program [37]. Over four semesters, 76 PSTs worked in groups of 2–4 developing the units. A convenience sampling technique was employed as the PSTs were required to enroll in the semester-long courses taught by two of the authors; additionally, informed consent was obtained from each student. The classes were designed to prepare the participants in the mathematics and science methodologies specific to the teaching of students in elementary and middle schools (grades 1–8).

Positionality Statement from Researchers

Two of the three authors for the current study were instructors of the methods course that supported PSTs in developing their PBL STEM units. Both authors contributed to the data analysis and interpretation. To avoid bias in the scoring and interpreting the findings, the authors brought in an external third author who independently scored the projects to determine consistency across all rubric categories. Additional parties independently read the article to ensure consistency and lack of bias.

2.2. Data Sources

Methods course instructors collaborated on implementing the PBL STEM unit plan assignment. The completed written unit plan proposals, developed over the semester, served as the data source for this research study. Before introducing the unit plan assignment, the first science methods unit focused on the nature of science (NOS). PSTs examined science as a noun, a verb, and a way of knowing. Identifying an SSI and how it related to the NOS discussion board helped them identify topics they thought would be relevant to their future students' lives. In math methods, PSTs discussed the importance of using mathematics to catalyze change and as an introduction to the standards for mathematical practice.

By the fourth week of the semester, instructors focused on introducing the PBL STEM unit plan as part of learning the intricacies of teaching K-9 students science and mathematics.

Instructors connected the unit plan final assignment to the globally responsive teaching attributes explicitly called for within the university's conceptual framework. While valuing human diversity and the various talents of their future students, PSTs at this university were expected to infuse a rigorous integrated curriculum linked to global events to make the world a healthy, sustainable, and just environment. While promoting global responsiveness and a socially just curriculum, instructors used a modified PBLWorks template and rubric to guide the assignment. PSTs self-selected into groups based on similar SSI topic interests. Beginning with a concept mapping activity, PSTs brainstormed sub-topics they could include in their projects. Using a flow chart or storyboard helped the PSTs to illustrate how their unit topics would flow, connecting the essential question with a series of activities to the culminating project; each series of activities is grouped into a milestone (Appendix A, project template).

Additional topics discussed during each science methods course included formative diagnostic pre-assessments, the learning cycle model, literacy integration, environmental science standards, and pedagogical content knowledge. Math methods classes focused on the five strands of mathematical proficiency: conceptual understanding, procedural fluency, adaptive reasoning, strategic competence, and productive disposition (National Research Council, 2001). In addition, PSTs discussed and practiced engineering design during science methods, followed by creating a STEM experience, which they implemented for a group of middle schoolers in the community. Feedback from the instructors on each group's project progress was given approximately bi-weekly for the remaining weeks of the semester. This required both instructors to stay on pace with PSTs' project completion by the end of the semester. Before their final submission, peer feedback was given anonymously based on the PBLWorks rubric supplied to the PSTs at the project's onset. Expectations on the project template included requiring PSTs to reflect and act upon both instructor and peer feedback.

2.3. Data Analysis

Rubric Development

The PBL Design Elements rubric was adapted from the Project Design Rubric from PBLWorks [16]. The development of the rubrics for (1) application of social justice and global awareness (Table 2) and (2) mathematical emphasis (Table 3) began with a review of the literature within each area, followed by initial development by the authors. Because the established PBLWorks rubric contained three performance levels for each criterion, the two additional rubrics developed for this study included three. Drafts of each rubric were sent to university colleagues for expert review. Rubric edits were completed, and, when applicable, the rubric was revisited by content experts until a consensus was reached that the rubric was sufficient for this study.

Table 2. Rubric for Application of Social Justice and Global Awareness.

Criteria	3 Demonstrating	2 Developing	1 Beginning
Application of Social Justice Issue	Teacher candidates integrate social justice issues * that deepen and extend students' understanding of the world.	Teacher candidates integrate social justice issues that develop students' understanding of the world.	Teacher candidates integrate social justice issues that pay little attention to students' understanding of the world.
Global Awareness	The project examines local issues and their connection to the global community or vice versa.	The project thoroughly examines a local OR global issue.	The project has a limited examination of a local OR global issue.

* Social justice incorporates environmental, racial, gender, disability, and economic injustices/inequities.

Table 3. Rubric for Mathematics Emphasis.

Criteria	3 Demonstrating	2 Developing	1 Beginning
Mathe-matics Standard	Targets a grade-level mathematics standard(s) to the full depth of the standard.	Targets a grade-level mathematics standard(s) but does not address the entire standard(s).	Targets a below-grade level mathematics standard(s) or unrelated mathematics standard(s).
Procedural and Conceptual	The project focuses on a balance of mathematical procedures and deeper conceptual understanding.	The project focuses on mathematical procedures with some connection to conceptual understanding.	The project focuses on mathematical procedures with no connection to conceptual understanding.
Application	Provides opportunities for students to apply mathematical concepts in authentic problem-solving situations.	Provides limited opportunities for students to apply mathematical concepts in authentic problem-solving situations.	Provides no opportunities for students to apply mathematical concepts in authentic, problem-solving situations.

Thematic analysis was employed as the PBL STEM unit plans were scored according to the three rubrics, in most cases by each of the three authors. Projects were individually scored according to the rubric criteria. Cross-case analysis was utilized to identify commonalities, differences, and overarching themes.

Trustworthiness and rigor: If scores were more than one half-point apart, the reviewers engaged in member checking by examining the unit plans together to find evidence to support their initial score. When necessary, the individual scores from each reviewer were averaged for each criterion. For example, initial scores for the *Water Waste* project for challenging problem or question were scored 2, 2, and 2.75 by each of the researchers. The higher scorer noted the driving question, "*How is water wasted in our community, and what can you do to reduce water waste?*" This was aligned closely with a three on the rubric, scoring 2.75 as the level of challenge was lacking. The other two scorers initially scored this a 2 for similar reasons, thinking the question lacked rigor for the grade level. Discussion ensued on appropriate levels of rigor, which led to an average score of 2.25 for this criterion.

3. Findings

Over four semesters, PSTs working in groups created 25 PBL unit plans. Teacher candidates had selected a variety of topics related to meaningful SSIs. The broad issues ranged from genetically modified organisms, climate change, vaccines, and endangered species to water quality and access. Table 4 highlights six projects that stood out across the three rubrics. These projects support key findings after scoring (see Appendix B for a complete list of 25 projects and final scores for all three rubrics).

Table 4. PBL design element results for exemplar projects.

		PBL Design Elements					
	Unit Driving Question	**Problem or Question**	**Sustained Inquiry**	**Authenticity**	**Student Voice and Choice**	**Reflection**	**Public Product**
Our Changing World	What is climate change, and how do you interact with it on a personal, communal, and global level?	2	2	2.5	2.5	1	2
Water Waste	How is water wasted in our community, and what can you do to reduce water waste?	2.25	2	2.5	3	2	2.5
Sustainable Farming	How can sustainable farming practices benefit our school?	2	1.5	2	1	2	1.5
Climate Change Social Media	Who will be affected the most by a changing climate, and what can we as middle schoolers do to make an impact and help people facing the most struggles with a changing climate?	2.75	3	3	3	2.5	3
Recycling in Wisconsin	How can we, as earth citizens, contribute to recycling efforts in our schools and homes?	3	2	2.5	2	2.5	2.5
Viruses	How do we protect our immune system from viruses, and how does it differ globally?	2	2	2	2	1.5	2

3.1. PBL Design Elements

The PBL STEM units were first examined for alignment to six PBL design elements: challenging problem or question, sustained inquiry, authenticity, student voice and choice, reflection, and public product. The PBL design element of learning goals was examined in the mathematics emphasis section of the rubric with the criterion of standard. The researchers did not discuss the design element of critique and revision as the time allotted for developing PBL STEM units was limited. Given the limited time, the PSTs were never explicitly taught how to build critique and revision within a student project; hence, the researchers did not feel justified in assessing PSTs on a concept they had yet to learn. The reviewers scored each of the six design elements. Table 5 highlights a rubric with modified criteria and identifies the results as a mean score and standard deviation, rounded to the hundredth place (see full rubric Appendix C).

Table 5. PBL design elements rubric and overall results (n = 25).

Criteria	3 Demonstrating	2 Developing	1 Beginning	Results
Challenging Problem or Question	The project is focused on a central problem at the appropriate level of challenge.	The project is focused on a central problem, but the level of challenge might be a mismatch for the intended students.	The project is not yet focused on a central problem, or the problem or driving question is too quickly answered to justify a project.	M: 2.21 SD: 0.52
Sustained Inquiry	Inquiry is sustained over time and academically rigorous.	The project includes limited opportunities for inquiry.	The project is more like an activity than an extended inquiry process.	M: 1.78 SD: 0.57

Table 5. *Cont.*

Criteria	3 Demonstrating	2 Developing	1 Beginning	Results
Authenticity	The project has an authentic context, impacts the world, and speaks to students' personal concerns, interests, or identities.	The project has some authentic features, but opportunities exist to deepen connections to the real world and students' interests.	The project resembles traditional "schoolwork;" no evidence of a real-world context or connection to students' interests exists.	M: 2.20 SD: 0.52
Student Voice and Choice	Students have opportunities to express their voices, make choices on important matters, and have opportunities to work independently from the teacher.	Students are given some low-stakes opportunities to express their voice and make choices. Students work independently from the teacher to some extent.	The project is primarily teacher-directed and does not include opportunities for students to express their voice and make choices that affect the content or process of the project.	M: 1.81 SD: 0.66
Reflection	Students and teachers reflect both during the project and after its culmination.	Students and teachers engage in brief or intermittent opportunities for reflection during the project and after its culmination.	The project does not include explicit opportunities for reflection.	M: 1.54 SD: 0.56
Public Product	Student work is made public by presenting, displaying, or offering it to people beyond the classroom.	Student work is made public to classmates and the teacher.	The teacher is the primary audience for student work.	M: 1.91 SD: 0.59

3.2. Challenging Problem or Question

After examining the PBL STEM unit plans, the average score on the challenging problem or question component was 2.21, with a standard deviation of 0.52. Of the 25 PBL STEM units, 19 scored a two or better, indicating that PSTs were on their way toward demonstrating a solid grasp of creating a question that challenged students appropriately. Within this rubric component, three criteria were established to analyze a challenging problem or question, namely that the question is (1) open-ended, (2) aligned to learning goals, and (3) understandable and inspiring to students. One strong example from the PBL STEM unit *Recycling in Wisconsin* was this challenging question posed to 3rd-grade students, "How can we, as earth citizens, contribute to recycling efforts in our school and home?" This question was rated as a three as it met all three criteria of being open-ended, aligned with learning goals, and inspiring to students. Contributing to recycling efforts for their school and personal household has the potential to excite 3rd-grade students who are eager to be helpful to the community.

In the *Viruses* project, the question posed to 7th-grade students is, "How do we protect our immune system from viruses, and how does it differ globally?" This question received a score of 2 for "Developing." Although the question was open-ended and aligned with learning goals, the question does not seem readily understandable and inspiring to potential 7th-grade students.

3.3. Sustained Inquiry

The average score on the sustained inquiry component across all 25 PBL STEM units was 1.78, with a standard deviation of 0.57. One of the main focuses of this component is student-driven inquiry. The only project to receive a score of 3 for "Demonstrating," *Climate Change Social Media* exemplified the practice of middle school students driving the inquiry. In milestone 2 of that project, students take notes on diverse informational materials regarding where or when the effects of climate change are happening; they then add their findings to a graffiti wall over a massive world map drawing. This research milestone then connects to milestone 3, where students use the graffiti wall map to identify which global communities are most affected by climate change to begin creating a climate change social media campaign. The PSTs authoring that project also included an opportunity for their future middle school students to investigate any topics they have further questions or concerns about, aligning sustained inquiry with student-driven questions.

Very little sustained inquiry existed in the *Sustainable Farming* project, leading to a 1.5 score. Each milestone read like a short one- or two-day lesson plan connected to the next milestone based on the theme of sustainable farming. For example, in milestone 2, students spend one day addressing misconceptions about percentages, decimals, and fractions. Then, in milestone 3, students spend one day examining the critical characteristics of a farming practice. In milestone 4, students spend two days creating mathematical story problems related to sustainable farming. Students are not generating questions, nor are the milestones showing the cyclical nature of students posing questions, gathering data, developing and evaluating solutions, and then asking further questions.

In the project Our Changing World, sustained inquiry scored a 2. Unlike Sustainable Farming, the thread from one milestone to the next was evident as students posed questions and interpreted data. However, each investigation lacks the depth and rigor to challenge students. The activities created by the PSTs led their students to merely graze over concepts without looking deeply at each topic, preventing this project from scoring higher.

3.4. Authenticity

The average score on the authenticity component was 2.20, with a standard deviation of 0.52. In this component, only four projects received a score of less than a 2, indicating a solid attainment of this standard by many PSTs. The project *Climate Change Social Media* exemplified a highly authentic project, scoring a 3. This project directly speaks to students' personal concerns, interests, and identities through the study topic and the final product. Students build empathy for environmental/climate refugees, coastal developing nations, and people struggling to access clean water, among others, through their research, humanizing climate change for middle-school students. Students examine various sources, from articles to TikTok videos to Instagram posts. Students then use real-world tools to create social media campaigns to impact the world. This leads to a very authentic experience for students throughout the project.

The *Viruses* project scored a 2 for authenticity. The topic of examining viruses may interest students, especially after COVID-19. However, the academic investigations did not deepen students' connection at a personal level. For example, students looked at prevention methods from a general standpoint. At no point were those prevention methods examined for the home, school, or local community. In the final product, students propose prevention methods for a country they researched, again keeping this topic from becoming personal to students' immediate lives and interests.

3.5. Student Voice and Choice

After examining the unit plans, the average student voice and choice score was 1.81, with a standard deviation of 0.66. A PBL STEM unit scoring a 1, *Sustainable Farming*, led with the question, "*How can sustainable farming practices benefit our school?*" This project centered on teacher-directed lessons rather than student-centered inquiry. For example, in one milestone, the teacher leads students through a lab, creating a 'wormery', a clear container of sand and soil to watch worms decompose organic matter to make richer soil. All students follow the exact directions throughout the lab and are posed the same questions. Students then use this lab and the results to persuade their school to install a compost pile. Although these activities are hands-on and engaging, there were several missed opportunities to provide students with voice and choice. For example, the driving question asked generally about sustainable farming practices. Still, the project led students only to consider a compost pile, failing to provide students voice and choice regarding other potential sustainable farming practices they may see as beneficial. After students were led to accept the solution of a compost pile, they focused on persuading their school to install one. To provide more voice and choice, PSTs could have engaged students in scientific engineering practices to design a better wormery, including mathematical skills and continued student-led research.

Contrastingly, a project that scored a 3, *Water Waste*, highlights multiple opportunities for students to express their voices and work as independent learners. For example, in the project, students act as engineers to create their filtration system, investigate their water usage, and develop action plans to share with others, often working in small groups independently from the teacher. For the final product, students create a persuasive argument to the government to advocate for people who do not have access to clean water, choosing the format most suitable for their argument with options of an infographic, presentation, poster, or podcast. In this project, students have multiple opportunities to express their voice, from the design of filtration systems to the research and creation of an argument with choice in the format of the final product.

3.6. Reflection

Of the PBL design elements examined, Reflection had the lowest mean score, with a 1.54 and a standard division of 0.56. Only one project scored a 3 for reflection. The project *Recycling in Wisconsin* proved to be a commendable example of reflection with a 2.5 score. In the project, 3rd-grade students are given two opportunities to reflect on the content they are learning. This content reflection occurs during the entry event in milestone one and as the kick-off to the final milestone. Before completing the final milestone, students are asked to consider how they can organize the ideas they have been learning to educate their peers. The reflection points range from considering content to reflecting on the successful skills of the organization and effective communication, which are critical indicators in the rubric. What would have moved this project from a 2.5 to a three on the rubric would have been more consistent reflection opportunities and the opportunity to reflect on academic and success skill growth after the project.

Contrastingly, the project *Our Changing World* lacked intentional reflection moments, scoring a 1. The closest opportunity for reflection described in the project is during an exit ticket where students were asked to share what they liked about the lesson's activity. However, this question does not prompt students to think deeply or carefully about content knowledge or success skills, which is the hallmark of an exemplary reflection question. The project itself has multiple missed opportunities for reflection. For example, in milestone 3, students take a carbon footprint quiz individually before compiling a classroom set of data. Students then analyze and interpret carbon footprint data. However, neither individually nor as a whole class do students examine the data and reflect upon their carbon footprint related to the world or how their carbon footprint could be decreased. Additionally, students never reflect upon their success or project management skills.

3.7. Public Product

The average score on the public product component across all 25 PBL STEM units was 1.91, with a standard deviation of 0.59. In a project that scored a 1.5, *Sustainable Farming*, 6th-grade students work towards creating a compost pile for their school. After the project, students tend to a school garden by continuously making compost. However, students have yet to present their ideas for compost piles to anyone in the school. Students appear to follow the steps provided by the teacher. The public product resembles a service-learning opportunity, where students enrich a pre-existing school garden with their compost. At no point do students create and deliver presentations or display public products. The teacher is the sole point of contact in this project.

Conversely, a project that scored a 2.5 for public product is the 6th-grade *Water Waste* unit. After examining local to global issues in water waste, students create a persuasive argument for the government to advocate for people who do not have access to clean water. Students share these persuasive campaigns virtually with the community and their school by uploading presentations to the school website. These project opportunities highlight how student products can be made public to people outside of the classroom. What kept this project from scoring a 3 was the need for more description of student reasoning and choice behind their public product.

3.8. Social Justice and Global Awareness

The PBL STEM units were examined based on the PST's abilities to integrate global awareness and social justice concepts. As defined above and outlined in the rubric (Table 2), PST's abilities within the criterion of global awareness were viewed as the ability of the teacher candidates to integrate a social justice issue that would also support the deepening of their students' global awareness by making connections between a students' local understanding and a larger global community. PST's abilities to integrate social justice, including a connection to environmental, racial, gender, disability, and economic injustices/inequities, was measured on a 3-point scale.

3.9. Social Justice Issue

The analysis of 25 PBL STEM projects for their application of social justice resulted in an average rubric score of 2.06 with a standard deviation of 0.60 (Table 6). Most of the PBL STEM projects (n = 20) integrated a social justice issue, but this integration was limited to developing (n = 16) rather than deepening students' global awareness. For example, the *Our Changing World* project investigated the driving question, "What is climate change, and how do you interact with it on a personal, communal, and global level?" and scored a 2 for its application to a social justice issue as the final product was an infographic with no connection to students applying mitigation strategies that made a true impact to the social or economic wellbeing of their community. On the other hand, in the *Water Waste* project, which scored a 3 in this category, students developed action plans to lessen their impact on water waste. Their project further directed students to conduct research and create a persuasive argument for the local government to advocate for people who do not have access to clean water. The *Climate Change: Social media* project scored a 3 for this criterion. PSTs included numerous opportunities for their students to use their voices via discussion, including within a social justice circle, which allows students to process and express their frustrations, concerns, and emotions. Their final project outlined various social media platforms that allowed young adolescents to act on their learning in a manner they felt was most effective based on their strengths as adolescents.

Table 6. Social justice, global awareness, and mathematics emphasis overall results (n = 25).

Criteria	Results
Application of Social Justice Issue	M: 2.06 SD: 0.60
Global Awareness	M: 1.92 SD: 0.65
Mathematics Standard	M: 1.98 SD: 0.93
Procedural and Conceptual	M: 1.68 SD: 0.60
Application	M: 1.87 SD: 0.63

3.10. Global Awareness

Upon analysis of the project's ability to connect local issues to the global community (or vice versa), the result was an average rubric score of 1.92 with a standard deviation of

0.65 (Table 6). This analysis revealed that most projects (n = 22) focused on a local or global issue with few connections. For example, within the *Sustainable Farming* project, PSTs did include a visit from a local organic farmer and the development of a community school garden. However, there was no extension of the benefits these practices would have on a larger national or global scale.

A few projects made explicit connections between a local issue and connected it to the global community. In the *Water Waste* project, students investigated their personal water usage and water issues where groundwater is drained internationally. Furthermore, they investigated water quality issues in their local environment related to PFAS contamination and extended this issue to national water contamination issues such as that in Flint, Michigan. Students then selected different countries to explore statistics related to water. In the *Viruses* project, which led with the driving question, "How do we protect our immune system from viruses, and how does it differ globally?" students learned about how to keep themselves safe from contracting illnesses by investigating a country of their choice on the policies and procedures enacted because of the Coronavirus pandemic.

3.11. *Emphasizing Mathematics*

The examination of the ability of PSTs to integrate mathematics in PBL STEM units focused on how PSTs addressed the full extent of a grade level standard within the mathematics portion of their project, how they build procedural fluency from conceptual understanding, and their ability to apply mathematics in accurate and relevant contexts within the project. Additionally, units were examined to determine whether mathematics was an integral component of the PBL STEM unit or whether the mathematics was isolated within a particular lesson or milestone.

3.12. *Grade Level Standard*

In analyzing 25 PBL STEM unit plans, most received either a 3 (n = 10) or a 1 (n = 10), indicating that PSTs could either address the standard or not. Projects that scored a one typically indicated that PSTs chose a standard one or more grade levels above the target grade. For example, in the *Climate Change Social Media* project, PSTs selected Grade 7 statistics standards in which students need to understand the meaning of sampling. Instead, the lesson focused on graphing data on either line plots or bar graphs using categorical or numerical data, content that is applied in grades 5 and 6. Though the data were collected from classmates during the lesson, there was no discussion about sampling techniques or the difference between a sample and a population, which would have moved this unit toward grade level.

On the other hand, projects that scored a three could connect the standard to mathematical activities found within their project. For example, in the *Sustainable Farming* project, PSTs selected a 6th-grade ratio standard focused on finding the percent of a quantity as a rate per 100. In the lesson, middle-school students were asked to create percentage tasks from their research on sustainable farming, thus aligning the standard and appropriate grade-level mathematics.

3.13. *Conceptual Understanding*

After examining the PBL STEM unit plans, the average procedural and conceptual components score was 1.68, with a standard deviation of 0.59 (Table 6). This indicated that teacher candidates developed PBL STEM units in which the project focused on mathematical procedures with limited (n = 9) to no (n =14) connections to conceptual understanding. A few projects emphasized conceptual understanding as the primary focus of the project. For example, in the *Recycling in Wisconsin* project, PSTs focused on a 3rd-grade standard centered on making scaled bar graphs. In this project, 3rd-grade students are tasked with collaboratively drawing scaled bar graphs with different scales. Then, students discuss questions such as "What is similar and what is different between these scaled bar graphs? What fraction of the class recycles? How did this fraction show up in each of the different graphs?" These questions lead to a rich discussion and a conceptual focus on the represented data.

On the other hand, in projects where similar standards were addressed, the lesson focused on mimicking how the teacher created a graph, scoring a two or below. For example, in the *Viruses* project, students were asked, "How do we choose data to create a mathematical representation?" After posing that question, the students engage in an *I Do, We Do, You Do* lesson where they mimic how the teacher creates a bar graph with the data they researched. A lack of critical questioning and analysis leads to a procedural lesson with little connection to a conceptual understanding of the mathematics standard.

3.14. Application

Over half of the projects scored at or above a 2 (n = 14), which allowed elementary and middle-school students to apply mathematical concepts through authentic problem-solving. A total of four projects provided multiple opportunities to engage students in doing mathematics through accurate and relevant contexts. For example, in the *Recycling in Wisconsin* project, the students applied their knowledge of scaled bar graphs from the data collected on their class recycling habits to create infographics related to the school's recycling program. This information was part of the public product, enhancing mathematics' critical role in the PBL unit.

On the other hand, the remaining unit plans (n = 11) needed to provide students with opportunities to apply mathematical concepts and procedures throughout. These projects focused on building mathematical content knowledge within a single lesson that did not extend across the PBL STEM unit plans. For example, students were asked to take a carbon footprint survey in the Our Changing World project. They used class data from this survey to create graphical displays. This mathematical milestone was limited to a single lesson, and neither the data nor the statistical learning was applied beyond the single milestone.

4. Discussion

4.1. Summary and Contextualizing the Findings

This study sought to answer three research questions related to PST's ability to incorporate PBL design elements, social justice and global awareness issues, and mathematics in PBL STEM unit plans. As such, our study begins to address the gap in the literature related to how PSTs incorporate effective PBL design elements into PBL STEM units. Through a content analysis of 25 PBL STEM units, this study also outlines the strengths and challenges of developing these units.

4.1.1. How Do PSTs Incorporate Effective PBL Design Elements in a Socioscientific PBL STEM Unit?

Based on our analysis of the PBL unit plan proposals, the PSTs were most successful with the PBL design element related to positioning the project within an authentic context, which is a significant criterion within both PBL design and STEM integration. This finding is consistent with prior research [12,17] that practicing teachers often infuse authenticity to motivate and engage students in learning through real-world contexts into their teacher-developed STEM PBL curricular material. By situating their PBL STEM units in an SSI, the PSTs inherently created an authentic situation that would motivate future K-12 students.

In our study, PSTs were also relatively successful in creating a challenging problem or question that was operationalized in part by the statement of a driving question. For example, the *Recycling in Wisconsin* project utilized the driving question "How can we, as earth citizens, contribute to recycling efforts in our school and home?" to guide the development of their STEM PBL unit. This driving question is aligned with the PBL design element of challenging problem or question as it centered the project on a relevant issue to guide student learning [13]. Studies focused on teacher-developed STEM PBL curricular material have found that teachers struggled with creating and implementing well-defined driving questions [9,12]. The differences in our results from these findings may be attributed to the substantial feedback loop we utilized with PST project teams. PSTs wrote several versions of their driving question in the science methods course. Students then engaged in a critique and revision process, providing targeted feedback on that specific aspect of PBL.

After peer feedback, PSTs submitted their revised driving question to their science and mathematics methods instructors, who provided feedback on the driving question before a final version was integrated into the STEM PBL unit. This significant feedback loop, therefore, led to powerfully written driving questions by the PSTs in this research study compared to cited research studies. Although future opportunities for critique and revision occurred, those opportunities focused on the overall project, which included multiple design elements. Therefore, using critique and revision to focus on one design element seemed to elevate PST's ability to succeed in the PBL design of challenging questions or problems.

The PSTs could have been more successful in integrating the PBL design elements of sustained inquiry, student voice and choice, reflection, and public product. Other studies focusing on teacher-developed PBL STEM units have also noted difficulty in the design elements of student voice and choice and public product [9,12]. For example, in the sustainable farming unit, the PSTs asked, "How can sustainable farming practices benefit our school?" In developing the public product, however, the unit funneled students into creating and tending to a school garden. This focused public product narrowly answers the driving question and limited student voice and choice throughout the project. This narrow application of the public product aligns with some of the findings by Markula and Askela [9], who studied teacher-developed PBL STEM units. These researchers examined PBL STEM public products, which they termed artifacts, and determined that public products took several forms—from one singular public product that may or may not have fully answered the driving question to several smaller public products that addressed various themes of the project topic, sometimes aligning clearly to the driving question and other times tangentially addressing the driving question. Markula and Askela [9] have noted that most teacher developed PBL STEM units showed inconsistent application of a public product, which aligns with our findings in this study of PSTs and their capability with the public product.

The instructors needed to link theory and practice more purposefully to strengthen the PST's abilities to incorporate the PBL design element of critique and revision. Instructors engaged PSTs in critique and revision processes, such as the feedback loop regarding the driving question. However, the instructors needed to connect the ways PSTs were more explicitly engaging in feedback throughout the development of their PBL unit plan proposal with ways to invite their future K-12 students to engage in critique and revision. More explicitly connecting theory and practice would have led to more robust PBL unit plan proposals.

In this study, the peer feedback cycle using the Gold Star PBL rubric, which was required by the instructors towards the end of the semester, resulted in project improvement. For example, PSTs in the *Recycling in Wisconsin* project realized their projects improved by engaging in their critique and revision process, and their PBL design skills deepened. They added a reflection activity to address prior learning during the entry event so students could connect their previous knowledge to the new content, and they included more independent work, which increased student autonomy, known as "student voice and choice".

4.1.2. How Do Resulting PBL STEM Units Integrate Social Justice Concepts and Global Awareness?

PSTs were also generally successful in incorporating elements of social justice within their PBL STEM units. This finding aligns with research that advocates for science teaching with SSIs [31]. Most projects are centered on the environment as a social justice issue, which is a topic that is readily accessible. Few PSTs incorporated what might be considered controversial subject matter, such as race, gender, disabilities, and economic injustices, into their final project proposal. While studies such as that of Cahill and Bostick [38] indicate that PSTs have the desire to discuss social justice issues in their future classroom openly, the OECD [25] report reasoned that teachers often find it challenging to engage in more controversial topics and focus on only "safe" topics, like the topics of the PBL STEM units within our study. A key idea for educators to take away is echoed in Cochran-Smith's theory of social justice teaching [28], wherein teachers must acknowledge their tensions and challenges with social justice-centered teaching, knowing they can be managed in concrete ways.

Despite prompting through multiple feedback loops to PSTs, the PBL STEM units they created tended to focus on either a local or a global issue. OECD [25] calls for teacher-learning communities to focus on dimensions of global competence (examining local to global problems, understanding and appreciating diversity, and acting for sustainable development) and the knowledge, skills, values, and attitudes of global competence. Global competence, like excellent teaching, is a process that develops over time. While teachers are often asked to include "one more thing" into their curriculum, this construct must not be considered an "add-on." Tichnor-Wagner et al. [39] (p. 156) assert that infusing global learning into a standard course is "akin to drizzling gravy over the turkey, stuffy, and potatoes," globally responsive teaching provides a richer, more enticing learning experience and is an essential part of all 21st-century curricula. Given the mission statement of the university education department, our PSTs are charged to become globally responsive educators, embodying the mindset and actions of a worldly educator preparing the future stewards of the planet.

4.1.3. How Do PSTs Emphasize Mathematics in PBL STEM Units?

Similar to other research findings centered on teacher developed PBL STEM curricular material [12,17,18], PSTs in our study demonstrated varied abilities to integrate mathematics content into their units. For example, the unit *Recycling in Wisconsin* scored 3's (demonstrating) in all categories of the mathematics rubric, indicating that they could align mathematical learning to the appropriate grade-level standards, integrate a balance of procedural and conceptual knowledge of mathematics, and provide multiple opportunities for students to connect to meaningful mathematics throughout the project. The project Vaccines scored 1's (developing) in all three categories. This lower score indicates difficulty aligning math content to grade-level standards and a view of mathematics as a procedural tool that can be applied in a limited capacity, such as a single lesson, during the PBL STEM unit.

In this research study, slightly over half of the 25 PBL STEM units scored 1.5 or below (developing) on the procedural and conceptual rubric. These scores indicate that many PBL STEM projects focused on procedural skills with little to no understanding of the significant concepts in mathematics. Guzey et al. [17] also found that scores on math integration in teacher-developed PBL STEM curricula did not significantly contribute to the overall score. Two factors might have contributed to these scores when aligned with this research. First, the PSTs may have focused more on the integration of science through an SSI lens [17]. Second, the mathematics content often served in an auxiliary capacity as a tool for data analysis rather than applying conceptual mathematical knowledge [18].

Additionally, PSTs in this study tended not to apply mathematics in authentic problem-solving situations throughout the project; instead, mathematics was often isolated to a single lesson or project milestone. Many of the PBL STEM units did include authentic contexts related to their overall projects. The units did not meaningfully contribute to the public products, even with the connection between math and authenticity. This result is also consistent with Wieselmann et al. [12], who found that much of the teacher-developed mathematics integration tended to align with a standard instead of advancing a deep understanding of both the mathematics and science content. A feedback loop later in the PBL STEM unit development phase (like the feedback loop for the driving question) may enhance the quality of mathematics integration. Additional support of PSTs is also needed to connect the mathematics to the authentic context and overall learning goals of the project to enhance a deep understanding of mathematical concepts [12].

4.2. Limitations

One fundamental limitation of the PBL STEM project was time. Even with both instructors dedicating time to PBL STEM unit development, PSTs were also heavily involved in completing essential pre-student teaching requirements within their degree programs. When instructors provided instruction and work time during class, the focus on those PBL design elements that were unique (e.g., challenging problem or question, authenticity, and public product) tended to be the focus. The challenging problem or question criterion was a central focus of the project launch and revisited often throughout the student's work time; this could have led to the overall highest average score for the 25 projects. On the other hand, the PBL design element related to reflection was noted as a part of the rubric; however, this element was not emphasized within the project template. Thus, PSTs were less successful using this pedagogical strategy within their projects.

In addition, within the final project template, PSTs were tasked with conceptualizing their whole project rather than focusing intensely on each PBL design element. For example, after identifying their topic and ideas, they began their project design with a concept map and storyboard, an outline of mathematics and science standards, and critical content knowledge for teachers. The key project milestones contained depth as required for a single math lesson and two science lessons in their respective courses. Though PSTs academically discussed STEM and applied their knowledge of STEM to an experience within the community, the PBL STEM unit plan template did not specifically address how engineering and technology could have been incorporated, nor were these components part of our analysis.

5. Implications for STEM Education and Future Research

Using an integrated PBL unit plan across undergraduate science and math methods courses did seem to support PSTs' abilities to produce meaningful PBL STEM units that incorporated a social justice lens and increased global awareness. Utilizing meaningful socioscientific topics to launch the project allowed PSTs to develop authentic student projects with challenging projects or problems. In the end, some PSTs were more aware of the need to push for public products and empower their students as agents of change.

Challenges related to STEM integration need to be noted. While PSTs integrated mathematics and science standards, the STEM component of our framework did not fully materialize within the PST's final projects. While STEM research pays attention to integrating science, technology, engineering, and mathematics as a cohesive curriculum [19], the shortcomings of numerous projects that embrace STEM entirely will need to be addressed in future iterations of this project.

Nevertheless, collaboration across university education courses allowed the authors to model how professionals plan and collaborate on a common curriculum. Our PSTs came away with the knowledge and ability to plan integrated curricular units focused on learning content and improving success skills such as communication and collaboration. PBL is both research-based and successful at engaging PK-12 students in authentic inquiry. When coupled with a focus on social justice issues and global awareness, our PSTs, as future educators, have the tools to make a difference in the lives of their students.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to the research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

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Data Availability Statement: Data are available from the authors and can be provided upon request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Unit plan template used across science and mathematics courses.

Integrated Project-Based Unit Plan Template	
I. Overview of the Unit Plan and Project	
Project Title	
1. **Driving question**	
Grade level/ subjects	
Timeframe	Estimate the number of class days for the project.
2. **Culminating project summary**	Describe the central focus of your culminating project and how it reflects the elements of project-based learning design (see rubric below).*Be sure to include service-learning components.
Student product(s) (individual/team)	Note which products are individual or team and the product/performance's intended audience.

II. Project Pre-planning tools

3. **Use this space to complete a** concept map **(or feel free to import your map from another source). The concept map should outline/list all of the big ideas within your project AND include linking words/phrases explaining how ideas connect.**
4. **Storyboard:** Use the frames below to show the critical unit plan milestones representing significant moments or stages and indicate how the inquiry extends throughout the unit plan.

Authentic context:	
Entry event	
	6. Culminating Project

III. Learning Goals, Standards, and Objectives

5. Standards: A list of the standards being covered in your sequence of lessons. (Based on your methods courses, please ensure that you at least include the respective professional standards aligned to your current enrollment, e.g., NGSS, NCSS, CCSSM, etc.)

6. Learning objectives: Write a list of learning objectives for the unit (make sure they are aligned with the standards).
7. **Vocabulary list: A list of the key vocabulary students will need to comprehend and apply their understanding of towards the final project**
8. **Literacy skills:** A description of the key literacy skills students will be practicing within the unit (should correspond with the listed literacy standards).
9. Success/SEL skills: A description of success/social-emotional skills students will be practicing within the unit.
10. A T chart with a bulleted list of **math and science** concepts: What students should know from previous lessons or grade levels and what they are expected to learn versus what they do not know (the common misconceptions held by learners).

Mathematics		**Science**	
Should know/ previous grade level	May not know	Should know/ previous grade level	May not know/research-based misconceptions

11. This is a detailed description of the teacher's math and science content knowledge needed to teach the unit, **sufficient for a novice teacher to have a strong grasp of the content.**
12. Interventions/accommodations: From what you know thus far about student learning needs, what specific skill/information would you target for intervention or accommodations? Why? Describe an intervention or accommodation you might use to provide instruction in the particular skill/information targeted.

IV. Unit Plan Milestones and Lesson Plans

13. **Milestones and focus questions table:** This section creates a high-level overview of your unit plan and project. Think of this as the broad outline of the story of your project, with the milestones representing the significant 'moments' or 'stages' within the story. As you develop these, consider how the inquiry process unfolds and what learning will occur.

Milestone #1	**Milestone #2**	**Milestone #3**	**Milestone #4**	**Milestone #5**	**Milestone #6**
Consider indicating if this is tied to team or individual learning/products					
Description of big idea and what students will be doing.					
Key Inquiry Question	**Key Inquiry Question**	**Key Inquiry Question**	**Key Inquiry Question**	**Key Inquiry Question**	**Key Inquiry Question**
This is the anticipated need-to-know question that guides the learning for the milestone. Be sure the questions are student friendly.					
Connections	Connections	Connections	Connections	Connections	
Identify the number of instructional day(s) and how you will make a connection to the next milestone. That is, how does each milestone connect to the next milestone?	.				

14. **Unit plan lessons:** Include the following:

- Lesson Objectives
- Brief description of what will occur in each phase of the lesson
- Each phase of the lesson connects to the next phase
- Lesson formative assessments present
- For science lessons (at minimum), strive to use the 5Es to guide each phase (this is your 5E lesson plan assignment; it is not an additional requirement).
- Use the launch, explore, and summarize lesson plan framework for the math lesson as a guide.

V. Field II Unit Plan Reflective Narrative

Use this section to create a narrative describing how your unit plan and culminating project address critical components of impactful teaching as defined in ALL of your Field II courses. This narrative should reflect your conceptual understanding of key course outcomes.

15. A description of how the project connects to the social and cultural assets of the young adolescent learner and learner's community (ages 10–15). (EDS 445/452)
16. A description of how your unit plan and culminating project addresses conceptual understanding, procedural fluency, mathematical reasoning, and problem-solving skills (EDS 422).
17. An explanation of how your unit plan and cumulative project provide students with opportunities to use **mathematics** as a lens to understand, critique, and create solutions for the world (EDS 422).
18. An explanation of how your unit plan and the cumulative project allow students to engage in science disciplinary core ideas and scientific practices (EDS 421).
19. An explanation of how your unit plan provides students with opportunities better to understand the nature of science (NOS).

VI. Convention, Style, and Feedback

20. Creative and critical thinking will be evaluated—review your unit plan and ensure novel thinking and logical sequencing throughout.
21. Conventions: Review your document for spelling, grammar, and writing style, and include APA citations where appropriate.
22. Feedback: Your project will be peer-reviewed using the PBL design rubric (see Assignment document). You will be scored on your reflective use of feedback from peers and instructors. Please include a link to your peer review rubric in the final submission.

Appendix B

Complete List of Projects and Scores (n = 25).

		PBL Design Elements						Globally Responsive		Mathematics Emphasis		
Title Grade Level	**Driving Question**	**Problem or Question**	**Sustain Inquiry**	**Authenticity**	**Student Voice & Choice**	**Reflect**	**Public Product**	**Social Justice**	**Local to Global**	**Standard**	**Proceedural & Conceptual**	**Application**
Our Changing World 6th	What is climate change and how do you interact with it on a personal, communal and global level?	2	2	2.5	2.5	1	2	2	2.75	2	1	1
Water Waste 6th	How is water wasted in our community, and what can you do to reduce water waste?	2.25	2	2.5	3	2	2.5	3	2.75	2	2	2.25
Sustainable Farming 6th	How can sustainable farming practices benefit our school?	2	1.5	2	1	2	1.5	1.5	1.5	3	2	2
Climate Change Social Media 6th–8th	Who will be affected the most by a changing climate and what can we as middle schoolers do to make an impact and help people who are facing the most struggles with a changing climate?	2.75	3	3	3	2.5	3	3	2	1	2	2
Recycling in WI 3rd	How can we, as earth citizens, contribute to recycling efforts in our school and home?	3	2	2.5	2	2.5	2.5	2	2	3	3	3
Viruses 7th	How do we protect our immune system from viruses, and how does it differ globally?	2	2	2	2	1.5	2	2	3	1	1	1.5
Climate Change States 5th	How does your life here in Wisconsin compare to lives of other 5th grade students around the country when looking at life through the lens of climate change?	1.75	2.5	2	2	2	1.25	2	1.5	1	1.5	2

		PBL Design Elements						Globally Responsive		Mathematics Emphasis		
Title Grade Level	**Driving Question**	**Problem or Question**	**SUSTAIN INQUIRY**	**Authenticity**	**Student Voice & Choice**	**Reflect**	**Public Product**	**Social Justice**	**Local to Global**	**Standard**	**Proceedural & Conceptual**	**Application**
Vaccines 7th	What role do vaccines play in our society?	1.5	2	2.25	2.5	1.5	1.5	2	1.75	1	1	1
Human impact on Earth Systems 7th	As humans, how does our lifestyle impact Earth Systems?	1.5	1.5	2.75	2	2	2	2.5	2	3	2	2
Endangered Species 6th	How can we protect endangered species in our state?	2.25	1.5	2.25	2	1	2	2	2	1	1	1
Get Outside 7th	How can nature benefit our well-being?	2.75	2.5	2.25	3	2.5	2.75	3	1.75	1	2.5	3
Water Access 6th	Is safe water accessible to all? Why or why not?	1.75	1	2	1	1	2	1	2	3	1.5	1.5
Plastic Waste 6th	How does plastic waste affect our environmental systems?	2.25	1	3	1	1.5	2.25	2	3	3	2	2
Climate Change Impact 8th	What small changes can you make in your life that if done at a larger scale would reduce the negative effects of climate change?	2.25	2	3	2	1.5	2.25	2.5	3	1	1.5	1.5
What's your impact? 8th	What is your impact on the environment?	1.5	1	2	1.5	2	1.25	2	1.5	3	2	2
Human Impact on Water 4th	How do our actions impact local and global waterways?	2.5	1.5	2	1	1	2	2	2.5	1	2	2
Single Plastic use 6th–8th	In what ways can we, as environmentalists, limit single use plastic at the school, community, or global level?	2.75	2.5	2	2	1	2.75	2	2.5	3	1.5	3
Oil Consumption 8th	How does oil production and consumption affect our world?	2	1	1.5	1	1	1	2	1.5	2.5	1.5	1.5

		PBL Design Elements						**Globally Responsive**		**Mathematics Emphasis**		
Title Grade Level	**Driving Question**	**Problem or Question**	**Sustain Inquiry**	**Authenticity**	**Student Voice & Choice**	**Reflect**	**Public Product**	**Social Justice**	**Local to Global**	**Standard**	**Proceedural & Conceptual**	**Application**
Organic vs. *Non-organic 6th*	Should we provide organic food options for students in school?	3	2.5	3	1.5	1	2	2.5	2	1.5	1.5	2
Sustainable practices 6th–8th	Who should be responsible for sustainable practices and choices?	1	2.25	2	2.25	2	2	2.25	1.5	3	1.5	1.5
Ag Run-off 7th	How can we positively impact Wisconsin waterways?	2.5	1.25	2	1.75	1	1	1	1	1	1	1.5
Save the Bees 6th-7th	How can we as middle school students positively impact biodiversity through supporting the bee population?	2.75	2	1.5	1.5	1	1	1.25	1	3	3	1.5
The green-house effect 6th-8th	How can we, as environmentalists, limit our impact on climate change by reducing our carbon footprint?	2.5	1.5	1.5	1.75	1	2	2	1.5	1.5	1	2
Radiation 6th	How does radiation affect you and your community?	2	1	1	1	1	1	1	1	1	1	1
GMO's 7th	How can I make an informed decision on what type of food we consume?	2.75	1.5	2.5	1	2	2.25	3	1	3	2	3
Average		2.21	1.78	2.2	1.81	1.54	1.91	2.06	1.92	1.98	1.68	1.87
SD		0.52	0.57	0.52	0.66	0.56	0.59	0.60	0.65	0.93	0.59	0.63

Appendix C. Project Design Rubric—PBLWorks.org

PROJECT DESIGN RUBRIC

	Beginning *This element is not yet strongly evident in this project. There are opportunities to brighten this Element in future revisions of the project.*	**Developing** *The project includes some evidence of this Essential Project Design Element, as well as opportunities to further brighten the Element in future iterations.*	**Demonstrating** *The project shows clear and strong evidence of this Essential Project Design Element.*
Student Learning Goals: Key Knowledge, Understanding & Success Skills	• Clear and specific student learning goals aligned to standards are not yet evident in the project. • The project does not yet explicitly target, assess, or scaffold the development of success skills.	• The project is focused on standards-derived knowledge and understanding, but it may target too few, too many, or less important goals. • Success skills are targeted, but there may be too many to be adequately taught and assessed.	• The project is focused on teaching students specific and important knowledge, understanding, and skills derived from standards and central to academic subject areas. • Success skills are explicitly targeted to be taught and assessed, such as critical thinking, collaboration, creativity, and project management.
Essential Project Design Elements			

Challenging Problem or Question	• The project is not yet focused on a central problem or question (it may be more like a unit with several tasks); or the problem or question is too easily solved or answered to justify a project.
	• The central problem or question is not framed by a driving question for the project, or the question:
	  • has a single or simple answer.
	  • may be difficult for students to understand or connect with.
		• The project is focused on a central problem or question, but the level of challenge might be a mismatch for the intended students.
		• The driving question relates to the project but does not capture its central problem or question (it may be more like a theme).
		• The driving question meets some of the criteria (in the Includes Features column) for an effective driving question, but lacks others.
			• The project is focused on a central problem or question, at the appropriate level of challenge.
			• The project is framed by a driving question, which is:
			  • open-ended; there is more than one possible answer.
			  • understandable and inspiring to students.
			  • aligned with learning goals; to answer it, students will need to gain the intended knowledge, understanding, and skills.

Sustained Inquiry	• The overall project is more like an activity or "hands-on" task, rather than an extended process of inquiry. • There is no process yet for students to generate questions to guide inquiry.	• The project includes brief or intermittent opportunities for inquiry, primarily focused on information-gathering. • Students generate questions, but while some might be addressed, they are not yet used to guide inquiry and do not affect the path of the project.	• Inquiry is sustained over time and academically rigorous (students pose questions, gather & interpret data, develop and evaluate solutions or build evidence for answers, and ask further questions). • Inquiry is driven by student-generated questions throughout the project.

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Authenticity	• The project resembles traditional "schoolwork;" there is not yet evidence of a clear connection to a real-world context, tasks and tools, impact on the world or connection to students' personal interests.	• The project has some authentic features, but there are opportunities to deepen connections to the real world and to students' personal interests.	• The project has an authentic context, involves real-world tasks, tools, and quality standards, makes an impact on the world, and/or speaks to students' personal concerns, interests, or identities.
Student Voice & Choice	• The project is primarily teacher-directed, and does not yet include opportunities for students to express their voice and make choices affecting the content or process of the project. • (Or) Students have opportunities to work on their own, but could benefit from clearer structures and guidance.	• Students are given some low-stakes opportunities to express their voice and make choices (deciding how to divide tasks within a team or which website to use for research). • Students work independently from the teacher to some extent, but they could do more on their own.	• Students have opportunities to express their voice and make choices on important matters (topics to investigate, questions asked, texts and resources used, people to work with, products to be created, use of time, organization of tasks). • Students have opportunities to take significant responsibility and work as independently from the teacher as is appropriate, with guidance.
Reflection	• The project does not yet include explicit opportunities for reflection about what and how students learn or about the project's design and management.	• Students and teachers engage in brief or intermittent opportunities for reflection during the project and after its culmination.	• Students and teachers engage in thoughtful, comprehensive reflection both during the project and after its culmination, about what and how students learn and the project's design and management.
Critique & Revision	• Students get some feedback about their products and work-in-progress from teachers. • Students do not yet know how or are not required to use feedback to revise and improve their work.	• Students are provided with opportunities to give and receive feedback about the quality of products and work-in-progress, but they may be unstructured or only occur once. • Students look at or listen to feedback about the quality of their work, but do not have opportunities to substantially revise and improve it.	• Students are provided with regular, structured opportunities to give and receive feedback about the quality of their products and work-in-progress from peers, teachers, and if appropriate from others beyond the classroom. • Students use feedback about their work to revise and improve it.
Public Product	• The teacher is the primary audience for student work.	• Student work is made public to classmates and the teacher. • Students present products, but are not asked to explain how they worked and what they learned.	• Student work is made public by presenting, displaying, or offering it to people beyond the classroom. • Students are asked to explain the reasoning behind choices they made, their inquiry process, how they worked, what they learned, etc.

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