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Problem-based Learning

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# "I Have Never Had A PBL Like This Before": On Viewing, Re-viewing, and Co-design

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## ABSTRACT

Video and co-design can be powerful tools to enrich problem-based learning experiences. We explore how a teacher and researcher engaged in co-design of a PBL experience focused on human-centered robotics as well as the resulting design. They explored the question "How can we design a robot that serves a need in our local community?" We highlight three aspects of the most recent iteration of our PBL curriculum that we have identified as central to its success. These three elements include: 1) co-design experiences that occurred before and during unit implementation, 2) the use of shared video viewing and analysis both in co-design and with student groups in the classroom, and 3) the bringing of local stakeholders into the classroom to work closely with students. These three aspects of our curriculum are positioned here as takeaways for researchers and educators working to design, implement, and study PBL.

*Keywords:* Professional development, co-design, video analysis, robotics

> "I really honestly have never had a PBL like this…I [usually] know what the end is…and this, this is just not pre-packaged" - *Quote from instructor Becky Hillenburg after implementing a PBL unit that was a catalyst for the co-design work explored in this article*

As educators and educational researchers, we strive to create learning experiences that bridge the "real world" with the classroom—supporting learners as they make connections between their everyday lives and disciplinary content and practices. Problem-based learning, a pedagogical approach that begins with an ill-structured and authentic problem and offers support to student groups throughout the problem-solving process, can provide a context for students to create change in their local communities. In its student-centered approach, PBL supports learner agency as it engages students in authentic disciplinary practices (Hmelo-Silver, 2004; Hmelo-Silver et al., 2007; Kolodner et al., 2003). Yet the design and facilitation of locally meaningful and empowering PBL is a complex challenge (Savin-Baden, 2003). Within PBL experiences, the instructor acts as a facilitator—scaffolding student learning and inquiry by asking guiding questions, providing just-in-time information, and supporting students' evaluation of the problem-solving process (Puntambekar, 2015). Further research is needed to consider the trajectory instructors take as they refine their understanding of themselves as PBL designers and facilitators and adjust what they attend to in the classroom environment—working to embrace a student-centered approach that is not the norm in our US classroom environments (Sedova et al., 2016). This "voice from the field" contribution works to tell one of these stories.

This article describes a human-centered robotics (HCR) PBL curriculum in a rural Midwest community that asked students to design robots that address social needs in their communities. Junior high students (ages 13-14) worked with design clients in their school to create robots that addressed social and emotional needs (e.g., patrolling hallways during school lockdowns). This curriculum, co-designed by an educational researcher (first author, Andi) and junior high educator (second author, Becky), engaged community stakeholders and emphasized user-centered design and feedback to help foster real-world connections. Co-design is considered here as work between teachers and researchers to design innovative educational experiences, implement and evaluate these experiences, and continue to refine them in order to fill local educational needs (Penuel et al., 2007). Together, we worked to cultivate a PBL experience that was ultimately transformational for students, their teacher, and their school community.

Here, we provide a description of our design partnership, our robotics curriculum trajectory, and key PBL facilitation insights we have cultivated across our experience designing and implementing this curriculum. We highlight three aspects of the most recent iteration of our PBL curriculum that we have identified as central to its success. These three elements include: 1) co-design experiences between teacher and researcher that occurred before and during unit implementation, 2) the use of shared video viewing and analysis both in teacher/researcher co-design and with student groups in the classroom, and 3) the bringing of local stakeholders into the classroom to work closely with students. These three aspects of our curriculum are positioned here as takeaways for researchers and educators working to design, implement, and study PBL across contexts.

We begin with a description of our most recent iteration of the robotics curriculum, our four-year design partnership history, and the structure of co-design work that was conducted before and throughout the robotics curriculum implementation. We describe how our co-design structure supported consistent reflection on curriculum design and teaching practice, co-construction of design decisions, and the real time refinement of the curriculum as it was enacted. We highlight how reflective video analysis practices within our co-design work has been transformative for our practice. Furthermore, our reflective video analysis informed the design of activities we did with students (e.g., viewing video clips of their own group work with them and supporting their reflections on these clips). We argue that the work of engaging in regular video reflection, which was productive for our teacher/researcher co-design work, can support both the nuanced work of real-time PBL facilitation refinement and students' work to refine their own practices as they review video of themselves.

To paint a picture of how teacher/researcher co-design and video analysis unfolded in our recent implementation, we present moments of shared video viewing and discuss how video viewing supported our own professional development and shaped design decisions. We also present moments in the classroom where students viewed and interpreted videos of themselves, considering how they might continue to improve their collaborative work. Finally, we examine inclusion of "design clients" from local communities as a means of framing authentic problem statements. Engaging community stakeholders at multiple time points in students' design work motivated student progress and made this PBL experience meaningful for students and the wider community. We present examples of students' interactions with design clients and artifacts they created to communicate their design. Furthermore, we consider how bringing local stakeholders into the classroom might be broadly beneficial for PBL experiences.

## Robotics Curriculum Background

The design and implementation of this robotics unit is the result of an ongoing research-practice partnership (RPP) between a junior high school science educator (Becky) and a research team in the Learning Sciences and Informatics Departments at a local university. This partnership has been cultivated over the course of 4 years. Throughout this article, we include our reflections as co-designers. These reflections are centered on the most recent implementation of our robotics unit and occurred immediately following its completion. We also include final reflections as we wrote this paper many months later.

In creating a robotics PBL unit over the past several years, we aimed to design a unit that provided the opportunity to navigate an authentic and local problem, but also empowered students to see themselves as capable of using STEM knowledge to create change as valuable team members. Through the process of authentic problem solving and design, this robotics unit aims to address a variety of twenty-first-century skills including collaboration, communication, creativity, critical thinking, flexibility, productivity, and technology literacy (Chu et al., 2016; Saavedra & Opfer, 2012). We engaged students in STEM via a socially focused human-centered robotics (HCR) experience. HCR, a field that focuses on the use of robotic technology to address human needs (Schaal, 2007), can help students understand how robots can help humans in their everyday lives.

Iterations of the curriculum occurred in both in- and out-of-school contexts, including an applied science course and an afterschool STEAM club at a rural Midwest junior high school. Students were given a design challenge to create robots that serve a need in their local communities. This design challenge has shifted over the course of our RPP, coming to focus on addressing social and emotional needs related to safety in one school community. As a problem-based unit (Hmelo-Silver, 2004), this robotics experience asks students to engage with an open-ended problem and to creatively locate and use resources to solve this problem.

Across all iterations, navigating an engineering design cycle (Resnick, 2007) was the central learning goal. In the design and implementation of our curriculum, we sought to engage students in an authentic process of design thinking that included asking questions, brainstorming possible solutions, collecting information, developing and testing solutions, and improving these solutions through iterative testing. We consistently came back to the engineering design cycle in our day-to-day planning and considered how to make students' understanding of and navigation of the design cycle visible. In our most recent iteration of the robotics unit, students were asked at several points in the unit to explain what part(s) of the design cycle they were engaging with and how these were connected to other pieces of the cycle. For example, students were able to articulate how the information they collected (e.g., a survey distributed schoolwide) would be used to improve their design (e.g., visual design preferences from the student body incorporated into final design). This iterative student articulation of the engineering design process was incorporated as a result of ongoing co-design discussions—described in the following sections. Across this work, design thinking helped deepen and structure students' experiences of PBL. In the paragraphs that follow, we share important social, political, and cultural background related to the trajectory of our design work as research-practice partners.

### "Lockdown Robot": A Motivating Case

This article focuses on our most recent iteration of the robotics unit. The design and implementation of this unit was motivated by experiences that occurred during an after-school iteration of our HCR curriculum in the Spring 2018. On February 14, 2018, 17 students and staff at a Florida high school were killed by a school shooter. This event foregrounded a national conversation about school safety. On February 22, 2018, during a STEAM club session, students opened up a discussion about the ubiquity of "lockdown drills"—drills that train students and staff to stay alive in classrooms when school shootings occur—and their emotional concerns about school safety. This case, centered on lockdown procedures, helped us deeply consider what it means to support authentic learning experiences.

Students in this after-school club navigated the following problem: "How can we design a robot that serves a need in our local community?" These students reflected on the recent shooting and discussed the shared experience of a lockdown procedure at their own school that same morning. Over the course of several weeks, 10 students designed and built a hallway patrol robot that would provide additional security and situational awareness during lockdowns. This cohort evaluated emotional and physical needs of their school community, connected with local stakeholders, and shared their prototype in a community-wide showcase. This case inspired both the instructor and the research team. Together, we worked to understand, through the process of co-designing the next iteration of the unit, how we could create connections with future students similar to those that occurred in the lockdown robot case and how we might help other teachers to make similar connections with their own students. This article focuses on how we acted on our motivation from this lockdown case—co-designing a five-week classroom experience in Fall 2018 that would support students as they addressed local problems and navigated an engineering design process. In the sections that follow, we describe co-design experiences that occurred prior to the beginning of the robotics unit and throughout the unit, as well as implementation, and our own reflections on co-design and its outcomes following the completion of the unit.

## Co-Design Structure

> "[Regular co-design] was something that we had not done in the three years past ...so that was a piece that we added...We hadn't planned for it to be an every-day thing, but it just felt natural to us to do that. To go through that assessment of 'what are we seeing, what are we hearing, what do we want them to get out of this and what should we go back to the next day?'" - *Becky Hillenburg, post interview*

In the most recent iteration of our robotics curriculum, co-design sessions were conducted in the month before the unit started and throughout the five weeks of the unit in order to consider how our designs were being taken up by students in real time. Both before and during the unit implementation, co-design experiences were structured to include goal setting, targeted video-based reflection, and the creation of planning artifacts. Co-design sessions shaped the implementation of the curriculum and helped us consider what we noticed in classroom interactions, how we interpreted these interactions, and how to respond (Sherin & van Es, 2005). Here, we describe the structure of our co-design and highlight key elements that supported our design work.

Formal and informal co-design sessions were held to support the design and implementation of our unit. "Formal" co-design sessions included a structured agenda, were designed to be approximately two hours in length, and incorporated joint video viewing and work with design scaffolds (e.g., planning artifacts inspired by conjecture maps, described below). "Informal" co-design sessions occurred during the unit implementation and included just-in-time planning and reflection by co-designers. Informal sessions were generally organized when further conversation and planning were needed. Across informal sessions, we discussed what we noticed during class that day and made planning decisions for the next class period. These reflections incorporated video viewing when requested (e.g., reviewing group presentations from earlier that day).

**Create/add to conjecture map**

- Set norms for conjecture mapping—a process to help us consider how the elements of the curriculum we design should function and how these elements set us up for desired outcomes (i.e., deep student engagement in designing technologies that meet real and pertinent human needs). A conjecture map will be created in the first co-design session to set the stage for the whole unit. Additional conjecture maps will then be created for specific activities/sessions.

- Collaboratively fill in conjecture map table (shown below)

| Conjecture | Designed Elements | Mediating Processes | Desired Student Outcomes |
|---|---|---|---|
| **The design of this learning experience will support…** | **Materials:**<br><br>**Student participation:** How will students participate in this task? | What will participation look like? How will we *see* that our conjecture is happening in the classroom? | What do we want students to come away with? |

**Plan class period(s)**

- Map out materials, probing questions, activities, scaffolds in a format that is accessible for the instructor.

*Figure 1.* Conjecture map planning template

Formal co-design sessions included shared video viewing of classroom clips and used reflections made during shared video viewing to inform design changes that were captured in planning artifacts. These planning artifacts, modeled after conjecture maps (Sandoval, 2014), helped us to consider how designed elements of an intervention should function and how these elements mapped to desired outcomes. Design elements within a conjecture map include materials, tools, and group structures that would be expected to support mediating processes (e.g., what we would expect to see as students interact). These mediating processes can be clearly linked to desired outcomes like increased motivation or engagement (Sandoval, 2014). A template was used to support the creation and refinement of these conjecture maps (Figure 1). Other planning documents included a rolling timeline document that catalogued key activities and materials for each class period (a to-do list and a shared document with running timeline of what we completed each day), lesson plans with resources, and agendas with notes from all structured co-design sessions.

These conjecture maps served as a shared space for capturing design decisions and assumptions that occurred in co-design work. The decision to include these artifacts was grounded in the understanding that design artifacts support the complex work of instructional design (Svhila et al., 2015). An initial conjecture map highlighting goals and designed elements supporting students' work towards these goals across the full robotics unit was created across our co-design sessions leading up to the start date of the implementation (Table 1).

Conjecture maps were also created for each of the major sections of the robotics unit. These tables were refined throughout the five extended co-design sessions held once per week across the five-week implementation. Video clips were carefully selected to include examples of 1) instructor facilitation, 2) student groups working without the instructor present, and 3) both high- and low-quality group engagement. For co-design sessions held prior to the start of the unit, video clips were pulled from the earlier STEAM club implementation. For co-design sessions held throughout the unit, video clips were selected from class periods that occurred in the 1-2 days before the session. Clips requested by the instructor were incorporated in several of these sessions (e.g., what a group was doing when she was unable to monitor them and asked to view their group work). Table 2 shows the prompts used to guide each video viewing experience.

Across the co-design trajectory, we also focused on quality of student engagement using a rubric that centered on different aspects of engagement (Engle & Conant, 2002; Rogat et al., 2019). We were inspired by high levels of engagement in the STEAM club and were aiming to support rich and multifaceted engagement throughout the implementation of the formal classroom unit. We therefore used video viewing in co-design as a space to interrogate if and how engagement was unfolding in the classroom environment and how we could better support it. Our engagement rubric helped us to better articulate what we were seeing unfold in real time and to retroactively interpret student engagement in our reflective video viewing (Rogat et al., 2019).

*Table 1*. Unit conjecture map jointly completed in pre-unit co-design sessions

| Conjecture | Designed Elements | Mediating Processes | Desired Student Outcomes |
|---|---|---|---|
| **The design of this learning experience will support...**<br><br>Applying PBL; Thinking beyond individual needs and towards global needs; Understanding of the engineering design process and standards that go with that (differences from more static scientific method); Being able to interact with different technologies and programming | **Materials:**<br><br>Design process visible all the time (poster)<br><br>Canvas<br><br>Technologies (robotics components, wiki on Canvas)<br><br>PBL structure, cycle, and facilitation style | *What will participation look like? How will we see that our conjecture is happening in the classroom?*<br><br>**Student participation:** *How will students participate in this task?*<br><br>Communicating with one another; staying on task and on topic; Asking questions not only about what's in front of them but also more broad (technology; programming) asking questions of each other | *What do we want students to come away with?*<br><br>Thinking beyond individual needs and towards global needs; Understanding of the engineering design process and standards (differences from more static scientific method); Being able to interact with different technologies and programming |

Appendix A includes an overview of our pre-unit co-design sessions as well as the first few co-design sessions held during the unit implementation. In Appendix A, we highlight details about our first formal and informal co-design sessions for our Fall 2018 unit, including the length of co-design sessions, artifacts created, and video clips viewed by design partners. In the following sections, we provide an overview of the Fall 2018 curriculum trajectory and the co-design experiences that shaped it throughout.

## Robotics Unit Trajectory: Fall 2018

As we prepared for our most recent robotics unit iteration, a five-week robotics curriculum in Becky's elective science course, we worked closely with school stakeholders to provide an authentic design experience for students. This decision was made in our early formal co-design sessions that occurred before the start of the unit. In these pre-unit co-design sessions, we reviewed video footage from the Spring 2018 STEAM club unit and considered what made it transformative. We identified school stakeholder participation as a defining element of the PBL unit. We then reached out to the school community and described our recent success with the after-school club—highlighting the exciting progress students made as they worked closely with school staff to workshop their design ideas and asked for their help to make this kind of experience possible for a new group of students. All volunteers described a need that they had on a daily basis that might be addressed by HCR. Four community members replied with design proposals, including a school counselor, staff members on the school safety committee, and a school nurse. These proposals became the anchoring point for our unit design, described below.

The Fall 2018 classroom implementation examined here included 21 students (ages 13-14). These participants enrolled in an eight-week elective science class. The HCR unit was enacted over the course of the first five weeks, with sessions held daily for twenty-two 40- to 50-minute class periods. Students were placed into 6 collaborative groups. These selections were made by Becky, who worked to include an even mix of male and female students in each group.

Students, who worked in design teams of 3-4, reviewed client design proposals and selected clients to work with over the course of a five-week design experience. They worked together to design and build robots that adequately addressed their clients' needs, integrating their own experiences as members of the school community as they worked to understand these needs. Students received formative feedback from their clients at multiple time points. Communication of design ideas was supported by facilitators and emphasized in assignments.

First, students worked as a whole class to brainstorm and define shared norms for working on design teams. Norms included making sure everyone's voice was heard, practicing open communication, celebrating successes and failures, and maintaining respectful interactions. We established these norms because of previous challenges in implementing this unit and with the understanding that many students had not had significant opportunities to work on extended collaborations (Gomoll et al., 2018a). Figure 2 provides a representation of unit trajectory and is referenced throughout the following description. This robotics experience required students to grapple with a complex problem and to collect information and apply design practices as they worked to solve it. Students were first introduced to robots designed to address everyday needs (e.g., cleaning robots, emotional support robots, and robots that allow students to attend school remotely) [A]. Students then brainstormed needs that robots could fill in their own communities and began to consider how technology might address these needs. Following this initial introduction phase, local stakeholder design clients were introduced [B]. Student groups came to a consensus about which client they'd like to work with, considering time and material constraints of the unit as well as their own personal experiences and interests related to client-identified needs. Robot design proposals selected by the six student groups in this implementation included a robot that could provide a live video feed of hallways during emergency lockdown procedures, a robot that could chaperone and support emotionally overwhelmed students who need to leave the classroom during class, and a robot that could help evacuate students with special needs during emergencies. As students considered which clients to partner with, they were encouraged to consider if a robot should address needs identified by clients (i.e., asking questions like "Are there simpler ways to solve the problem?" and "Is there anything problematic about having a robot address a certain human need?").

After they had selected their clients, student groups focused on documenting their ideas for addressing client needs through robot design. In this phase, groups had opportunities to explore "driving" the robotic platform they would use throughout the unit (the iRobot Create), play with circuitry through the construction of play-doh circuits, and interact with a therapy robot via station-based activities [C]. These stations inspired students as they began to create design artifacts related to their interpretations of the problems identified by clients and how a robot could address these problems.

Students created design drawings and collages [D], maps of the routes their robot prototypes could take within the school [E], and storyboards [F]. These design artifacts were created in preparation for an initial meeting with clients

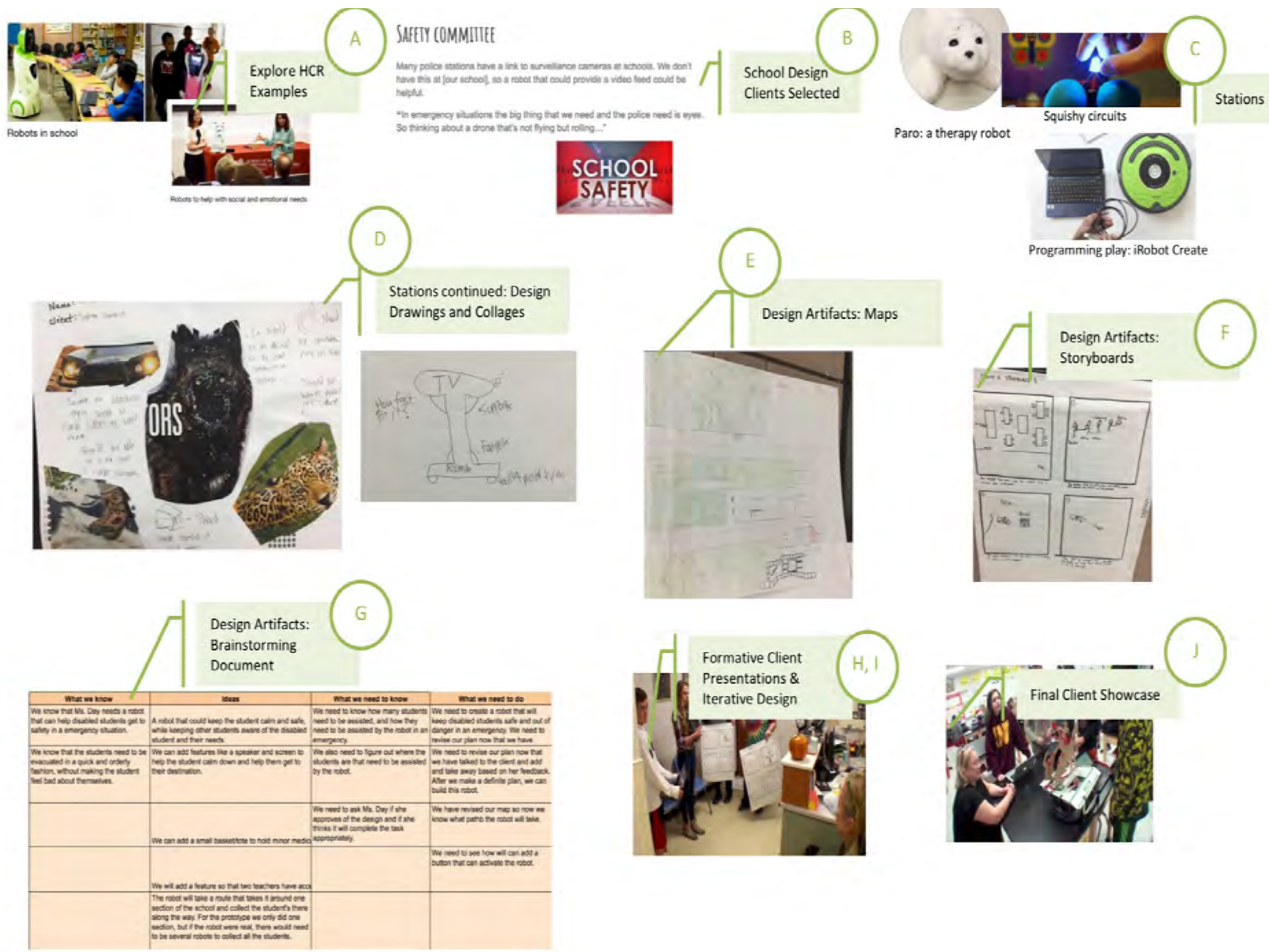


*Figure 2*. PBL unit trajectory

where students would share their ideas and receive feedback before constructing their imagined robot designs. As design artifacts were created, facilitators helped students anticipate client questions and address them in their presentations. Throughout this initial design work, the engineering design cycle served as a shared framework for the students' process (Resnick, 2007). Groups repeatedly considered what they had done so far within this cycle and where they might go next, recording design ideas, questions, and decisions within a shared Google document modeled after "KWL charts" typically used in problem-based learning environments (Kolodner et al., 2003) [G]. This shared document served as another design artifact used to communicate and justify design decisions to clients.

In initial client meetings [H], students presented design artifacts to clients and asked questions about the function and desired features of the robot design. Throughout this interaction, students recognized where they had misinterpreted their clients, understood what additional information needed to be collected, and worked to explain to clients what was possible within the scope of their work. Students then re-iterated their design ideas, followed up with their design clients, and developed "must have" lists related to programming and materials for their final prototypes [I]. All formative presentations were recorded, and student groups worked with their instructor to review and reflect on presentations, articulating actions they could take in response to client feedback.

Scaffolded video reflection helped students to prioritize specific pieces of client feedback that could be realistically achieved and to communicate to clients which design requests could not be met. The need for the instructor to work through this reflection process with each student group emerged when students initially struggled to interpret video recordings of themselves (i.e., focusing on physical appearance). Though student groups were initially overwhelmed by client feedback, they quickly learned to talk about their evolving designs as in-progress prototypes. Students used this language to set realistic goals with clients and adjust expectations for what robots would look like at the end of the unit. The final two weeks of the unit were predominantly student-driven as student groups used compiled resources to present their working prototypes during a final showcase with their design clients [J].

Throughout the unit, students applied the engineering design cycle as they navigated an authentic problem and worked to create change in their local communities. As students worked to construct their robot prototypes, they acquired valuable communication skills. The broader school community (including participating design clients, the principal, and the district superintendent) was inspired by students' design ideas and prototypes. These stakeholders communicated to the students that their ideas had potential to create change in the community, and they requested further documentation of these ideas to inform ongoing decisions (e.g., the superintendent requested a showcase video to help inform design of the district STEAM curriculum).

We were inspired by the work that students did in this implementation of our robotics unit, as were the community stakeholders who participated in it. In the sections that follow, we unpack how the work of co-design, and specifically how our process of joint video analysis, helped to make this particular PBL experience transformative.

## Video Viewing and Analysis

> "As a teacher you need to evaluate yourself. And that's what we did on a daily basis. [I] looked at what I was saying the students when I was talking to the whole group or one group at a time. I'm watching my film, I'm watching what I'm saying and evaluating myself and what I could do differently as the instructor...It's not something I do on a regular basis in my classroom. And that was a huge piece that Andi and I worked on with this. I learned so much more and I was constantly [thinking] 'Oh I should have said this in that part,' or 'tomorrow I think I need to say this over again in a different way.'" - *Becky Hillenburg speaking about video analysis within our co-design work*

Throughout our co-design work, video analysis helped us to move forward and make changes to our facilitation and design of student activity in real time. In our case, viewing video from the classroom was important to personal growth for teacher, researcher, and students. As Becky's quote at the beginning of this section shows, video viewing and reflection within co-design pointed out the strengths and weaknesses of PBL facilitation as it unfolded in the robotics unit and shaped future performance. Returning to video recordings collected in the classroom, educators can evaluate how well the content was conveyed to and taken up (or not) by the students. In our case, co-design and video viewing were used to improve and iterate the unit in real time—creating the richest and most authentic STEAM experience for students possible. We worked together to design engaging and transformative learning experiences that helped students to see themselves in STEAM and to feel like they were making a difference in their communities.

Next, we present a moment of video of co-design to paint a picture of what this looked like for us as design partners. In the example that follows, we (Becky and Andi) reflect after watching a video clip of one student group's work. This group was one that we had identified as struggling to coordinate their activity and a group that appeared to have some social tension. We decided to view a clip of their work (without a facilitator present) to get a clearer sense of the challenges the group faced and to reflect on how we might better support them. This example begins with connections between a comment one student in the group made to Becky about feeling left out of her group, and what we see happening in the video clip.

| | |
|---|---|
| Andi (A) | She said "I think" and then they kept talking and so she just went back. |
| Becky (B) | That is what she was feeling the other day. |
| A | Mmhm. |
| B | When she was struggling I think that's what |
| A | But they didn't even necessarily-- |
| B | They didn't hear her....She was very quiet… I mean I don't think I would have... I mean we just were trying to listen for it...But I don't think I would have noticed it. |

This example highlights how the video supported Becky in noticing inequitable interactions that she was not able to observe during the classroom period. After viewing more of this group's interaction, and recalling other instances where there seemed to be inequitable contributions and students had trouble working on shared tasks, we considered how what we were noticing applied to the group's coordination. In this consideration, we recognized that students' ability to work collaboratively was essential for their work in our largely student-directed robotics unit.

| | |
|---|---|
| A | …We noticed a lot about division of labor. |
| B | Mmhm. |
| A | [They] seem to not be on the same page about if individual or collaborative organization of the script is happening. One student seems to be shut out when trying to make contributions. |

In this brief example extracted from our co-design session, video recordings helped us to better understand how student group work was occurring in the classroom and allowed us to speak with this group and help them to coordinate their group moving forward. It also inspired us to emphasize and reiterate the group norms introduced at the beginning of the unit to all student groups. In other video viewing and analysis experiences centered on PBL facilitation, we looked at how our actions as co-facilitators worked (and did not work) in the classroom.

Across the work of our informal and formal co-design, we used video viewing to consider how students were (and were not) engaging in an iterative engineering design process and how we were supporting students as they made connections. As we reflected on the Fall 2018 implementation, we identified this process of shared video viewing as a practice that shaped the day-to-day work of the unit. For example, reflections on video in co-design led to changes in the way we implemented the subsequent activity (e.g., incorporating opportunities for students to view their own video, scaffolding elements of the design process like storyboarding and scripting client presentations, and asking students to articulate where in the design process they were). For us, video viewing was a dynamic formative assessment of our PBL facilitation.

We recognize that most teachers cannot regularly collect video and review it on a daily basis, but intermittent opportunities to use video to get a more nuanced sense of what is happening in the classroom during a complex PBL experience can be incredibly helpful for teachers' and students' growth.

## Integrating Design Clients

> "Providing a diverse set of clients and problem statements is helpful when you think about serving a group of diverse learners. And that was productive here."
> *-Researcher Andi Gomoll in a post-interview*

The biggest change we made to our curriculum design for this most recent implementation of our robotics curriculum was the decision to include local stakeholders as design clients. As described in our overview of the robotics curriculum, we worked closely with four local stakeholders throughout this unit. As students worked with their local "design clients" throughout the semester, we saw growth not only in their design process and higher quality in their final products, but we also noticed growth in students' communication skills, confidence, and sense of place within their communities. Though the decision to integrate design clients was made in our pre-unit co-design sessions, how these design clients were engaged throughout the unit was continuously shaped by the reflections made in our co-design work (e.g., we introduced more scaffolds to support students' communication with design clients as we recognized specific challenges student groups had articulating their designs). Continued reflection supported by video viewing allowed us to fully leverage the participation of local stakeholders.

As we prepared to design this robotics unit, we talked about how we might involve the greater community. In our work together, we interrogated what counts as "real" PBL and


*Figure 3.* Example robot designs

discussed the integration of outside communities. Involving the community facilitates bringing in the "real world" and makes the PBL experience authentic. When community and classroom intersect, students are able to see themselves as empowered to make a change in their world. We strove to support students as they brainstormed ideas to solve problems in their local spaces and to help them see these ideas come to fruition. In our robotics unit implementation, students did ultimately see themselves as potential change agents after bringing their design prototypes into public spaces and having them validated by local communities. Figure 4 shows the six robots that student groups built for their design clients by the end of the unit.

**Design Client Integration Adaptations Inspired by Co-Design**

Integrating design clients in this iteration of our curriculum was grounded in the desire to make the PBL experience as authentic and meaningful as possible. In our co-design work, we established that it was important for students to have regular communication with their design clients, and we worked hard to create multiple opportunities for feedback. Throughout the unit, students were asked to consider how they were communicating design ideas to clients, take client feedback into account when making design decisions, and refine design artifacts (storyboards, maps, KWL charts) to reflect their ongoing conversations with their clients. In one KWL chart (see Figure 2G), students' consideration of client needs and perspective is clear. This student group worked to design a robot to help during lockdown procedures. They engaged with administrative staff to determine what exactly happens during a lockdown, consider where there were gaps in this process that could be filled by a robot, and understand logistical challenges specific to the local context. Here, the group considered technical and physical components of their robot design in connection to the social context of their school.

Beyond the use of design artifacts to help students consider the engineering design process, we also made the decision to have groups view and reflect on video recordings of interactions with their design clients. This decision was inspired by the success and growth Becky felt when engaging in video viewing and reflection herself. We recognized that students had trouble capturing all of the feedback and information their clients gave them in early conversations, and we opted to create short clips of groups' presentations. These clips were then viewed with a facilitator (Becky) present to probe and support students' work to productively interpret and apply client feedback. This process was important for students' preparation for their final showcase, and it helped them more clearly articulate the changes they had made in their designs with respect to the social purposes their robots served. In the example below, Becky worked with one student group to interpret a video recording of their initial presentation to their design client. All student names are pseudonyms in this example.

| | |
|---|---|
| Becky (B) | So these are just some things that we noticed... Will was being very professional in this. He was making eye contact, he was using resources to communicate design ideas. [He's] providing reasoning for his design decisions so when she asked a question you would say, "We did this..." |
| Student Will (W) | I don't think I was very professional. |
| B | You very much were because you were giving [the design client] eye contact... And you were explaining everything and when she would ask a question or even when she didn't ask you a question you still said, "It looks like this because...we decided that it needed to have a friendly face on it."...So you were able to give reasoning behind why you made the choices you did including with your chart, with your design, right? |
| B | So make sure you're giving eye contact, make sure that you're being professional... make sure that you will address the questions that she has for you. At one point [you] stopped and asked her for feedback ((Becky finds the place in the video clip where students stopped to ask for feedback and begins playing it)) |
| B | So there you're explaining ((gaze directed at Will))…do you guys see how ((pointing at another student in the group, Nola)) she kind of jumped in and said something |
| Student Nola (N) | Yeah we decided that we could step in |
| B | Oh so you guys decided that. Okay that's awesome… you did stop and ask for feedback and you asked her questions. I know that you ((gaze directed at student Aaron)) had questions that you did |
| Student Aaron (A) | Yeah I had a sheet of paper that had all of the questions on it. |

B ...You really listened to what she had to say, what your client was saying to you. I know she didn't have much criticism... she didn't have to ask for much clarification because you gave it along the way. So that was super.

Here, Becky helped students to attend to specific aspects of their presentation—celebrating their successes and highlighting things to keep in mind for upcoming communication with their design client. This kind of shared video viewing was helpful for students to recognize what they were doing well in their communication of design ideas and what they could improve, functioning in similar ways to our use of video viewing in co-design.

## PBL as a Transformational Experience: Outcomes in Our Most Recent HCR Iteration

As noted earlier, this Fall 2018 robotics experience was a transformational one for the students, teachers, and the community. We observed several individual students who were personally changed (e.g., becoming more comfortable working in groups or pursuing additional STEM opportunities). Community-wide recognition of our robotics unit occurred when we were asked to participate in a "STEM showcase" at a school board meeting. Here, three students volunteered to present their work and discuss what they had learned. These students talked about how this robotics unit showed them that they are capable of doing more in STEM than they imagined, and all noted that they had learned new things about how to work in groups and to collaborate.

As we reflected on the co-design and implementation of this experience, we observed that students seemed to have a clearer sense of purpose in connection to the content and practices they were learning. For example, we noticed a greater sense of ownership as students worked in teams and were accountable for their progress by a partnering community member. Updates about the robots being built in Becky's classroom quickly spread across the school, and students in different grade levels were brought in by some student design teams to provide additional feedback about their robot designs (e.g., 100+ students completed a survey ranking robot aesthetics for a counseling robot that would be used in their school). As Becky noted in final reflections, "I see this difference when I observe the same students in a separate science class, the engagement and excitement during HCR far exceeds what I see during the other science class because they are making a difference in their community." Here, we highlight how addressing the design challenge "create robots that serve a need in your local community" was an important outcome of our iterative PBL unit design. This design-centered problem framing supported student engagement in helping them see the local impact of their work. The integration of design clients in our most recent iteration made students' impact even more tangible.

For the instructor, this experience was rejuvenating and led to shifts in teaching practice. Becky noted:

> This experience has made me a more reflective teacher. I am more aware of how I word what I say to students so that I stimulate thought rather than feeding students answers. I found myself looking forward to this class, I often felt a tinge of disappointment when I had to switch curriculum and students. During video reflection, I would make notes that I should have used a different method at certain points in the lesson. It also gave me insight into how students were processing the curriculum, how to adjust pacing if students needed more time, as well as how to cultivate growth for all types of learners.

## Next steps

Through video analysis, co-design, and reflection, PBL facilitators can improve their own practice and help their students better engage in PBL processes. Beyond our specific example, this article also contributes to ways of thinking about PBL professional development and designing problems that take engineering design seriously. Engaging in regular co-design and reflection, there is time made to see the gains students have made and to consider how to facilitate growth in the next class period. In this section, we consider concrete actions teachers across disciplinary contexts and grade levels can take to make the work of designing and implementing innovative PBL experiences as productive and meaningful as possible.

**Find a co-design partner**

Prior to the use of co-design, Becky noted that she might have responded to a disappointing lesson with a, "Well that was awful, hopefully tomorrow will be better" without changing anything for the next day's plan. She has highlighted co-design as "a gift that allowed [me] to step back and take a different perspective at how successful the lesson was and make changes accordingly." Co-design allowed her to watch video footage to zero in on groups of students or on the delivery and receiving of the curriculum. This gave her the opportunity to set new goals and give students the education she knew and believed they deserve. Though co-design partnerships between researchers and teachers may not always be possible, co-design partnerships between teachers in a grade level subject area are possible for many teachers and can provide the same kinds of benefits described here.

Finding a co-design partner for jointly viewing videos has benefits similar to other PD opportunities (e.g., video clubs). However, when done on a regular basis and as part of a co-design partnership, joint video viewing of one's own classroom video becomes even more productive. The availability of inexpensive cameras and editing software helps to make this kind of partnership feasible. Although the intensity of video viewing described throughout this article may not be realistic for already overscheduled teachers, co-design sessions held between design partners every 1-2 weeks may be more manageable. Setting norms for viewing guided by the prompts in Table 2 can help to provide structure and help with making shared video viewing a routine. Shared video viewing provides opportunities across domains of PBL contexts by allowing teachers to see their facilitation practices and problem enactments when they have time to reflect. As curriculum designers, it provides opportunities to better understand which aspects of a problem worked well and which might need to be refined for the future.

**Find Ways to Help Students Reflect on their Learning**

Just as video viewing is helpful for teachers' practice, we found that it was also helpful for students' understanding of their own progress. Finding the appropriate times to record and engage in joint viewing with students was exceptionally powerful in helping students identify how they were moving toward their goals. In addition, KWL charts allowed the students to reflect on their design progress as they made updates regularly to what they knew about the problem and what they still needed to know. Taking time to cultivate a shared set of norms for video viewing and reflection as well as incorporating scaffolds that helped students to track their progress proved helpful in our work to create a student-centered unit where student design teams felt in control. We believe these same practices would be beneficial in a variety of PBL contexts.

**Involving Stakeholders**

The focus on HCR put the humans (and their surrounding environments) in the foreground of who the students were designing for. They found ways to make their work locally relevant. Although we had sought to do this in earlier implementations, we were not always successful in helping students to consider broader uses beyond their own classroom (Gomoll et al., 2018b). What was particularly important here, as for most engineering problems, was deeply involving stakeholders. In designing PBL problems with an engineering focus, it is important to consider how students will get information and feedback from the stakeholders in their design. Here students accomplished this through interviews and presentations. Other contexts might consider different ways of presenting stakeholder perspectives and engaging the greater community.

Throughout this article, we have worked to provide an example of how a PBL classroom and a PBL curriculum can look different when co-design, video viewing, and local stakeholders are integrated. For us, bringing together these three elements was a perfect storm. We have begun to notice and design in new ways, and we are inspired to continue providing students and teachers with the resources they need to have their voices heard and create change in the contexts that surround them—leading to transformations big and small.

*Table 2.* Prompts for video viewing

Watch each clip once through, with initial reflections at the end of the clip. Then watch each clip and pause, noticing how and when students are engaging with engineering design and how this is supported by facilitators. Ask:

- What do I notice about the ways that students are interacting and engaging?
- How are facilitators and/or the design of the activity supporting this engagement?
- How do we see PBL in this clip?
- What improvements could be made? What new goals come to mind after watching this clip?

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Andrea (Andi) Gomoll received her MS and PhD degrees from Indiana University Bloomington in the Learning Sciences, and she is currently a postdoctoral researcher at the University of California San Diego (UCSD). At UCSD, she contributes to a multidisciplinary project exploring teacher learning and noticing through reflection. Andi's dissertation work was focused on her five-year research-practice partnership with co-author Becky Hillenburg and the iterative design and implementation of their co-designed robotics curriculum—explored in this IJPBL contribution. This partnership with Becky, her students, and the school district has shaped Andi's research trajectory and perspective as a learning scientist. Her ongoing research interests center on the ways that teachers learn to attend to specific features of classroom environments in the work of co-design and multimedia reflection experiences—using what is noticed to shift practice.

Becky Hillenburg is a science teacher at Edgewood Junior High School in Ellettsville, Indiana. She loves teaching because she gets to connect with and foster relationships with students. She uses PBL in her classroom because it has a way of drawing in every student. She feels that she has become a better teacher by using PBL and inquiry-based learning with technology integration, and she has partnered closely with first author Andi over the course of a five-year research-practice partnership. She continues to move their robotics curriculum co-design work forward as she presents her curriculum design (forensics and robotics) at nationally recognized conferences.

Cindy E. Hmelo-Silver is the Barbara B. Jacobs chair in Education and Technology as well as Professor of Learning Sciences at Indiana University. She has published widely on problem-based learning as part of her focus in understanding collaborative learning in complex domains. As part of this research, she designs and studies technology to support problem-based and inquiry learning. She served on the founding editorial board of IJPBL. Most recently, she has been co-editor of the International Handbook of the Learning Sciences.

## Appendix A. Co-Design Session Overview Example

This Appendix provides an overview of the formal co-design sessions that occurred before the start of our Fall 2018 robotics unit as well as the first informal and formal co-design sessions during the unit. This table paints a picture of how our co-design work unfolded by providing an overview of just a slice of our 25+ hours spent engaging in co-design.

| Date | Session Length | Artifacts Created | Video Clips Viewed |
|---|---|---|---|
| 9/4/2018<br>Pre-unit | 1:31:00 | Unit conjecture map<br>Documentation of problem framing in upcoming unit<br>Engagement rubrics referenced | 1 STEAM Club clip (Spring 2018) |
| 9/24/18<br>Pre-unit | 1:45:34 | Revised unit conjecture map<br>Lesson 0/1 Conjecture Map and outline | 3 STEAM Club clips<br>(Spring 2018) |
| 10/1/18<br>Pre-unit | 1:48:27 | Revisited unit conjecture map<br>Lesson 2 conjecture map<br>Lesson outline and plans for week 2 | 4 STEAM Club clips |
| 10/8/18<br>Pre-unit | 1:34:11 | Lesson plans for week 3<br>Final prep for week 1 | 3 STEAM Club clips |
| 10/16/18<br>During unit<br>(Informal) | 1:39:10 | Rolling timeline edits; Planning documents<br>Group norms artifact<br>(reviewed student responses, organized, compiled into set of norms) | N/A |
| 10/17/18<br>(Informal) | 33:29 | Rolling timeline edits; Planning documents<br>Group norms artifact<br>Reflections on how the day went<br>Brief interview with design client | N/A |
| 10/18/18<br>(Informal) | 46:54 | Rolling timeline edits; Planning documents<br>Group norms artifact<br>Updated seating chart | N/A |
| 10/19/18<br>During unit<br>(Formal) | 1:49:23 | Logistics and coordination of station activities captured in agenda notes and rolling timelines; Canvas assignments<br>Revisited conjecture map for group norms and introduction to Human-centered Robotics | 2 clips from current week of unit |