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Supporting Informed Engineering Design across Formal and Informal Contexts with WISEngineering*

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This paper describes the design of WISEngineering, a computer-based engineering design environment focused on helping learners in formal and informal settings engage in informed engineering design activities. This paper compares and contrasts results of implementing WISEngineering projects in both formal and informal learning settings. In particular, this paper reports on insights gleaned from implementing WISEngineering middle school science and math classrooms as well as in after-school settings with Boys and Girls Clubs. We discuss design principles guiding the development of WISEngineering for school settings and how these principles were adapted and refined for youth and facilitators in informal learning contexts. We provide implications for the design of technology-enhanced engineering learning environments across school and out-of-school time settings.

Keywords: computer-based learning environments; K-12; formal and informal learning

1. Introduction

Recent state and national policymakers have called for more emphasis on engineering in K-12 settings [1]. Many states have incorporated explicit engineering learning standards for K-12 classrooms [2], and the Next Generation Science Standards (NGSS) explicitly call for integrating engineering into science classrooms [3]. Engineering applies mathematics and science to real-world problems, and as such, incorporating engineering in K-12 settings has the potential to motivate learning in STEM domains as well as increase interest in STEM careers [4]. Research demonstrates that engineering curricula can lead to improved mathematics and science content and self-efficacy gains [5–7], especially for populations typically underrepresented in STEM fields or students coming from backgrounds with fewer economic resources [8, 9].

Although studies document successful approaches to incorporating engineering into precollege settings, studies document challenges to engineering approaches in formal and informal settings [10]. Computer-based learning environments (CBLE's) can provide solutions to many of these challenges [11], yet very few CBLE's involve engineering design [12]. This paper describes the iterative design process of WISEngineering, a computer-based engineering design environment that explicitly guides students and youth through design challenges. By capitalizing on the affordances of a computer-based environment, WISEngineering supports students and youth to engage in rich, hands-on design projects. This paper provides an overview of design principles used to guide the development, implementation, and revision of the environment and curricular modules.

2. Background

A variety of successful K-12 engineering design curricula exist in formal and informal settings [10]. For example, Project Lead the Way offers engineering curricula to schools that include courses in basic engineering design, and specializations such as Aerospace or Environmental Sustainability [13]. Learning by Design provides units that guide science students through iterative cycles of engineering design and scientific inquiry [14, 15]. Engineering Teaching Kits provide challenges for teachers that focus on student misunderstandings [16, 17]. Engineering is Elementary provides rich curricula for 1st through 5th grade classrooms [18]. In informal contexts, many programs have used LEGOs as a basis for teaching STEM concepts [19], including national competitions such as FIRST Robotics. Other programs investigate how youth engage with engineering in museums, home settings, or makerspaces [20–22].

Although research demonstrates successful engi-

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neering efforts in school and out-of-school time settings, research also documents barriers and challenges to engineering in formal and informal settings. For example, practicing engineers have been trained in and use a variety of design processes, however, many K-12 students and teachers have little to no explicit exposure to engineering design [23]. As a result, many engineering projects in classrooms result in students using trial-and-error approaches or focus heavily on building products without engaging in other processes of design [24] or connecting to deeper conceptual knowledge. Likewise, many science and mathematics teachers understandably are not familiar with the nature of engineering or engineering design, which can influence the success of engineering curricula. Existing curricular approaches often involve technology-enhanced design artifacts (e.g., Lego mindstorms) instead of CBLE's to support student learning of science, engineering, and mathematics concepts [12]. Furthermore, evidence suggests that engineering curricula designed around technology-enhanced products may be very difficult for teachers to integrate authentically into instruction [25].

Computer-based learning environments (CBLE's) provide unique affordances to support learning of STEM concepts and have the potential to address many challenges facing engineering education in K-12 settings. For example, CBLE's can provide students with simulations and visualizations of difficult science and mathematics concepts to help students develop rich conceptual understanding of the principles that undergird design challenges [26]. CBLE's can structure and support students engaging in design processes and offer feedback on student artifacts [27]. CBLE's can also provide students with explicit models of engineering design to help foster an understanding of the fundamentals of engineering design, similar to explicit scientific practices [28]. CBLE's offer ways to facilitate collaboration and knowledge building within and across classrooms. Thus, CBLE's can help teachers integrate rich engineering curricula into their practice. Despite the potential for engineering education, very few engineering design CBLE's exist for K-12 students.

3. WISEngineering design for classroom environments

WISEngineering builds upon past research in supporting engineering design and scientific inquiry in classroom settings to explicitly support general engineering design projects and processes in a computer-based environment. WISEngineering is freely available and is powered by open-source technologies from the Web-based Inquiry Science Environment (WISE) [29]. WISEngineering was first developed by creating an independent instance of WISE 4.2 and customizing the environment to fit the needs of design challenges instead of scientific inquiry projects in classroom settings.

WISEngineering uses an informed engineering design and scaffolded knowledge integration approach to guide the development of both the learning environment and curricular materials [30, 31]. An informed engineering approach emphasizes the intelligent nature of engineering design to help motivate learning of engineering and mathematics concepts in K-12 classrooms [32]. Scaffolded knowledge integration emphasizes practices and instructional patterns to help learners develop coherent understanding of STEM concepts, tested in a variety of settings over the past three decades [31]. Combining scaffolded knowledge integration and informed engineering design in WISEngineering aims to motivate and support deep learning of STEM content and practices.

3.1 Design principles for the WISEngineering environment

We used design principles of *make engineering accessible*, *make thinking visible*, *help students learn from others*, and *promote reflection*, adapted from principles for knowledge integration [33], to guide the development of the environment.

Making engineering accessible. As precollege students and teachers are largely unfamiliar with engineering, we created an explicit model of informed engineering design to help make engineering accessible (Fig. 1). Although there is no ''one'' engineering design process, we wanted to make all processes of design understandable and explicit for learners. Each activity within each project aligns with a different phase of engineering design, which we have defined as: (1) identifying the specifications and constraints of the challenge; (2) developing relevant knowledge to the design challenge; (3) ideating solutions that meet the specifications and constraints; (4) building a prototype of the best idea; (5) testing and evaluating the prototype; and (6) refining the design. Although these are presented in a somewhat sequential manner, students are encouraged and can jump back and forth between phases as needed to come up with their final design solution through *Design Navigation*, where students can also navigate through the project by clicking on the different phases in the diagram. Engineering habits of mind such as collaboration, systems thinking, creativity, and understanding optimization and tradeoffs are engendered in the scaffolding around certain phases. For example, creativity matches with ideating solutions, and optimization and tradeoffs match with phases of building, testing, and

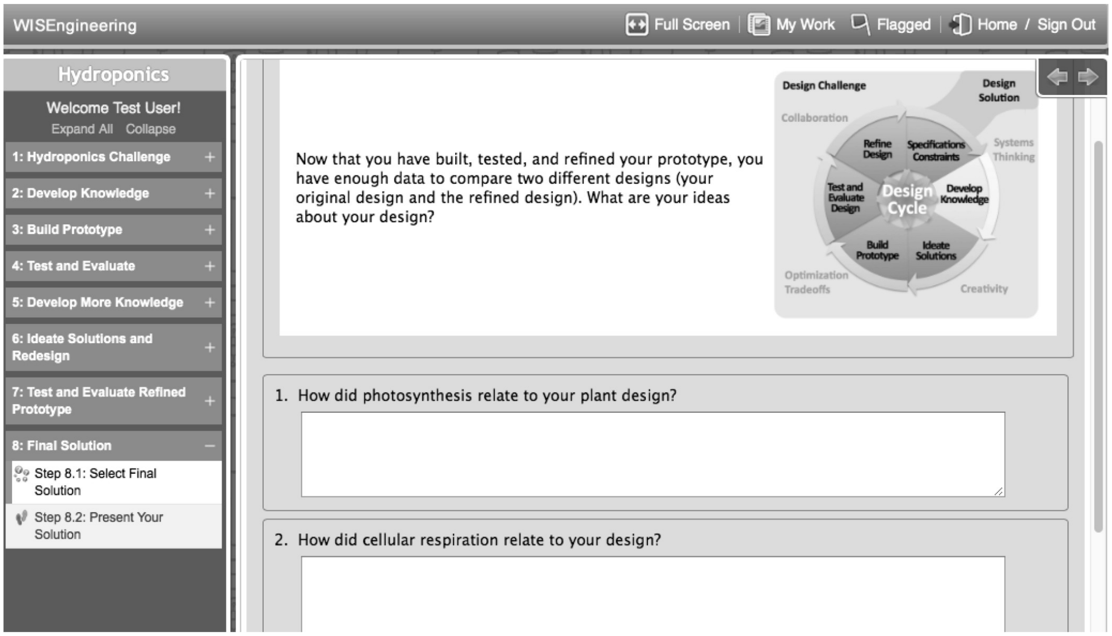

Fig. 1. An explicit model of engineering design (upper right hand corner) is a prominent feature that aims to help students understand engineering practices.

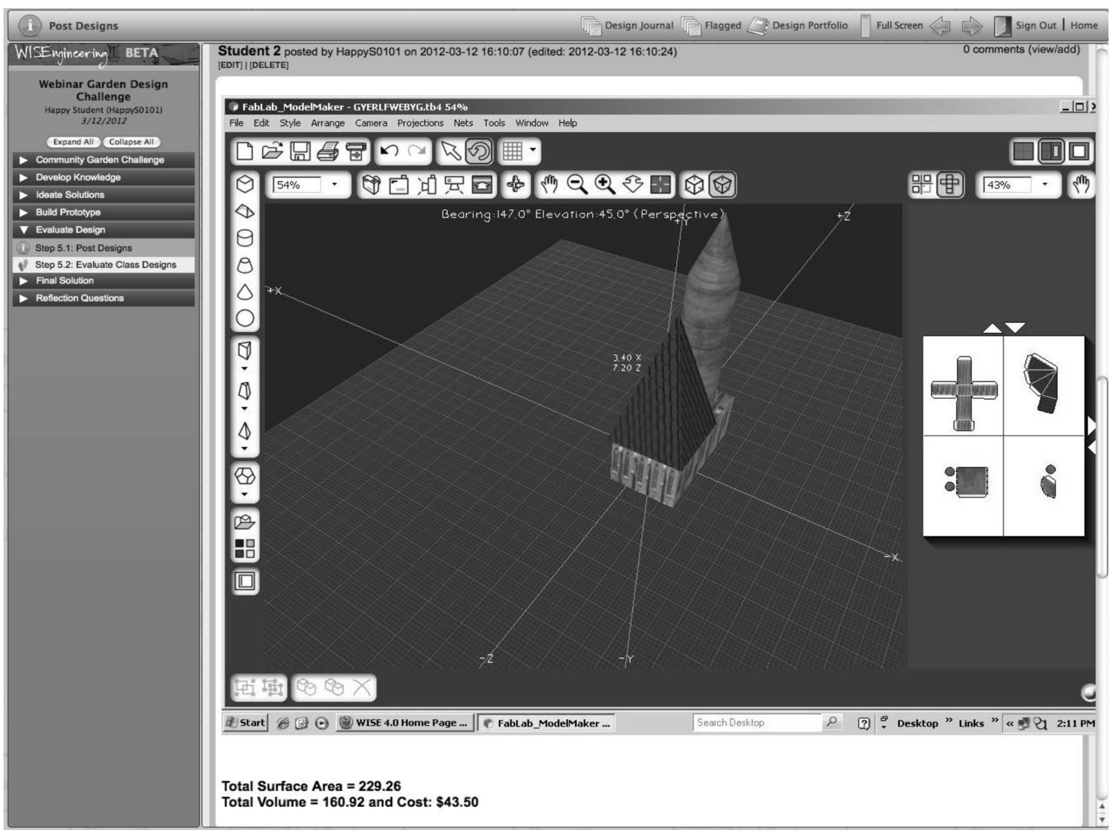

Fig. 2. Students can post pictures of their CAD designs to the Design Wall and get feedback from peers.

evaluating designs. In this way, WISEngineering explicitly supports engineering practices as put forth in the Next Generation Science Standards as well as encourages habits of mind [3, 10].

Making thinking visible and helping students learn from others. To help make students' thinking visible and to encourage sharing and building upon ideas, we created the *Design Wall* (Fig. 2). The *Design Wall* enables collaboration and critique of designs by using functionality similar to social networking websites or blogs by posting on a "wall." Students can post images that they have found for inspiration in the ideation phase, post computer-aided designs, pictures of their physical design after they have developed a prototype, or post revised designs after testing. Students can use the *Design Wall* to share with team members who may be within their same class or with other students across schools. Teachers can monitor students' ideas and make comments on each group's designs.

Promote Reflection. The *Design Journal* was created to keep track of everything students generate within WISEngineering, including drawings, answers to embedded assessments, posted designs, and critiques of others' work. From the *Design Journal*, students can select and annotate specific artifacts to include in their *Design Portfolio*, which is used to share with teachers or their peers (Fig. 3). Both the *Design Journal* and *Portfolio* were designed to facilitate authentic engineering practices of communication as well as encourage reflection.

3.2 Design principles for WISEngineering curricula

In addition to the design principles for the environment, we used the following principles based on informed engineering design and knowledge integration to guide curricular development.

Use engineering design to encourage knowledge integration. Knowledge integration calls for learners to engage in processes of eliciting, adding, evaluating and refining normative scientific and mathematical ideas. Informed engineering involves ideating, building, testing and refining design solutions [26]. In every curricular unit, we aim for the process of design to help students engage in knowledge integration. For instance, when students engage in ideation, or come up with ways to meet the design criteria, it brings forward students' existing ideas. Helping students develop knowledge can encourage students to add normative ideas about underlying STEM concepts. When students test and evaluate their design, students can test and evaluate their own ideas, perhaps realizing that they didn't fully understand a concept or connection. As part of refining their design, students can similarly refine their understanding of the STEM concepts. Embedded prompts, curricular supports and resources in WISEngineering curricula focus around helping students connect the design process to underlying STEM concepts.

Focus specifications and constraints around science and mathematics concepts. Crucial to helping students engage in knowledge integration through engineering design is creating targeted design criteria. WISEngineering modules strive to have specifications and constraints focus on important and challenging science and mathematics concepts so that students have to understand underlying ideas to successfully complete the challenge. For example, the Community Building design challenge uses volume and surface area constraints to motivate learning of volume and surface area concepts. Students have to learn how to calculate volume and surface area in order to successfully complete the challenge. Similarly, design criteria for WISEngineering science projects try to address particularly

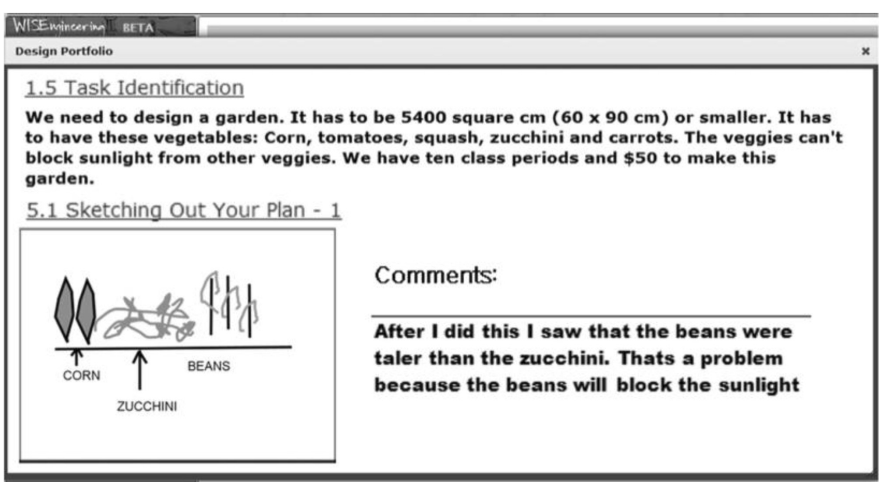

Fig. 3. Students are able to post and reflect upon their work in the Design Portfolio.

difficult or commonly held alternative student ideas. For example, the Hydroponics unit challenges students to learn about photosynthesis by designing a system for plants to grow without soil. Thus, to successfully complete the design challenge students need to address possible alternative ideas that plants eat soil or get their mass from the ground. Framing design challenges with special consideration of criteria and constraints helps students use engineering design to develop deeper understanding of science and mathematics concepts.

Support virtual and physical design. Although WISEngineering is computer-based, we aimed for WISEngineering curricula to leverage affordances of virtual and physical design experiences. Virtual experiences can enable students to rapidly iterate on ideas or test and get immediate feedback on designs. In addition, virtual tools such as simulations and visualizations enable students to manipulate or interact with phenomena to gain understanding. Thus, we aimed for WISEngineering curricula to include both virtual and physical design challenges. That is, students using the WISEngineering Hydroelectric Generators actually make a physical device that converts mechanical energy of water to electricity. In Balancing Act, students use a virtual simulation to learn about torque and simple equations. In Community Building, students use a CAD tool to create, evaluate, and refine their designs before building the physical model.

In addition to these added features, WISEngineering leverages the core functionality of the WISE system, which includes student learning, teacher, and researcher tools [29]. WISE functionality includes a variety of tools to help students learn, featuring knowledge-building steps such as drawing and simulation pages, as well as advanced assessment technologies. Teacher tools include monitoring, grading, and management functionality. Researcher tools include complete logging of student interactions as well as authoring capabilities. Using functionality from WISE, teachers using WISEngineering can instantaneously monitor progress, give real-time feedback on learners' work, and customize the projects for their own contexts and communities. Embedded assessment technologies enable teachers and researchers to capture student thinking during the projects.

3.3 Implementing WISEngineering in classroom settings

WISEngineering projects have been implemented in middle school math and science classrooms. We have implemented four mathematics projects with four teachers from four schools, covering topics of ratios and proportional relationships, expressions and equations, and geometry. Two teachers implemented three units with multiple classes, and two teachers implemented one unit with multiple classes. We have implemented five science projects with five teachers from two schools, covering topics of forces, energy transfer, heat, electromagnetism, and photosynthesis/cellular respiration. Two physical science teachers implemented three units with multiple classes, one physical science teacher implemented one unit with multiple classes, and two life science teachers implemented the same unit with multiple classes. Students typically worked in groups of 2-4 using either a desktop or laptop computer. For all implementations, data sources included pretest and posttest content assessments, embedded items from within WISEngineering, classroom observations, and student and teacher interviews.

Overall, results across implementations reveal that WISEngineering units help students learn targeted mathematics and science content. For example, students using WISEngineering in mathematics classes improved their understanding of Common Core mathematical concepts from pretest to posttest for all three mathematics projects. Students also outperformed similar students using traditional approaches on state standardized tests [34]. Similar learning outcomes were found for science classes. For example, students conducting the hydroponics activity significantly improved scores from pretests to posttests with a large effect size [35].

Classroom observations and interviews across both mathematics and science classrooms suggest that WISEngineering promoted positive behaviors such as collaboration and tolerance with at-risk and underperforming students. Both math and science teachers reported unusual and remarkable levels of persistence, initiative, and creativity by students that are usually disengaged and/or problematic in class. Teachers were very enthusiastic in their appraisal of not only the activities (format, content, and language), but also in what they regarded as successful implementations. Both math and science teachers reported higher levels of engagement and participation by their students as compared to regular days.

3.4 Lessons learned from classroom implementations

Although learning objectives were generally positive, the classroom implementations revealed important evidence for refinement of units. First, log data from the WISEngineering environment revealed that although students were spending a large proportion of their time developing knowledge, students spent relatively little time evaluating, refining, or reflecting upon their designs or ideas [36]. Although we had aimed to promote all of the design processes, students tended to spend the most time building their prototypes. Understandably, creating a physical object requires time. However, this should not be at the cost of important processes of testing, evaluating or refining designs and ideas as these may influence important processes of evaluating and refining networks of ideas. Relatedly, students often gave minimal evaluations of their designs, stating whether or not their design did or did not meet criteria with little justification. Across implementations, we began to see patterns in terms of simulation use and scaffolding. The following principles emerged out of the classroom implementations.

Providing explicit rubrics for evaluation. To address these issues, we added explicit rubrics with quantified outcomes to help students evaluate their designs. Providing explicit rubrics can potentially help students articulate criteria for their own ideas and spur deeper engagement into iterative testing and refinement. Rubrics can also be used to emphasize justifications using science principles. For example, the Ice Cream Cooler activity includes a rubric tied to the mass of the remaining ice cream, where under 70% is a score of 1, 70–90% is a score of 2, and 90–100% is a score of 3. The rubric also included explicit scores for the amount of materials used (less material corresponded to a higher score) and justification of designs based on heat transfer (more explanation of design aspects corresponded to a higher score). Instead of students merely stating that a design with 80% ice cream remaining met specifications and constraints, the rubric provides a clear metric to target for refinement. Likewise, explicit rubrics for design justifications based on science principles may help students focus on making evidence- and science-based refinements.

Aligning simulations with the design task. Across the four physical science units, two of the units incorporated PhET simulations [37] that directly mapped on to the physical design task (electromagnetism and energy transfer). In these units students could use the simulation to visualize typically invisible processes of electricity and magnetism or energy flow on a physical object that directly corresponded to their designed object. The other two units on forces and heat used simulations that addressed the underlying science concepts, but did not directly map onto the design. For example, the Constructing a Stronger Building project used PhET simulations of force in a horizontal tug-of-war. However, their design task was to create a structure to hold at least five pounds of weight vertically. The Ice Cream Cooler project used molecular simulations to help students understand heat and temperature [38] but they were designing an object out of various materials to keep ice cream cold. Classroom observations revealed that students had more difficulty translating what they learned from the simulations in the non-aligned units than in the units that had aligned simulations to the physical design. Ideally, students would be able to design, test, and evaluate virtually designed objects before building physical objects, similar to practicing engineers. We are currently working to develop new simulations and incorporate aligned simulations into the projects.

Providing tailored scaffolding for learners. Looking across mathematics units, results suggested a trend that students with lower levels of prior knowledge benefitted from more structured support and guidance, and students with more prior knowledge benefitted from less structured support [33], mirroring an expertise reversal effect [39]. Given other studies have demonstrated the benefit of automated guidance on science learning within the WISE environment [40], we are currently exploring how to implement tailored guidance for individual project teams within the WISEngineering environment (see section 3.2.1 below).

4. WISEngineering design for informal settings

With the success of WISEngineering in classroom settings, especially with students who were disengaged from traditional learning experiences, we sought to extend WISEngineering to informal learning settings. WISEngineering has the potential to address many recommendations for learning in informal STEM programs [41]. Specific recommendations include designing informal programs with targeted learning goals in mind, which WISEngineering ensures through informed engineering and knowledge integration approaches. Recommendations also involve making informal learning environments interactive, providing multiple ways of engagement with concepts, practices, and phenomena. Engaging multimedia such as simulations and videos in WISEngineering can help youth develop their designs while also gaining an appreciation of the design task's social relevance and an awareness of professionals engaged in related STEM careers. Another important recommendation for informal environments is to facilitate learning across settings and extend learning over time, which WISEngineering enables by allowing students to come back to projects at any time if they have access to a computer and Internet. WISEngineering has the potential to help learners interpret their experiences in light of prior interests and experiences by leveraging interest-driven and friendship-driven participation [42], through the use of learning technologies such as the Design Wall.

4.1 Design principles for the WGG environment in informal settings

As we piloted WISEngineering in informal settings we found the need to tailor WISEngineering to meet the needs of youth learning in these contexts, resulting in another instance of WISEngineering, or WGG. WGG is a separate instance of the WISEngineering environment specifically targeted for learning in informal settings. In particular, we used the following guiding principles to shape the development of the WGG environment and curricula.

Support identity development. As the creation of self-representation has the potential for learners to be able to see themselves as STEM learners [43], WGG was redesigned to include the ability for participants to create avatars that persist with them throughout their challenges (Fig. 4). The first design challenge we advocated using with participants involves logging into WGG and creating personalized avatars. In this way, youth (and the learning facilitators) become familiar with the WGG environment and engage in a simple yet motivating design activity, and potentially support the development of an engineering self-identity.

Highlight engineering careers. As out-of-school-time experiences can influence STEM persistence and career choice [44], we aimed to provide examples of different kinds of engineering and engineers for each activity. For example, the dance party activity highlights software engineers, the water filter activity highlights civil engineers, and the speaker design activity highlights audio engineers.

Promote excitement, interest, and motivation in engineering. An important difference between formal and informal settings is youth in informal settings are able to choose what activities to engage in after school, making interest and engagement central to success [41]. We specifically chose WGG activities to try to be interesting and exciting for the youth in BCGs. For example, one activity focuses on designing shoes, whereas another activity focuses on creating a dance party in Scratch [45]. To support programming in Scratch, WGG integrated its own instance of a programming environment using the open source Scratch technologies from MIT. Thus, there is a link to a Scratch environment alongside links to the Design Journal in WGG and learners can save Scratch programs to their design journal.

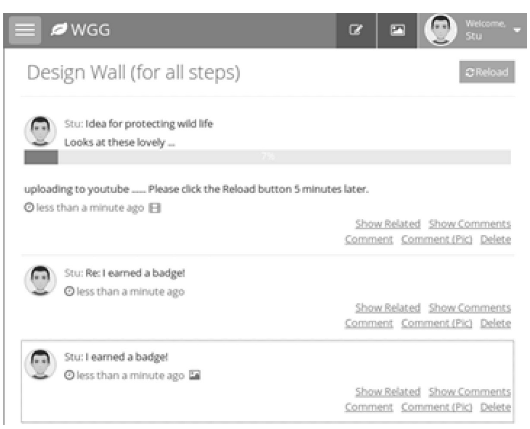

Fig. 4. Students create their own avatars that persist through activities in WGG.

Another difference between informal and formal settings is the audience in out-of-school settings may change, that is, different youth may take part in different activities every week. That, coupled with the different time constraints of informal settings (around 75 minutes max) led us to develop much shorter, concise projects that focus on helping students engage in informed design quickly, at the cost of focusing on multiple STEM content learning objectives within one project. For example, the WISEngineering hydroponics unit has two develop knowledge activities with 14 steps in total focusing around photosynthesis and cellular respiration, whereas the WGG speaker activity has 13 steps in total with 2 devoted to learning about sound. Although we still scaffold informed engineering design in WGG, we place more emphasis on getting youth engaged in engineering practices, awareness of STEM careers, and persistence in STEM fields as opposed to focusing on multiple, specific content objectives needed for successful classroom integration.

4.2 Lessons learned from WGG implementation in informal settings

Over 100 projects have been implemented in eleven different Boys and Girls Clubs (BGCs) across two states. Data sources include WGG reports from learner's use of WGG projects, observations of project implementations, interviews with learning facilitators and club directors, and surveys of participation and interest completed by club directors. The following section describes obstacles that were encountered during implementation and current efforts to address the challenges.

Making WGG more accessible through tablets. One of the first and biggest challenges was access to computers. Although many BCGs had designated computers for youth to use, access to computers was problematic and sometimes limited. Even if clubs had enough computers, crucial time was lost to transitions from the computer lab to hands-on designing of projects, as the space for making the designs was often separate from the computer lab. We decided to try to make WGG more accessible by developing a web-based app that would work with

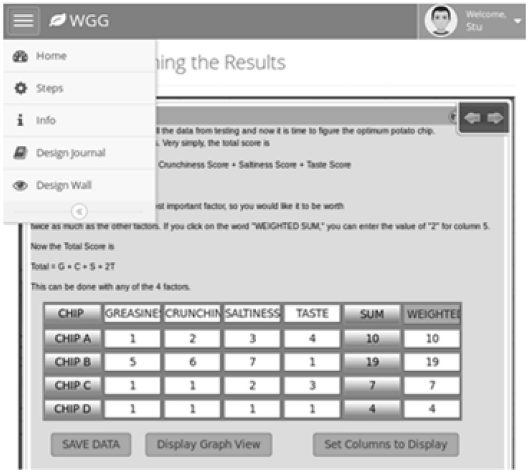

Fig. 5. The WGG tablet-based app provides most of the WISEngineering functionality, like the table shown here.

low-cost (~$50) tablets [46]. By making WGG tablet-based, we aimed to facilitate a more blended learning experience so that students could engage in WGG in the same physical space as the building, testing, and refining of designs. We also aimed to capitalize on the ease of capturing photos and videos of design projects with tablets. Fig. 5 provides a screenshot of how the WGG app supports the rich toolset of WISEngineering functionality.

Providing support for learning facilitators. Many of the BCG learning facilitators had very little experience with engineering and turnover of facilitators was also a problem for some of the clubs. As a result, an emergent need was providing the learning facilitators with some sort of professional development to be able to effectively lead WGG projects, with constraints of keeping it short enough that facilitators could complete it with busy schedules. To address these needs, we developed quick (5–10 minute) videos to demonstrate the design challenges, emphasize targeted STEM learning objectives, and provide helpful facilitation tips. We are currently piloting these videos with the facilitators and initial feedback on the videos has been positive.

Automated feedback to enhance STEM learning. Related to facilitators not necessarily having STEM expertise was the need to give youth feedback on their STEM learning. Although the base WISE technologies include tools to give automated feedback on multiple choice, fill-in-the-blank or drag-and-drop assessments, learners needed feedback on open-ended items regarding explanations of STEM concepts. To address this need, WGG has been refined to provide automated feedback on open responses to learners. WGG integrated automated grading and assessment tools from the open source EdX EASE automated grading engine [47]. With the EdX engine, WGG can assign automated scores for targeted open-ended questions (Fig. 6). Criteria can be defined, trained, and calibrated for each project. To use the automatic grader, a researcher or curriculum designer must generate a grading model, define grading criteria, and link them to overall learning objectives of the unit. For example, to set up the grading criteria for responses to "understanding design tradeoffs" involves picking sub-questions, picking grading methods, providing grading details, a description, and assigning weights (if necessary) and aligning with a learning objective. With the automatic grading functionality, instructor comments can be automatically selected based on learner responses, and provided to WGG so that youth can see near-instantaneous feedback in the system.

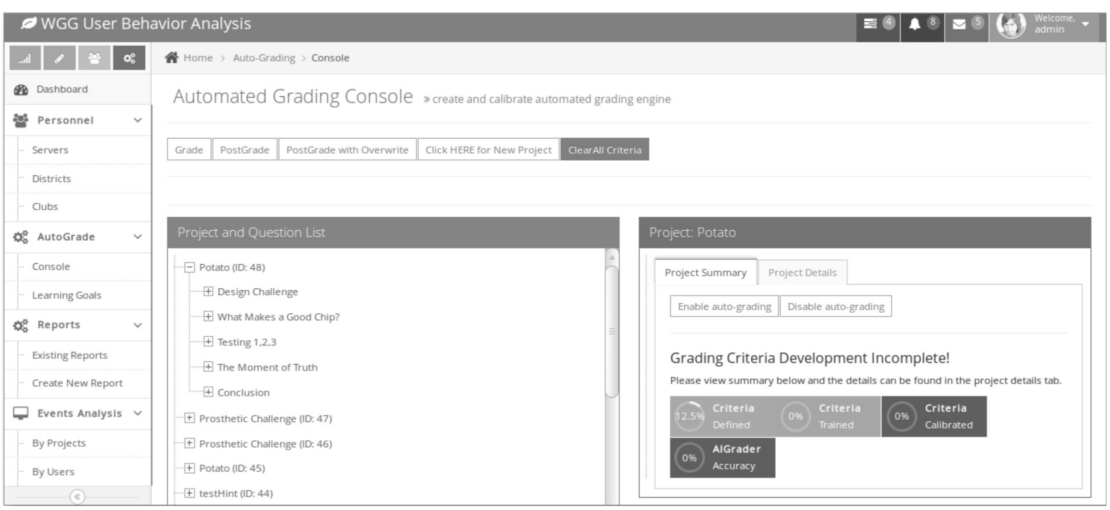

Fig. 6. Screenshot of the automatic grading console in WGG.

Preliminary testing of the automated feedback system compared human raters to the EASE-generated scores [48]. Using data generated from WISEngineering runs (n = 217) coded by two independent human raters on a 5-point scale, half of the responses was used to train the EASE model and the remaining half was used to test the EASE model. Results found a nominal agreement of 66% between human and EASE scores, a marginal agreement (+/ − 1) of 90%, a Pearson's R of 0.78 and a weighted kappa of 0.76. These results are comparable to other studies investigating the accuracy of automated scoring of automated assessments in STEM learning contexts [49]. We are currently working on generating other grading models and developing formative feedback to benefit youth learning.

Contextualizing reports to informal settings. Due to the differing needs of BCGs as opposed to classrooms, WGG also changed the reporting system for facilitators, BCG staff, and researchers. Weekly reports display overall summary data (e.g., the number of design wall and journal posts, the number of pictures/video clips uploaded, as well as steps visited and questions answered). Reporting functionality can then aggregate learning outcomes across clubs, as well as present itemized analysis for each learning goal for each club.

5. Discussion

Although we have highlighted differences between WISEngineering and WGG design and implementation, we also found commonalities across settings. A surprising finding was relatively little use of the Design Wall to share pictures or design ideas, given how frequently youth and students share pictures and comments on social media. This could potentially be due to the nature of how the Design Wall was orchestrated. In the BGCs and classes, youth are implementing the projects in the same space as their peers, so they can easily see each other's designs and share ideas verbally. So once youth post their designs there may be little motivation or need to revisit or comment on the Design Wall. However, for one of the initial project implementations in math classes, the Design Wall was shared to students across all classes running the project, so students could see what other students in different classes in other schools were designing. In this case, students spent relatively more time posting and looking at other designs as they were not available any other way. Thus, use of the Design Wall could potentially be related to whether students and youth are physically together or separated. Future studies can investigate these relationships and potential affordances for collaboration and design across physically separated spaces.

As WISEngineering informed the design of WGG, we are currently working on using results from informal settings to inform the refinement of WISEngineering in classroom settings. We are currently working on extending the automated scoring system to classrooms, leveraging other studies that have developed automated formative feedback in WISE [40]. We are also exploring how teacher professional development may be augmented by educative materials, such as the videos developed for WGG. WISEngineering has also helped inform revision to WISE technologies. Features developed by WISEngineering are now also available on the WISE platform.

Results from WISEngineering and WGG highlight the potential to blend formal and informal learning experiences. Research demonstrates a growing need for connected learning approaches across settings [50]. WISEngineering has the potential to provide the structure and guidance for students to take engineering projects home or to other after school settings, as well as the ability to record when and how students may engage with the environment across contexts. Future studies can explore the potential for WISEngineering to bridge formal and informal settings.

6. Conclusion

WISEngineering and WGG are computer-based learning environments designed to help students and youth engage in engineering projects. Built upon WISE functionality, WISEngineering and WGG offer many tools for teachers and learning facilitators to use in formal and informal settings. This paper highlights the iterative design of the two environments for classrooms and out-of-school time contexts, using results of multiple implementations across settings to refine technologies and curricula. By offering design principles and guidelines, this manuscript aims to inform the design and refinement of other learning technologies for engineering education.

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