Enhancing PBL Authenticity by Engaging STEM-Professional Volunteers

Celeste Nicholas (Indiana University Purdue University – Indianapolis)
J. Adam Scribner (Indiana University - Bloomington)

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ABSTRACT

The article profiles a project addressing a central issue in reform-driven STEM education–the need to align educational experiences with real-world STEM. The interdisciplinary program aimed for authenticity by purposefully designing an authentic PBL project and incorporating STEM professionals as volunteer facilitators. These volunteers enhanced authentic elements of the project task (e.g., open-ended task, accountability) and context (e.g., autonomy, collaboration). Volunteers also alleviated pedagogical barriers to PBL–their expertise allowed both volunteers and teachers to take up the facilitator roles foundational to PBL. Professionals who volunteer their time can play vital roles in STEM capacity-building initiatives, including programs designed to broaden participation. Further research is needed to understand how to prepare and utilize volunteers most efficiently in a variety of classroom roles, including the role of PBL facilitator.

Keywords: problem-based learning, authenticity, STEM outreach, STEM-professional volunteers, rural education, community partnerships

Introduction and Background

Recent reforms in US K-12 science, technology, engineering, and math (STEM) education call for educators to design learning experiences that are more authentic to STEM disciplines and workplaces (National Research Council [NRC], 2012; National Research Council & National Academy of Engineering [NAE], 2009). More traditional models of STEM education can be disconnected from real world contexts–involving teacher-driven, over-simplified tasks and siloed applications of disciplinary knowledge (Bybee, 2013; Kelley & Knowles, 2016; Windschitl, 2002). In contrast, authentic learning experiences are student-driven, interdisciplinary, and collaborative (Jonassen et al., 2006). These experiences are also designed to support STEM interest and engagement and the transfer of knowledge and practices beyond the classroom (NAE, 2009; NRC, 2012). More meaningful, collaborative STEM learning experiences are important as they may appeal to students who are underrepresented in STEM

fields and students who face multiple barriers to accessing STEM pathways (Avery, 2013; NRC, 2011; National Science Board, 2018).

In this article, we describe the development and implementation of a high school STEM project designed to simulate a local, real-world STEM workplace in the Midwestern US. The project is unique in its approach to authenticity: engaging STEM-professional volunteers from the community to serve as problem-based learning (PBL) designers and facilitators. In the sections that follow, we describe authenticity in our project design and how various participant groups (e.g., students, teachers, volunteers) experienced that authenticity. In doing so, we use a framework for authenticity that can be applied across STEM PBL settings.

Authentic Learning Environments

To inform the purposeful design of authentic STEM learning experiences, Strobel et al. (2013) proposed a systematically derived model of authenticity in learning environments. They describe four different types of authenticity, building

upon existing conceptions (Barab et al., 2000; Jonassen et al., 2006) and incorporating sociocultural perspectives (Anderson et al., 1997). Task authenticity occurs when tasks are modeled after those in the real world (e.g., scientific inquiry or the engineering design process), which causes them to be ill-structured and open-ended. Context authenticity refers to ways in which an experience resembles real-world professional situations, including similarities to real-world problems and social interactions. Impact authenticity refers to the significance of the learning experience beyond the classroom and in the context of social practices. Personal/value authenticity is the relevance of the learning experience to an individual's values, interests, and identities (Strobel et al., 2013).

Strobel et al. (2013) recommend that designers consider the applicability of the type(s) of authenticity within their learning contexts, incorporating combinations as appropriate. Given that a central goal of our project was to simulate our industry partner's workplace, we prioritized task and context authenticity in our design and interpretation within the present study. We hope to design for and assess impact and personal/value authenticity in future iterations of the project.

Problem-based Learning

Strobel et al. (2013) recognize that PBL is a design model aligned with their framework, as it was developed with authenticity as a central tenet. PBL is a constructivist, learner-centered approach, which increases authenticity by engaging students in real-world problems (Savery & Duffy, 1996). In PBL, students work collaboratively on realistic, ill-structured problems, which supports development of higher-order thinking skills and disciplinary knowledge (Barrows, 2002; Hmelo-Silver, 2004). When students are engaged in PBL in STEM education contexts, their designs often reflect work done by STEM professionals who engage in complex problem solving (Capraro & Slough, 2013). In the present study, we used PBL as a way of translating Strobel et al.'s framework into our designs and practice (see "Project Design"). We selected a PBL approach to help the participating students solve real-world, industry-aligned problems they may encounter in their future careers. PBL was also selected to emphasize the sustained, collaborative nature of real-world STEM work environments.

Developed within the context of medical education (Barrows, 1994; Norman & Schmidt, 1992), PBL tenets have been emphasized within K-12 STEM education reforms to better prepare students as innovators and to address workforce development needs of industries (American Association for the Advancement of Science [AAAS], 1994; National Council of Teachers of Mathematics [NCTM], 2000; NRC, 2012). The PBL approach to STEM arouses students'

curiosity, encourages collaborative problem solving, helps students understand the process of scientific inquiry, and expands student knowledge of mathematics and science (Asghar et al., 2012).

Instructors who seek to design and implement authentic K-12 STEM experiences through PBL face several structural and pedagogical barriers (Asghar et al., 2012; Walton, 2014). For example, a key structural barrier involves disrupting traditionally siloed STEM disciplines to allow the interdisciplinary problem-solving characteristic of PBL (Kelley & Knowles, 2016). Another structural consideration is the ways in which PBL challenges conventional notions of educational accountability. In PBL, more authentic, flexible forms of accountability are privileged over traditional high-stakes standardized tests (Park & Ertmer, 2008; Windschitl, 2002). However, the administrative support needed to rearrange school structures in the ways described above is often absent (Asghar et al., 2012).

Additionally, PBL presents several pedagogical challenges. To be successful, PBL practitioners need professional learning and time to develop and align PBL activities collaboratively to curricula (Walton, 2014). Furthermore, the interdisciplinary nature of real-world PBL problems presents a pedagogical challenge of teaching across unfamiliar disciplines. PBL practitioners may experience discomfort as they attempt to make connections across content areas outside of their own expertise (Nikitina, 2006). Several additional pedagogical barriers to the implementation of PBL relate to how knowledge is constructed and by whom. The constructivist approach of PBL engages students in self-directed learning (Hmelo-Silver, 2004). To promote self-directed learning, PBL practitioners support students in becoming aware of what they do and do not understand about the problem, setting learning goals, determining next steps, and monitoring their progress toward their goals (Hmelo & Lin, 2000). Centering student thinking in this way requires PBL practitioners to shift from traditional classroom roles (e.g., as transmitters of knowledge) to facilitators who model problem solving and scaffold student thinking through strategies, such as questioning (Hmelo-Silver, 2004; Stepien & Gallagher, 1993).

Due to the collaborative nature of PBL, the facilitation of self-directed learning also means supporting students as they co-construct knowledge with peers. PBL facilitators are challenged with creating a culture of collaboration and skillfully managing the learning and activities of multiple student groups (Ertmer & Simmons, 2006). PBL also challenges traditional assessment practices that tend to evaluate predetermined, one-size-fits-all targets of learning. In general, the varying ways the learning of students may take shape in PBL requires facilitators to design flexible assessments flexibly (Windschitl, 2002). To support self-directed learning, PBL

assessments should also be viewed as feedback mechanisms by which students monitor their own progress toward self-selected goals (Hmelo & Lin, 2000).

STEM-Professional Volunteers

Involving STEM-professional volunteers in K-12 educational programming can enhance authenticity and support student outcomes (Gamse et al., 2017). Practicing and/or retired STEM professionals may enact a variety of roles across diverse program models, including leading or supporting inquiry-based activities (Bachrach et al., 2010; Countryman & Olmsted, 2012), serving as role models and mentors (Richardson et al., 2003; Smith & Erb, 1986), and presenting or teaching content (Hirsch et al., 2007; Nadelson & Callahan, 2011). Engagement with STEM professionals also supports a variety of STEM-related student outcomes such as attitudes and beliefs (Bachrach et. al., 2010; Koch et al., 2010); achievement; skills; knowledge (Hirsch et al., 2007; Lee-Pearce et al., 1998); career awareness; and enrollment and persistence in post-secondary STEM courses (Clewell et al., 2005; Melchior et al., 2005).

In a review of empirical studies, Gamse et al. (2017) found that while volunteer professionals may inhabit multiple roles, the most common role was the facilitation of inquiry-based learning activities and research/design projects. In over three-quarters of programs studied by Gamse et al., STEM-professional volunteers engaged students in various hands-on projects to demonstrate how STEM professionals solve problems in the real world. As such, volunteers often provided content expertise from their respective fields. In some of these programs, students could also directly observe the experts "in action" as they modeled STEM practices by conducting research or designing solutions. Although the instructional methods in these studies were not described specifically as PBL, the involvement of volunteers as facilitators of inquiry-based STEM activities suggests an opportunity to engage them in the design and implementation of authentic PBL activities.

Description of Practice

In this section, we describe our project, a high school STEM project designed to simulate a local, real-world STEM workplace. The project is unique in its approach to enhancing authenticity–engaging local STEM-professional volunteers as PBL designers and facilitators. We begin by providing contextual information about the project. This is followed by a detailed account of authenticity in project design and implementation, situated with respect to relevant literature. Participant data will be presented in the Interpretation section.

Context

The communities in the rural region near our midwestern university center have many STEM career opportunities due to a high concentration of STEM industries in the area (e.g., defense, life science, and advanced manufacturing). For instance, the defense industry and its subcontractors employ over 3,000 highly qualified STEM workers (scientists, engineers, and technicians). However, with 40% of their workforce projected to retire over the next decade (STATS Indiana, 2020), an urgent need exists in the region to ensure students fully understand career prospects and have the knowledge and skills necessary to capitalize on these opportunities.

To address these needs, our university center designed and implemented several PBL projects in rural midwestern high schools in partnership with the local defense industry (Cross Francis et al., 2019; Tan et al., 2019). The authors of this paper, university STEM education faculty, oversaw the design and implementation of the project. The offices of our partner, Engineering Services, were located within walking distance of the participating high school. Most of the contractor's STEM-professional volunteers lived within the community or surrounding towns. One of the senior executives of the company was an alumnus of the high school and very committed to the project's success. In total, seven STEM professionals volunteered for the project: five male and two female engineers. Most of the volunteers were retired or semi-retired, with expertise in electrical, mechanical, and systems engineering. The Engineering Services company facilitated the paid release of employees during project workdays.

Over 16 weeks during the Spring 2018 semester, the STEM-professional volunteers (all engineers) worked with groups of students one day per week (Friday) and guided them as their PBL facilitators. Each Friday, 46 students from three participating classes met during their usual 50-minute class time as well as during a 30-minute common planning time that allowed all participating classes to meet together. This schedule was arranged by the school administration. In total, the students worked on the project for 80 minutes each week. The STEM-professional volunteers, who worked with all three participating classes, logged 180 minutes each week. The participating classes for the project included Geometry and two Project Lead the Way (PLTW) courses: Principles of Engineering (POE) and Computer Integrated Manufacturing (CIM).

Professional Development

Recognizing that professional development is essential for successful PBL implementation (Walton, 2014), we provided three professional development days to the two participating teachers and seven STEM-professional volunteers prior to

project kick-off. These sessions helped build rapport between the participating teachers and volunteers and provided skills and expertise necessary to implement the project. The professional development days, facilitated by the authors, included training on content knowledge and pedagogy as well as curriculum alignment and articulation.

Day One of the professional development sessions emphasized the general facilitation of PBL projects and the specific facilitation of engineering design process activities. Day Two instructed the participating teachers and STEM-professional volunteers how to provide students with the necessary support to complete the project's tasks. This session included discussions on the challenges of facilitating PBL, such as reducing students' fear of failure, addressing competition in the classroom, and scaffolding student learning by way of open-ended questions. Day Three focused primarily on project development. In this emphasis, the STEM-professional volunteers provided feedback on a draft curriculum initially created in a previous PBL project within the defense industry (Cross Francis et al., 2019; Tan et al., 2019). This feedback helped to ensure Engineering Services of the authenticity of the project. Questions for the volunteers included those about authenticity (e.g., Was the project realistic from an engineer's perspective? Did it model their real-world work?) and manageability (e.g., Could the student tasks be adequately completed within the given timeframe?). The latter parts of Day Two and Day Three positioned the STEM-professional volunteers as learners, in which they were provided with LEGO, VEX, and Arduino robotics kits–the same kits the students receive for the project. For many of the volunteers, it was their first experience with off-the-shelf robotics kits and/or LEGO/VEX/Arduino computer programs. Faculty from our university center provided lessons on the use of the kits to the volunteers and led the participating teachers through robotics activities. The volunteers went home with the kits in-hand so they could continue to become familiar with them.

Project Design and Implementation

In this section, we provide detailed descriptions of the project design and implementation, supported by classroom examples. The section is organized in parallel to a framework for authenticity that we developed to guide design, implementation, and interpretation of data within our project (Table 1).

We used the framework to align ideas from literature on design considerations for authentic learning environments with more practice-oriented literature on core PBL features. We then mapped the PBL features to the involvement of STEM-professional volunteers as PBL facilitators in our project. Taken together, the framework can be used to understand how STEM-professional volunteers, acting as

PBL facilitators, supported authenticity in our project design and implementation. In alignment with our framework (Table 1), the headings for the following sections are organized according to types of authenticity and associated core authentic design elements (Strobel et al., 2013). Within each section, we use classroom examples to describe supporting PBL features and the ways in which the STEM-professional volunteers enacted them within the context of the project (indicated in underlined italics). Participant data related to authenticity is presented in the Interpretation section.

Task Authenticity: Open-ended Task

According to Strobel et al. (2013), tasks are authentic when they are ill-structured and open-ended. In PBL, the tasks are real-world problems that are used to support open-ended student inquiry (Barrows, 2002; Hmelo-Silver, 2004). As PBL facilitators, the STEM-professional volunteers in our project contributed to this kind of authenticity in multiple ways. For example, they _co-designed the open-ended problem to align with problems they face as defense industry engineers_ who design advanced detection systems. In this project, students were tasked with designing and building devices to "Detect, Analyze, and Deter" a model robotic intruder (i.e., a LEGO robot designed to move at various speeds across a large, 20 foot by 20 foot gridded tarp). The open-ended task invited multiple approaches from students in course-specific missions. (See Appendix A, "Entry Documents," to view student-facing project requirements for each class.) The participating classes were chosen during the project's co-design efforts by members of Engineering Services, the participating teachers, and the project researchers. The classes were selected according to the courses offered at the participating high school and how well the courses aligned with the design tasks of the project.

The "Detect" class was made up of students from the Computer Integrated Manufacturing class of Project Lead the Way (PLTW). Students in this group were tasked with designing and building devices that used sensors to detect the model intruder robots. The "Analyze" class consisted of students from the Geometry class who were responsible for analyzing the intruder's movements. The Analyze class then provided data to students from the "Deter" class–students from the PLTW Principles of Engineering class. The Deter class was required to design and build robots to stop the model intruder robots, using the data gathered by the Detect and Analyze classes. Every Friday, the students met in small interdisciplinary groups (three or four students) with student representatives from each of the participating Detect, Analyze, and Deter classes. As a result, each group had access to expertise from the PLTW Computer

Types of Authenticity and Core Authentic Design Elements	Corresponding PBL Feature(s)	Involvement of STEM-Professional Volunteers as PBL Facilitators
Task Authenticity		
Open-ended Task	An ill-structured problem with multiple solutions drives open-ended inquiry. The problem and its constraints are based on the real world.	Co-designed the open-ended problem to align with problems they face as defense industry engineers. Used models and scaffolds to support students in solving open-ended problems like professional engineers–using the engineering design process (EDP).
Accountability	Assessment is used flexibly to account for varying learning processes, outcomes, and audiences. Assessment mirrors professional practices.	Facilitated frequent "debriefs" for students to share progress and receive constructive feedback on their developing solutions. Helped students manage/meet deadlines. Prepared students to present their ideas professionally at a public culminating event.
Context Authenticity		
Autonomy	Facilitators act as model problem solvers and learners, not disciplinary experts Students engage in self-directed learning.	Used modeling and scaffolding to support students in their problem solving using EDP. Supported students in monitoring their own progress.
Collaboration	Knowledge from multiple disciplines is required to address the problem. Facilitators act as model problem solvers and learners, not disciplinary experts. Communication is aligned to professional or real-world practices	Arranged common meeting times across multiple STEM classes in a shared space. Encouraged coordination between classes. Supported students in engaging in communication practices used in their workplace.

Table 1. Framework for How STEM-Professional Volunteers Supported Authenticity in the Project as PBL Facilitators

Integrated Manufacturing, Geometry, and PLTW Principles of Engineering classes to develop solutions for the Detect, Analyze, and Deter tasks of the project.

The STEM-professional volunteers also *used modeling and scaffolding to support students in solving open-ended problems like professional engineers–using the engineering design process (EDP).* At the beginning of the project, the volunteers talked to the students about how they use the EDP in their own work. Then, the volunteers helped the participating students to learn and apply each step of the EDP throughout the 16-week program. First, they worked with the students to brainstorm ideas and to design, build, and test their prototypes. Students began by hand-drawing their individual designs on paper. Afterwards, each group decided on salient features from the individual designs and transferred those features to large whiteboards. The teachers and STEM-professional volunteers then provided feedback on the students' designs. Each student group received one 4x8-foot whiteboard on which all group members could openly share their designs, thoughts, and solutions. (See Figures 1-3 for examples of student designs from each class and how the STEM-professional volunteers supported the students).
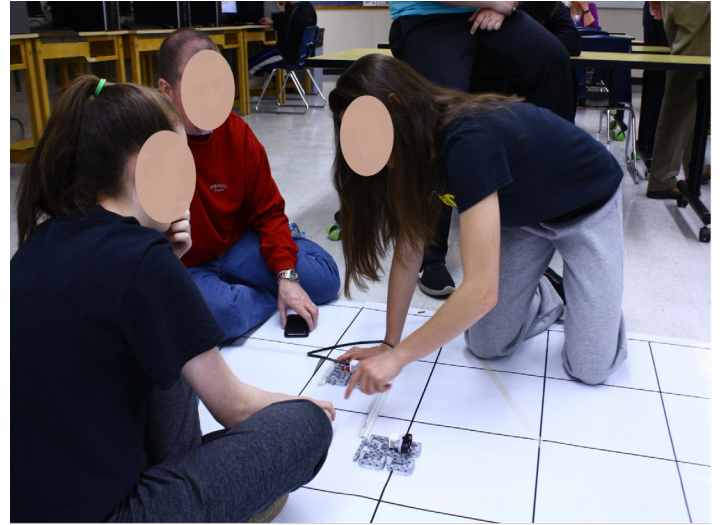

Figure 2. A STEM-Professional Volunteer Supports "Detect" Students (PLTW Computer Integrated Manufacturing Students) in Testing a Sensor to Detect the Intruder Robot.
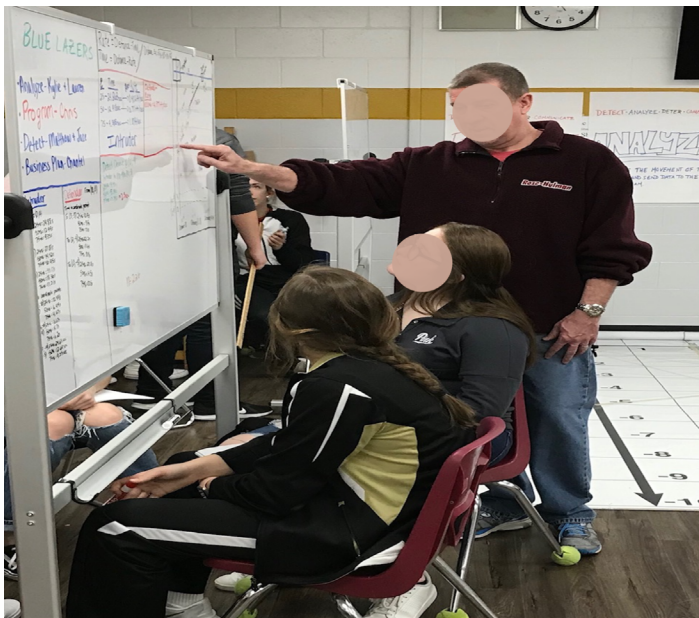

Figure 1. A STEM-Professional Volunteer Working With Geometry ("Analyze") Students to Create Tables and Graphs About the Intruder Robot's Movement.
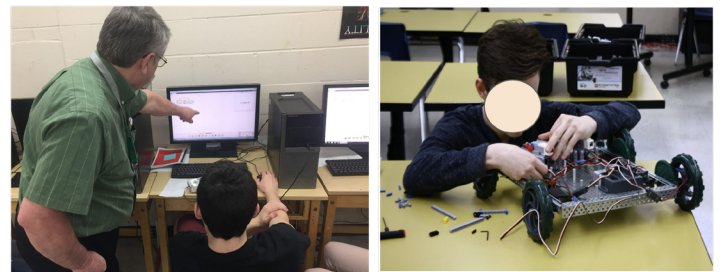

Figure 3. A STEM-Professional Volunteer Aids a "Deter" Student (a PLTW Principles of Engineering Student) Programming the Robot to Intercept the Intruder (left). At the Same Time, His Deter Classmate Builds the Robot (right).

Throughout the process, the teachers and volunteers continuously encouraged the students to make informed design decisions by applying their knowledge and practices of math, science, and engineering. Some student groups designed solutions using off-the-shelf robotics kits (e.g., LEGO, VEX) while others used more sophisticated devices such as Arduino (open-source hardware and software used for electronic prototyping). For each of these groups, the STEM-professional volunteers supported students in developing computer programs for the student designed devices.

Task Authenticity: Accountability

Authentic tasks require real-world forms of accountability (Strobel et al., 2013). In PBL, this means that assessment is used flexibly to account for varying learning processes, outcomes, and audiences (Grant & Hill, 2006; Windschitl, 2002). As such, assessment is more like professional accountability practices than conventional educational assessments. To incorporate 21st century skills and model real-world forms of accountability, the engineers in our project facilitated frequent debriefs for student groups to share progress and receive constructive feedback on their developing solutions. Their audience included peers, the Engineering Services volunteers, and teachers (Figure 4, 5).
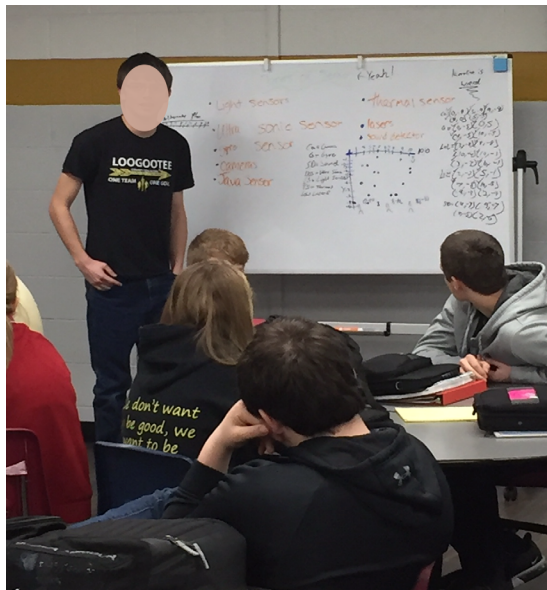

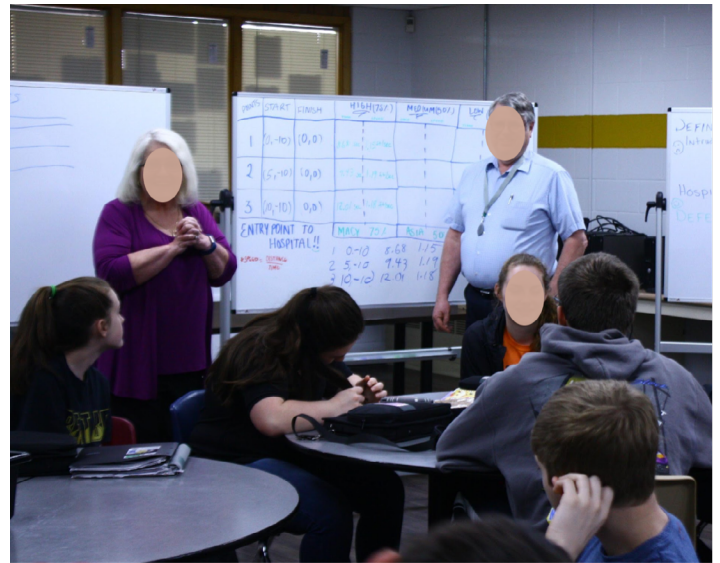Figure 4. A Student Debriefs His Peers.

Figure 5. Following a Debrief, STEM-Professional Volunteers Provide Feedback.

Each student group provided debriefs that lasted five or six minutes every two or three weeks, with at least one group providing debriefs weekly. Every student group had at least two assessments throughout the 16-week project. To debrief the groups, the STEM-professional volunteers would ask the students specific questions about their designs and devices: why they made the decisions they made; what alternative designs they considered; what obstacles they encountered; and how they were _managing and meeting project deadlines._ The volunteers would also ask the students to consider "interoperability"–how each groups' designs/devices worked within the larger "Detect, Analyze, Deter" system.

After 16 weeks, the project culminated with a large STEM showcase event titled "Detect, Analyze, Deter: A Demonstration of STEM Learning." All the project stakeholders–students, school administrators, teachers, and Engineering Services employees–attended the event held in the school's gymnasium. Other attendees included parents of the students, local and state politicians, business community members, and the media (including print, TV, and radio) who broadcasted live from the event. Total attendance for the event numbered over 300 people. During the event, the STEM-professional volunteers spoke to the audience, explaining their roles and ways they were impacted by the program. A few students also volunteered to speak to the audience about their group, their designs, and what the project meant to them (Figure 6).

Figure 6. Project Culminating Event

Before the big day, the STEM-professional volunteers _helped prepare students to present their ideas professionally._ For example, the volunteers coached the students on public speaking and how to look and sound professional. The showcase event began with a poster session; student groups displayed large posters that explained their designs and roles. Each student group created a poster that displayed the group's work, including each step of the EDP. The poster templates were developed by our university center with input from the STEM-professional volunteers (Figure 7).
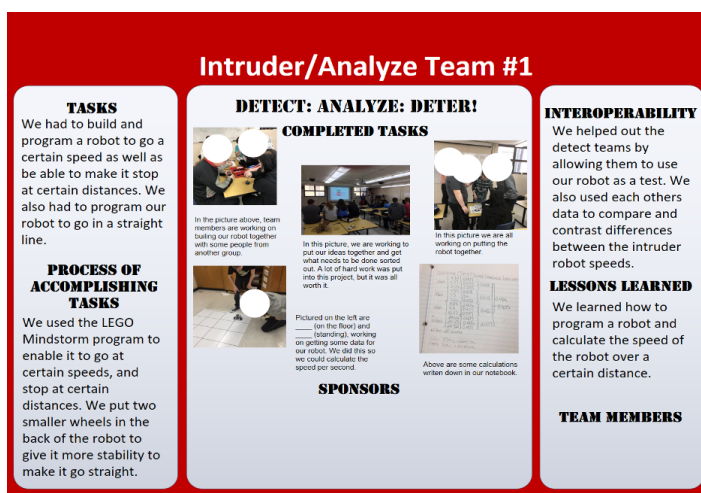

Figure 7. Poster Created by an Interdisciplinary Student Group

Prior to the event, the STEM-professional volunteers provided the students with feedback on their poster designs. After the event's poster session, each student group–often with the help of the volunteers–demonstrated their devices and how their final designs were informed by the work of other participating classes in the project. Throughout the event, the STEM-professional volunteers sat beside the student groups with whom they worked during the project.

Context Authenticity: Autonomy

In authentic STEM learning environments, students are in control of the learning process (Strobel et al., 2013), which means student ownership and flexible use of time must be supported. In PBL, some of this ownership is supported by the open-ended nature of the problem, as described above, which invites students to make decisions around their own learning. In our project, the overall problem was open-ended, and students decided how to pursue its resolution. They chose what devices (such as robotic sensors) to research and test, using their learnings to make informed design decisions. Student groups were afforded the opportunity to organize their time to meet the project's tasks and work on the project outside of those times as necessary.

As introduced in the previous section, weekly debriefs were a key factor for the development of accountability in the project. We also found that the interactions in debriefs exemplified the ways in which STEM-professional volunteers in our projects supported students' self-directed learning, which is essential for their autonomy (Hmelo-Silver, 2004; Hmelo & Lin, 2000). Within debriefs and other interactions, the volunteers encouraged students to rely on their own or peer expertise, rather than the expertise of the adults. Instead, the teachers and volunteers used _modeling and scaffolding to support students in their problem-solving using the EDP. They refrained from offering solutions as experts._ For example, the volunteers used the open-ended prompts we discussed during professional the development sessions, such as, "Could you change something to make your designs better?" and "What else do you think you should try?" These interactions allowed volunteers to provide real-time feedback that students could use to monitor their own progress both in terms of their goals and timeline. For example, a group of students became frustrated that their detection device's complex computer program was not working. In response, a volunteer asked, "What else do you think you should try?" One of the students replied that they had already exhausted all their ideas. The volunteer then provided the students an anecdote about one time when she was "stuck" similarly at work and ultimately suggested a different approach– starting over with

a simple program and then adding complexity. As a result, the volunteer and the students discussed simpler programs that could accomplish the same task.

Context Authenticity: Collaboration

Real-world problems are interdisciplinary, meaning that knowledge to solve problems is distributed among group members with varying disciplinary expertise (Jonassen et al., 2006). Therefore, authentic STEM learning environments require substantial collaboration (Strobel et al., 2013). Collaboration is a central tenet of PBL (Barrows, 2002; Hmelo-Silver, 2004) as facilitators support and manage student groups who pursue varying problem-solving pathways (Ertmer & Simmons, 2006). In our project, we realized our first step in supporting interdisciplinary collaboration was to bring the participating classes–and their knowledge–together in the same physical space. Like in most traditional schools, this school's participating classes were siloed in separate classrooms with separate curricula (Bybee, 2013; Kelley & Knowles, 2016; Windschitl, 2002). With the support of school administration, we *arranged two common meeting times for multiple STEM classes in a shared space.* Both meeting times occurred on Fridays, the day the STEM-professional volunteers visited the school. The first meeting time occurred during the regular 50-minute period of the participating classes. During this time, students simply met in the shared space rather than their separate classrooms. Students used this time to focus primarily on using the content knowledge gained from the class to develop solutions for their given tasks. The second meeting time occurred during a 30-minute period toward the end of the day. (Before this project, this class was a study hall for students.) This time was mainly used for student groups to meet, reflect on their tasks and progress, and plan next steps.

The shared workspace was a large room decorated with signage from Engineering Services. To help make them feel more like professionals, every participating student was provided an Engineering Services polo shirt to wear on Fridays and during the culminating event. The room was set up with enough tables and large whiteboards for each group. Within our common meeting time(s) and spaces, the STEM-professional volunteers were able to *encourage the collaboration between classes* required to solve the interdisciplinary problem. The volunteers called this coordination "interoperability," a term they used often at Engineering Services. This coordination was supported as students worked in interdisciplinary groups with disciplinary expertise from each of the participating Detect, Analyze, and Deter classes. Because each group had the disciplinary knowledge needed to address overall problem, the STEM-professional volunteers could more easily embody the facilitator role–supporting the student groups in driving their own learning through modeling and scaffolding strategies rather than relying on the facilitators as content experts. Beyond its affordances for interdisciplinary problem solving, collaboration in our project also made the overall problem one that could be addressed through simultaneous, rather than sequential, problem solving. That is, students in our project did not need to wait for other groups to develop their solutions before they could begin working on theirs. For example, a student from the Detect class may be working on building a detection device (typically, computer-programmed sensors), while another student from the Deter class (in the same group) created the deter device (i.e., robots programmed to stop the intruder robots). However, if the detection device was going to work "interoperably" with the deter device, the students had to ensure they exchanged information with each other while they made changes to their devices.

Although much of the work for the project occurred in the common planning/work time described above, some tasks occurred separately and asynchronously. For example, some of the students worked before and after school on their tasks. Teachers also supported students in using any downtime during their normal class period to work on the project. This arrangement provided an opportunity for the STEM-professional volunteers to *support students in engaging in communication practices used in their workplace.* The STEM-professional volunteers required the student groups to send professional emails to each other–the preferred method of communication at Engineering Services. The students also developed alternative communication methods, preferring to send text messages to their teammates or writing on the whiteboards of other groups.

Interpretation

To this point, we have described the project from the perspective of the authors: university STEM education faculty who oversaw the design and implementation of the project. In the next section, we present qualitative data from semi-structured interviews we conducted with members of the various participant groups involved (e.g., STEM-professional volunteers, teachers, and students). These individual post interviews were 15-20 minutes in length and included all STEM-professional volunteers (n=5), both teachers (n=2) and a subset of students from each class (Geometry n=6, PLTW Principles of Engineering n=2, and PLTW Computer Integrated Manufacturing n=3). Although we refer to these meetings as "post interviews," we should note they occurred during the last common class meeting time and just prior to the culminating event. Interviews were transcribed verbatim.

The purpose of the interviews was for program evaluation. That is, we wanted to obtain insights about the project that were useful to us and other PBL practitioners who were engaging in similar projects in their own settings. Specifically, we wanted to understand how participants experienced the elements of the project that were designed to be authentic. We used the ideas which outlined our design and implementation (Table 1) to frame the development of our interview protocol and interpretation of the data. Our questions focused on three main areas of participant experiences. (See Appendix B, "Interview Protocols,") Across participant groups, we asked (1) how well participants thought the project simulated the real-world workplace of Engineering Services; (2) how participants thought the project compared to their normal school learning environment; and (3) how they perceived the role of STEM-professional volunteers in the project. After each question set, we also asked the participants which aspects mattered most for student learning and engagement.

Questions were purposefully aligned with our project framework. For instance, we asked each participant group how they thought the project compared to normal class time. After participants responded to this initial open-ended question, we asked specifically about four of Strobel et al.'s (2013) core authentic elements that comprise our framework, translating the language as needed to be more accessible to participants. For instance, we asked about the core element of accountability by inquiring what participants thought of the project as compared to the students' normal class time. Our questions related to "the kind of final product students created," "expectations of students and classmates," and "how students were assessed/graded." Similarly, we asked about the involvement of STEM-professional volunteers in the project, aligning our questions to the components depicted in Table 1. After participants responded to an initial open-ended question about the role of STEM-professional volunteers in the project, we asked if they could describe specific types of involvement, including "helping solve problems" and "connecting the project to work."

Due to the alignment of the specific interview questions aspects of our framework, we were able to apply our framework as a practical, deductive coding scheme for both the open-ended and more structured responses. Findings are organized in parallel to the project description section. Headings for the sections below are organized according to types of authenticity and associated core authentic design elements (Strobel et al., 2013). Within each section, we use participant interview data to describe participant experiences of these elements and the ways participants perceived STEM-professional volunteers enacting them within the context

of this project (indicated in underlined italics). The quotes and examples presented here were selected as representative examples of experiences of the various participant groups.

Task Authenticity: Open-ended Task

As mentioned in the project description, the STEM-professional volunteers had _co-designed the open-ended problem to align with problems they face as defense industry engineers._ In interviews, we asked the volunteers to reflect on the way in which the project achieved that alignment. The volunteers expressed that the project's complex, open-ended task was reminiscent of engineering problems with unclear constraints. One engineer compared the ill-structured student tasks of the project to indecisive customers of the engineering company by saying, "The customer doesn't really know what they want and only has so much money. No one's worked through the problem. It's a crisis when you're given the task." Another volunteer, a professional systems engineer, related the interdisciplinary nature of the task to the real-world work of engineers. She described the project as a "mini systems engineering" project that required students to work across three subsystems to (1) "Detect," (2) "Analyze," and (3) "Deter."

Students described the project tasks as more open-ended than their traditional class activities and similar to the real-world work of engineers. This scenario was particularly true for the Geometry class, in which students were used to working toward a single correct answer. As one Geometry student put it, "When we were doing stuff with robots, we weren't really having to make sure we got it right because there was always more than one solution." Another Geometry student identified the open-ended task as one of the aspects of the projects that made it realistic to the Engineering Services workplace. She pointed to the iterative nature of the engineering design process, saying, "[The engineers] gave us a problem. Then we had to solve that. But, then that led to more. And then, you just keep solving one after the other, and things just keep improving."

Throughout the project, students viewed the engineers as problem-solving resources who helped them if they got "stuck." When asked about the role of the volunteers, one PLTW Principles of Engineering student said, "The volunteers gave us a lot of answers, or they gave us questions that we answered that helped us answer our own questions and figure out what we needed." We interpreted statements like these as reflective of volunteers _using modeling and scaffolding to support students in solving open-ended problems like professional engineers–using the engineering design process (EDP)._

Task Authenticity: Accountability

The project was designed to incorporate forms of accountability authentic to the engineering company's workplace. Students recognized and valued these forms of accountability, which differed from normal school experiences. For instance, one Principles of Engineering student described the project, saying "I feel like the expectations in the [project] were a lot more demanding than school, but demanding in a good way–something to kind of push you." Many students described the project as the first time they had firm deadlines and were required to document their work from one week to the next. They discussed having clear roles and expectations and saw collaboration and the final product being emphasized over grades. As one PLTW computer integrated manufacturing student stated, "we were assessed on how well we reacted to the problems, how well we came up with solutions, and how well we worked with others on coming up with the solutions." The students tended to speak generally about the project without calling specific attention to the roles of the volunteers. However, we interpret the responses as evidence that students were being supported by the project's PBL facilitators in *managing and meeting deadlines.* Furthermore, although students did not mention debriefs by name, the approach to assessment described by the students similarly reflects opportunities to *share progress and receive constructive feedback on their developing solutions.* The students did not talk about accountability in terms of the culminating event because these interviews occurred just prior to the event.

Participants pointed out some limitations to accountability in a school setting, compared to the workplace. The PLTW teacher, a former engineer, asserted, "The project is a simulation. In a school, a bell will go off, and students go to another classroom. In a workplace, there's no bell. The boss says to work on this project until it's done." Other limitations included time and access to technology. The engineers noticed how time limited accountability measures. For instance, one engineer noted that meeting one day per week for 16 weeks was not enough time for the students to test multiple technologies, produce multiple design iterations, meet "milestone deliverables," and have a final evaluation. Furthermore, both the students and the engineers observed that most students were limited to the VEX and LEGO robotics options for their design solutions because they were already familiar with them. Given more time, additional students may have tried other solutions, such as Arduinos. (Only one group utilized Arduinos in their final design.)

Context Authenticity: Autonomy

When volunteers considered how autonomy in the project compared to their workplace, they noted that the environments were similar in multiple ways. (In the interviews, we used the term freedom to accomplish the task, rather than autonomy.) One engineer mentioned that students determined the technical approach, the kind of robot, and the sensors used. She summarized, "[Students] had complete freedom to detect something, and they knew that they had to be able to stop it or deter it." According to another engineer, this kind of autonomy allowed students to come up with innovative ideas, requiring them to iterate based on their own work and that of the other groups.

When asked to compare the project to their normal class time, students reported that they experienced more freedom in the project. Again, this distinction was particularly true of Geometry students who were accustomed to using a defined procedure to find a single correct answer. One Geometry student explained, "In the project, we had freedom to do whatever type of design we wanted to accomplish the task, as long as it worked." Beyond design choices, several students mentioned being able to work "independently" and at their "own pace" in the project, compared to a "rushed" feeling in their traditional classes. In the project, students described being given time to think about their tasks and how to solve them. Students spoke about the affordances of the project, in general, rather than pointing to the involvement of volunteers. However, their statements reflect positive appraisals of the self-directed learning characteristic of PBL.

Context Authenticity: Collaboration

Engineers characterized collaboration in the project as similar to what occurs in their workplaces. One engineer asserted, "Most of engineering is a group effort with multiple people or groups involved." All engineers identified collaboration as the element of the project that mattered most for student engagement. Students reported having more collaboration in the project compared to their other traditional classes, where individual work was the norm. Across classes, students said they valued working with their peers because (1) they were better problem solvers, valuing their peers' differing backgrounds, talents, and ideas; (2) interdisciplinary groups supported peer learning (e.g., programming and robotics); and (3) students linked project experiences to improved interpersonal skills (e.g., listening, managing disagreements, and leadership). Students did not directly relate collaboration to professional communication practices.

When asked about the most important aspect of the project for student engagement and learning, the Geometry teacher stressed the importance of collaboration with peers in the

project. She said, "Students had to learn to work in groups and put trust in each other. And if somebody wasn't pulling their weight, they had to make a decision–and either talk to that person or ask for help." Students' comments about peer collaboration were similar, with some students discussing the affordances of working in groups that included students from other classes. A Geometry student connected the need for increased collaboration in the project to higher expectations in the project, in contrast to her typical classroom experience. She noted that in a regular class, expectations may be lower due to challenging content and the individual nature of the work, which makes it less likely that students will "get it right all by themselves." The student contrasted this experience with the project, saying that "…in here the expectations were that, if we all work together, then we shouldn't need too much help, because we should all have enough brain power to do it." Several students discussed collaboration in terms of the open-ended task and autonomy afforded in addressing the tasks. One Geometry student reflected, "The adults didn't tell us exactly what we had to do. Our group worked together to figure out what each of us were best at." While these comments were not explicit, we interpret mentions about "the project" and "the adults" as references to ways in which students were supported by _arranging common meeting times across multiple STEM classes in a shared space and encouraging coordination between classes._

Key Take-Aways for Research and Practice

In this article, we adapted Strobel et al.'s (2013) framework for authenticity to describe how STEM-professional volunteers enhanced authentic tasks and contexts in our STEM learning environment as PBL facilitators (Table 1). This work suggests multiple ways that designers can engage STEM-professional volunteers in K-12 settings, while simultaneously addressing some of the structural and pedagogical challenges in implementing PBL as an approach to authentic learning (Asghar et al., 2012). For instance, the school principal also relaxed some of the traditional school structures, which allowed three project classes to meet within one workspace during and outside of class time. This arrangement allowed us to overcome a major barrier to the implementation of PBL in schools–the siloing of disciplines.

Our approach also allowed us to confront pedagogical barriers. For example, prior to their involvement in the project, participating volunteers and teachers were inexperienced in the open-ended, student-driven approach to PBL. Furthermore, having additional disciplinary and problem-solving expertise on-hand allowed all adults in the room to adopt facilitator roles, each with knowledge and skills to scaffold students' thinking around project tasks. As facilitators,

the volunteers explicitly drew from experiences solving interdisciplinary, real-world engineering problems and experiences of being held to authentic standards of accountability. Finally, the facilitators helped students make disciplinary connections and supported them as they worked independently in collaborative groups–a new experience for many.

For project authenticity to be enhanced in these ways, we found it was very important to engage the professional volunteers in all aspects of the project, from inception to conclusion. This continuous engagement invited buy-in from all stakeholder groups and ensured that we remained in agreement throughout the implementation of the project. Specifically, we found the project's professional development sessions, which included the STEM-professional volunteers, to be invaluable from a PBL design perspective (Walton, 2014). In these sessions, we were able to develop shared understandings of the PBL strategies central to the design of the project. When working with students, these strategies were familiar, albeit still challenging at times.

It is worth noting that the school and volunteers profiled in this article continued to implement the project annually without the support of our university center. This development suggests that involving STEM professionals as PBL facilitators can enhance both the authenticity and sustainability of partnerships and projects. We recognize that the STEM-professional volunteers, school district, and community were highly committed to our project's success and sustainability. This level of commitment was largely fostered by leveraging existing community assets and relationships in ways we would recommend to all STEM practitioners. First, STEM-professional volunteers spent substantial time designing and implementing the project but were locally-based and had a history of doing STEM outreach at the school. The senior executive, an alumnus of the school, was passionate about giving back to his alma mater. We were not surprised by his generous offer to provide volunteers with paid release time to work on the project. Moreover, volunteers who spent the most time on the project were retired or semi-retired, which required a smaller financial commitment from Engineering Services. Second, administrative support from the school mattered to the success of the project. The school principal made it possible for students to meet outside of their normal classrooms in a shared space–supporting synchronous, interdisciplinary collaboration. Again, we see this willingness to disrupt structural barriers to PBL as a product of the existing trust relationship between the school and Engineering Services, which we leveraged but did not create. Finally, the scale of the project's culminating event exceeded our expectations and was evidence of the commitment of this small rural community to local education. While an event of this size may initially strike readers as an unsustainable practice,

we believe a smaller event would similarly support learning outcomes. Ultimately, the commitment of the students to demonstrate their learning to their peers, teachers, STEM-professional volunteers, and other project stakeholders in an authentic manner was more important than the size of the gathering.

We have argued that STEM-professional volunteers are a valuable resource for engaging students in authentic learning experiences like PBL, which defy pedagogical and structural norms of schooling. To fully realize this potential, we conclude with recommendations for designers and practitioners. First, Although PD was foundational to our project, facilitating PBL was still challenging for volunteers. We find this fact to be unsurprising, given the pedagogical difficulties that confront even trained educators when implementing PBL. As such, future work might inform the development and evaluation of the professional development model(s) geared towards STEM PBL facilitators–those who have disciplinary expertise but not K-12 education experience. Second, we described the school-industry partnership in this project primarily in terms of its benefits to the school. However, to be sustainable, these relationships must also be of benefit to the industry partner. Limited evidence suggests that participating in outreach can be beneficial for individual volunteers in the STEM workplace. For example, when surveyed, the majority of STEM-professional volunteers reported that providing outreach increased their job satisfaction, motivation, and advanced their careers (Tillinghast et al., 2015). These kinds of outcomes could translate to increased productivity and innovation for the business. Finally, while this paper focused on how STEM-professional volunteers enhanced our project's authenticity, the ultimate goal in involving professionals is to support student outcomes, such as STEM disciplinary knowledge, interest, and engagement. Empirical research is needed to understand any causal relationship between the activities of STEM-professional volunteers and student outcomes (Gamse et al., 2017). Based on our experiences and data, we recommend conducting fine-grained analyses of interactions in which volunteers engage in modeling and scaffolding practices.

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As a STEM education and public health researcher, Celeste Nicholas brokers between partners from diverse sectors (e.g., university, K-12 schools, community, and local industry) to design and implement relevant, engaging STEM programming with underrepresented youth. Celeste's research interests include investigating how youth learning experiences (STEM and health education) influence both individual empowerment and social change.

Adam Scribner is the Director of STEM Education Initiatives in the School of Education at Indiana University where he bridges theory to practice to develop transformative STEM teaching and learning experiences designed to foster the next generation of engineers, scientists, creators, and innovators. His expertise lies in the areas of the design of K-12 STEM curricula and teacher professional development programs around the integration of multiple STEM disciplines.