AC 2012-4695: WISENGINEERING: A WEB-BASED ENGINEERING DESIGN LEARNING ENVIRONMENT

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Abstract

In this paper we introduce WISEngineering, a new curriculum delivery, assessment, and feedback system that uses engineering design to teach science, technology, engineering and math (STEM) concepts to middle school and high school students. WISEngineering is a free, open-source environment that supports STEM learning by guiding students through informed engineering design projects[1]. WISEngineering includes learning modules that involve extensive hands-on engineering for real-world problems and integrate computer-aided design (CAD) and digital fabrication technologies. Here we present three facets of WISEngineering that we predict will make it well suited to teach STEM concepts: (i) engineering authenticity, (ii) student-documentation that drives learning and assessment and (iii) whole-class and peer collaboration. We describe the design and development of WISEngineering and its theoretical underpinnings. We will briefly describe the partnership of teachers, researchers, developers and engineers that created and refined the environment. Finally, we report on preliminary usability studies with undergraduate pre-service students.

WISEngineering

WISEngineering is a new web-based learning management system that is available free of charge online (http://wisengineering.org). It provides support for students and teachers to conduct engineering design projects in middle and high school settings. Teachers, researchers or curriculum developers can use tested and refined projects in the WISEngineering Library, or use authoring tools to create their own projects. Anyone can take pre-existing projects and customize them to suit a particular context or need. WISEngineering supports engineering design processes with technologies such as a shared virtual "Design Wall" where students critique and comment on each other's' designs, or digital design journals and portfolios, where students save and share their designs and design process.

WISEngineering builds upon the open-source Web-based Inquiry Science Environment (WISE) from the University of California at Berkeley (http://wise4.berkeley.edu). WISE has been widely used by teachers and students around the world for science education and has demonstrated impact on inquiry learning from upper elementary through high school[2]. Over 100,000 students internationally have used WISE projects, including projects in English, Norwegian, German, Dutch, Japanese, and Cantonese. Although developed initially for the middle to high school level, WISE has also been used to support computer science education at the university level. WISE also serves as a platform for educational researchers to gain valuable insight about student learning[3],[4]. WISEngineering leverages core functionality of the WISE system, including assessment, teacher monitoring, and researcher tools. WISE encourages collaboration within and across classrooms with technologies that support collaborative brainstorming, discussion and idea management. Using functionality from WISE, teachers using WISEnginering can instantaneously monitor student progress, give real-time feedback on student 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[5]. WISEngineering also builds from WISE functionality to enable researchers to log student interactions with the environment. WISEngineering extends WISE by transforming the supports for scientific inquiry to support engineering education. For instance, instead of scaffolding students' asking inquiry questions, WISEngineering aims to support students to define problems, including specifications and constraints[6].

Engineering as a K-12 subject

Engineering draws upon and can enrich the study of both science and mathematics at K-12 levels. The National Research Council (NRC) and National Academy of Engineering (NAE) recommend including engineering education in K-12 because it supports mathematics and science and can increase students' career interest in engineering or related fields[7]. Engineering has been used as a vehicle to teach rigorous mathematical[8] and scientific[9] concepts to students. The NRC's *Framework for K-12 Science Education* explicitly includes engineering as equal in importance to science[6]. However, engineering concepts are less used and researched than scientific inquiry at these levels[7]. WISEngineering aims to provide a tool to support students to engage in design projects, support teachers by providing research-based, guided design projects for their students to use and assessment tools to delineate individual from group work, as well as a platform for researchers to investigate how engineering design projects support learning in pre-college environments. The development of the WISEngineering system draws from past research in STEM and engineering education.

Related Frameworks and Systems

The WISE system draws heavily from the knowledge integration (KI) learning perspective, which draws on cognitive, socio-cultural, and learning science research[10,11]. KI evolved alongside learning research using a series of technological supports, and WISE is the most recent and the most fully featured of these software systems[3]. The KI perspective values the diversity of ideas that students hold, and views learning as a process of eliciting, adding, sorting, and refining ideas and connections among ideas. The KI framework rests on the tenets that science learning should be accessible, visual, collaborative and life-long. The WISE system provides support for all of these tenets, and WISEngineering leverages the affordances of WISE, including modular, reusable projects based on step-by-step interaction and sharable information.

The KI framework aligns well with engineering design processes[12]. Engineering design naturally encourages KI learning processes of eliciting, adding, sorting and refining ideas. Past projects with WISE demonstrate the success of using design approaches with KI to teach science content, including to designing energy-efficient houses[13] or marine explorations[9].

Other successful examples of using engineering design to teach science include Learning by Design™ (LBD)[14]. LBD tightly aligns student activity and student-driven content learning. LBD has incorporated optional software-based enhancements, including innovative tools for organizing searchable information that have shown a promising impact on student learning and organization of new knowledge[15]. WISEngineering provides similar tools to several core LBD components, such as pin-up sessions and gallery walks (for sharing knowledge) and Design Diaries (for documentation of student progress).

The Concept Map Project-based Activity Scaffolding System (CoMPASS) is a navigable learning system that supports connections between science concepts and principles[15]. Students use these technologies alongside design challenges for learning physics concepts. Early research demonstrates learning gains associated with students' use of the non-linear hypertext resources, and indicates that the system produces deeper learning when combined with a student-driven-inquiry teaching style[16]. Similarly, WISEngineering will incorporate non-linear online navigation elements and will emphasize students' deep exploration of content.

Building upon these approaches, we developed WISEngineering to support authentic engineering design, to foster reflection through the documentation student work, as well as to encourage collaboration among peers.

Supporting Authentic Engineering Design

Learning from inquiry or design-based approaches depends on careful, appropriate choice of tasks. Chinn and Malhotra[17] define a continuum of scientific inquiry from simple to authentic, with school science often occurring on the simple end, involving over-simplifications and few decisions made by the students themselves. More authentic science occurs at the opposite end of the continuum, where questions are complex and murky and means of approaching research are not always obvious. Software tools support student science inquiry and math exploration at various points along this continuum[18]. For example, Inquiry Island[19] is a software program that supports students to develop their own research projects. Explicit models of the various inquiry processes support students to develop scientific questions and frame them in researchable ways.

Similar tools need to be developed and researched to support engineering design projects. Engineers use a variety of design processes, characterized by such features as solution decomposition into modules and transformation function reversibility[20]. Goel and Pirolli[20] suggest that adults have an intuitive understanding of what design professions are, however, many K-12 students receive little to no exposure to engineering design. Thus, explicit models of engineering design can help students develop an understanding of the fundamentals of engineering design, similar to explicit model of inquiry used in Inquiry Island[21]. One such model is informed engineering design[1] . Informed design is a process in which students develop knowledge and skills before attempting to suggest design solutions as opposed to solving problems through trial-and-error alone. Students following the informed design paradigm learn in discrete phases, called knowledge and skill builders (KSBs). Sample projects with accompanying KSBs have been validated and tested with students[22].

WISEngineering builds from the informed engineering design pedagogical approach to provide an explicit design cycle to guide students' design projects (Figure 1):

- *Clarifying design specifications and constraints* – design challenges have particular specifications and constraints to consider in developing a solution. Typical constraints emphasized in projects include time or cost. Specifications can emphasize particular concepts to be learned during the project, for instance, certain volume and surface area constraints require students to develop and apply their understandings of these concepts.
- *Develop Knowledge* – A consideration of the specifications and constraints lead to investigation or inquiry into related concepts needed to solve the problem.

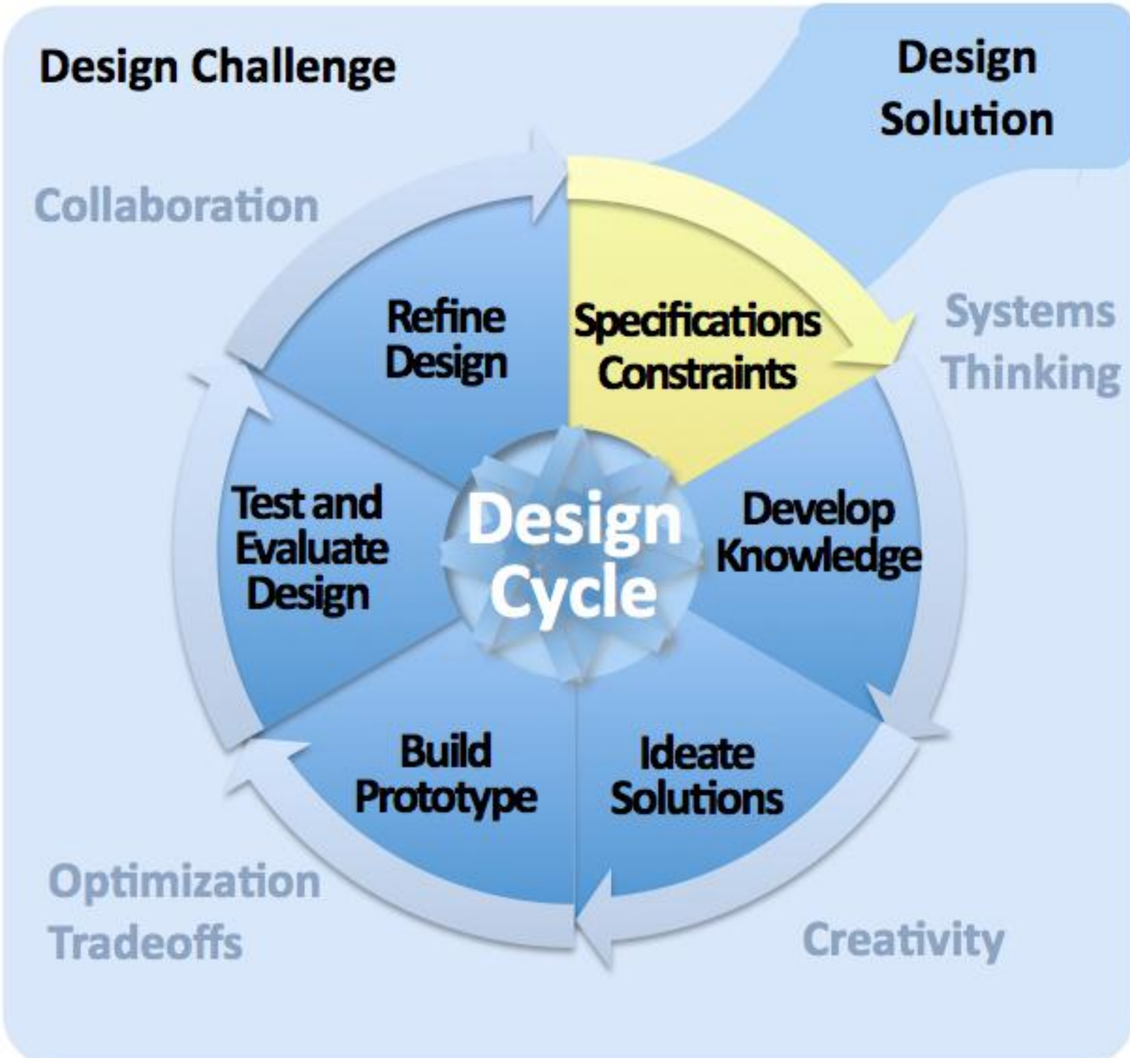

Figure 1. Explicit Design Cycle used in WISEngineering projects.

- *Ideate Solutions* – Ideating Solutions is not simply brainstorming, rather, ideation encourages students to develop multiple, *appropriate* solutions to the task at hand.
- *Build Prototype* – Selecting from their potential solutions, students construct virtual models or real-life prototypes.
- *Test and Evaluate Design* – Students test designs and evaluate whether they satisfy the project criteria.
- *Refine Design* – Based on tests, students revise designs to optimize their solutions.

These phases are not considered to be linear, rather, students are encouraged to revisit steps iteratively, revising design solutions with the aid of repeated research and investigation. This explicit representation of an informed engineering process also includes key engineering habits of mind[23]. By using this representation to guide the student experience, we aim to foster a classroom environment in which students will be aware of and involved in systems thinking, use creative thinking and problem solving skills, work to optimize and consider tradeoffs in design, and collaborate with classmates.

In theory, access to the Internet in a classroom allows for intellectual collaboration with everyone in the world. In practice, however, it can be a source of distraction or diversion when students are asked to perform engineering design projects[24]. WISEngineering leverages the vast resources on the Internet by embedding external web-pages in the interface, allowing curriculum developers to focus student attention on relevant pages and sites with guiding questions and prompts.

WISEngineering incorporates authentic engineering practices into curricular projects. A key component of the system is inter-operability with computer-aided design (CAD) software tailored for use by precollege students. Software packages such as ModelMaker, and Silhouette Studio, and Google Sketchup strike a balance between the ease-of-use necessary for classroom learning and the flexibility to solve various design challenges. Digital fabrication, leveraging desktop computer-aided manufacturing (CAM) promises to transform society in ways comparable to the desktop computer revolution of the 80's and 90's[25]. Students who enter the workforce with familiarity with such technologies will be well positioned to lead the way. Digital desktop fabricators are dropping in price and increasing in user-friendliness (e.g., RepRap http://www.reprap.org; UP! 3D printer http://www.pp3dp.com; Fab@Home http://www.fabathome.org) with communities of 3D designers coalescing to share designs (e.g., http://www.thingiverse.com). WISEngineering will smoothly interface with these emerging technologies and provide students with insight into their functioning and capabilities.

Fostering Reflection through Documentation

Many precollege students have difficulty reflecting upon their learning or work products. This lack of metacognitive self-regulation can be particularly detrimental to students engaging in design or inquiry-based projects[26,27]. For example, students can use trial-and-error approaches instead of careful analysis of tasks, leading to superficial satisfaction of product "success" based on appearances even though hardly any science or engineering principles have been applied. Moreover, allowing students to start systems design projects by proposing their own questions can promote an understanding of project relevance which can in turn increase STEM learning[28].

Giving students guided practice with articulating their knowledge and strategies is a proven way to promote autonomy for lifelong learning, one of the tenets of knowledge integration[10]. A powerful method for ensuring that students reflect on their own inquiry processes is to have them document each phase, from initial ideas and thoughts, through final analyses[29]. Engineering design-based lessons have employed similar scaffolds[30]. In WISEngineering, the *Design Journal* and *Design Portfolio* guide and document students' design processes.

The general user-flow of the interaction in WISEngineering is called a project run. Runs depend on students following a step sequence, provided by the project author, tied in the database to an individual or group identification code. Students' responses to prompts, such as multiple-choice or open ended questions, as well as drawings, brainstorms, and images or videos that students import as part of their design process persist in a student or group's run. Projects that include CAD software include persistent representation of students' designs (Figure 2).

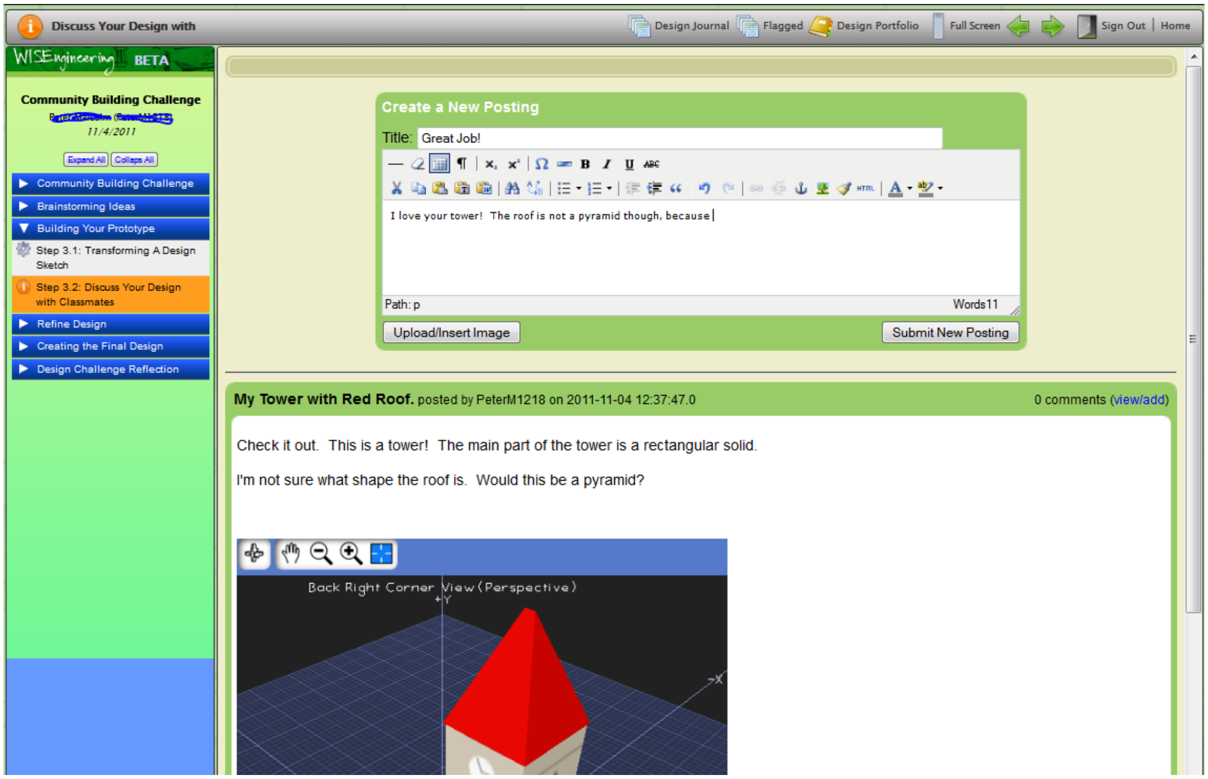

Figure 2. The WISEngineering interface. This screenshot demonstrates the Design Wall, including a screenshot of a digitally designed clock-tower. Links to the Design Journal and Design Portfolio features are at the top-right corner of the interface.

Every student action is documented in WISEngineering, and students can select highlights of their work to transfer to a Design Journal where they can comment and reflect upon their own work and the processes they used to get there. Finally, students can select parts of their Design Journal to move to their electronic Design Portfolios to showcase their work for teachers and peers.

Student generation of documentation during classroom design activities provides three benefits. First, reflective documentation supports metacognition. Students can reflect upon what they have learned or how they have applied concepts in their design. Second, teachers can use student work both summatively and formatively. These assessments can include traditional multiple choice or short answer questions, as well as matching and sequencing, modeling or designing problems to be automatically scored by the software[5]. Teachers can monitor student progress by observing how student respond to these assessments, allowing them to formatively assess students and provide help if needed. Finally, documenting and sharing information allows students to view and learn from one another, as described in the following section.

Encouraging Peer Collaboration

One of the tenets of the scaffolded knowledge integration framework is helping students learn from each other[10]. Practicing engineers collaborate and learn from one another. In the classroom, students may put considerable stock in one another's opinions and input, especially at the middle and high school levels. Also, as long as there are mechanisms to ensure that students have accurate, normative information, then classroom discussion can speed up the dissemination of information and peer-level debates can deepen student's thought processes. Early work with computer-supported knowledge integration environments helped researchers develop best practices for facilitating group work for equity and distributed collaboration[31] that inform our curriculum and interface development.

In design challenges, students can successfully share ideas when they are encouraged to collaborate, with some friendly competition[14]. Teams of students can establish "rules of thumb" for successful design of solutions to problems. The WISEngineering interface allows students to define and develop knowledge about an engineering problem, generate, implement, test and revise possible solutions, and give feedback on others' designs. WISEngineering also provides a virtual forum for sharing ideas.

WISEngineering supports a collaborative approach with a Design Wall, whose interface is similar to social networking websites or blogs (see Figure 2). The Design Wall is shared between all individuals or groups. Students can post images that they have found for inspiration in the ideation phase, post their CAD designs after they have developed a prototype, or post revised designs after testing. Projects provide specific guidance to help students critique the work of others appropriately. The Design Wall step also allows teachers or administrative users to remove or modify inappropriate posts or additions by students. All activity performed on a Design Wall step, even that which has been deleted, is preserved in the database for later retrieval by researchers or teachers. A single project can incorporate multiple Design Wall steps through different phases of the design project.

WISEngineering Project Development

The WISEngineering system is being developed by a multidisciplinary team across multiple universities. The team consists of engineers, educational researchers and evaluators, practicing teachers and software engineers working together to develop the technologies as well as curricular projects. Project development includes multiple cycles of usability testing and formative evaluation, with eventual implementation in middle and high school classrooms.

Usability Studies

To collect information about the effectiveness and usability of WISEngineering, studies were conducted with a convenience sample of students enrolled in two college courses at a northeastern university. Usability testing was conducted to provide valuable information for the instructional design and technology development[32]. Information on the interplay of the users, tasks, tools, and environment was gathered to see where users may have difficulty and where improvements could be made to the system[33].

Students were given the *Community Building* WISEngineering project as a homework assignment to be completed outside of the class. The project guides students to design a model of a community building with certain surface area, volume and cost constraints. Students had no prior experience with either WISE or WISEngineering, but had prior instruction on the related mathematical concepts. Students gave feedback in a subsequent class about their experiences and emailed if they had any trouble with the environment.

Results

These formative studies provided valuable insight that resulted in a number of changes to the WISEngineering environment. Feedback included aesthetic and functional responses to the system. Aesthetic responses included, for example, that students disliked the layout of some of the informational pages and the *Design Journal*. Functional responses spoke to certain flaws in the *Drawing Step* and *Design Wall* components.

Aesthetically, students did not find the layout of informational pages appealing, due to excessive white spaces in the display. The Design Journal and Design Portfolio were considered “too bare”. Graphic design expertise will inform these elements in the next iterations of WISEngineering to address the visual “look-and-feel” of the interface.

Functionally, there were some bugs found in WISEngineering. These took top priority for future development, and any that prevent the minimal functionality have already been addressed. Generally, students were able to login and complete steps without too much difficulty. The large data size of student vector drawings caused a display error, which required adjustment to a data-type in the database. Initially, the *Design Wall* was created to exist in only one place per project run. This was later revised to have separate instances in a single project run to allow for different threads of discussion to begin at different points in the students’ design process.

Graduate students with curriculum development experience were given the task of creating projects in WISEngineering, as part of the user testing process. This led to some useful suggestions, centered on making the curriculum development process easier for non-technical users. First, they recommended the creation of a what-you-see-is-what-you-get (WYSIWYG) editor for curriculum developers. Second, they suggested automatic resizing of images once these are inserted into a project.

Future work

The project is currently developing and testing two-week design projects for use in seventh-grade mathematics classes. Each unit covers Common Core standards for learning in mathematics including geometry, proportional relationships, expressions and equations through the lens of engineering design. These projects are based on prior studies demonstrating the effectiveness of engineering design on mathematical understanding[1]. In addition to raising student achievement in these areas, goals of the project include raising student engagement and enrollment in science, technology, engineering and mathematics (STEM) electives.

Future work on the development of the software system will address the limitations described above. They will also build toward a fully web-based system that will let students both design and test their solutions virtually. This might include, for example, building and testing solar-powered satellites and testing them at various simulated distances from the earth's surface. A fully integrated physics simulator to test the CAD designs is one of the possible future directions for the WISEngineering system.

Conclusion

WISEngineering provides a scaffolded engineering design environment. It seeks to foster student learning in STEM by encouraging authentic design, developing student reflection through documentation, and creating an online space for student-teacher and whole-class peer collaboration. User studies have provided valuable information, and the implementation of pilot studies in 7th grade classrooms will demonstrate the potential of this new system.

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