DIGITAL CADCAM PEDAGOGY

Prototype for Inquiry Education

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Abstract. Prototype manufacturing as an educational tool has been very successful at the college level in architecture and engineering design. This paper discusses an innovative inquiry-based learning approach rather than the problem-based learning models commonly utilized by other similar programs. For example, several research-funded technology projects (e.g., Cappelleri et al. 2007) look at involving students in problem-based learning exercises (e.g., building robots); however, these exercises (while providing valuable experiences) have predetermined outcomes ingrained by the teachers, the project structure, and the components used to construct the devices. Therefore, inquisitive and creative problem solving is limited to the "kit-of-parts" in their approach to solving the problem. The inquiry-based CADCAM pedagogy model is more concerned with the process of solving a problem through the vehicle of prototyping than with the specificity of the design project itself. This approach has great potential. First, the need to solve the problem drives learning on multiple levels, integrating interdisciplinary ideas into the problem and solution. Second, the problem interlocks disciplines through inquiry knowledge building in team exercises. Finally, it encourages diversity and flexibility by allowing students to look at problems from multiples perspectives and points of view.

Keywords. Inquiry-based education: CAD; CAM; pedagogy.

1. Introduction

Prototyping technologies are used by automobile, aerospace, industrial design, and other professional engineering/manufacturing industries to study, test, and trouble shoot innovative new designs for their competitive marketplace. (Roost, 2007; Mills, 1999; Henderson, 1995). Prototyping technology – the fabrication of small models (prototypes) to visualize, test and validate solutions – is widely utilized to facilitate critical thinking by engineers solving complex problems. Innovations such as the Dyson Vacuum showcased this process in a recent television commercial. The problem-solving process used by many engineers is a critical educational component that can contribute to core math, science, technology, and computer learning central to advanced engineering and design education (Fraser and Hodgson, 2007; ITEA, 2000).

Rapid Prototyping (RP) is a manufacturing technology that utilizes three-dimensional (3D) computer-aided design (CAD) models and special hardware to produce a physical model directly from the CAD data. Uses of RP include design verification and visualization, supplier involvement, field testing, and marketing. The verification phase allows the designer to conform to accepted standards and practices. It also allows the designer to check for form, fit, and assembly. The current solid modeling software packages have enhanced features that will allow the project participants to test their design for adherence to standards and practices. However, there is a significant need for students to see, touch, and handle physical prototypes in order to check the form, fit, and assembly.

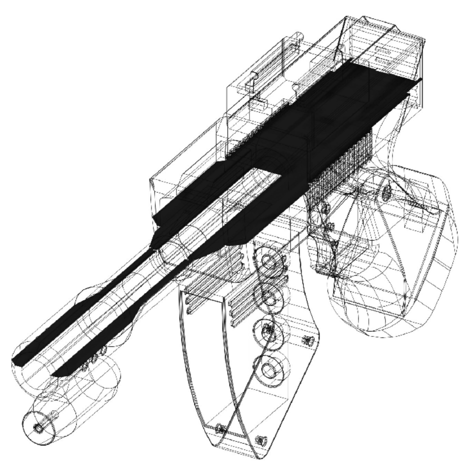


Figure 1. Prototype model by student.

Prototyping technology, such as Rapid Prototyping is being used extensively at the college level to improve undergraduate education in engineering and architectural schools that utilize computer-aided design and manufacturing (CAD/CAM). Additionally, instruction in manufacturing engineering and engineering design processes is common in many undergraduate courses. The prototype design process being primarily project-based (e.g., to design a new set of golf clubs or a vacuum cleaner) (Newman, 1995) which enables incremental student learning to develop as the project evolves. This and the widespread success of prototyping with CAD/CAM tools as hands-on learning tools at University of Nebraska-Lincoln, Colleges of Engineering and Architecture and at other major research universities internationally (Fraser and Hodgson 2007; Cassola 2007) leads us to believe the design of prototypes strongly relates to inquiry-based science education.

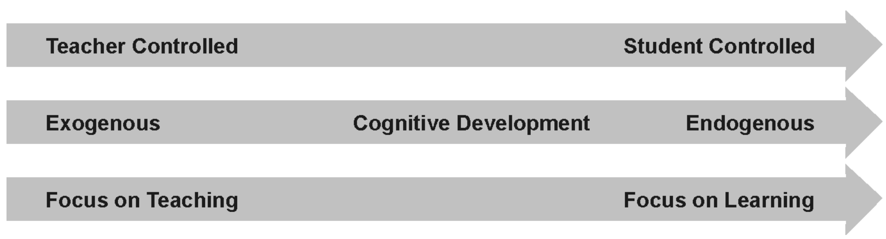
2. Methodology

Recent years have seen a growing call to redesign instructional methods to increase student engagement and learning (e.g., NRC 1996; Kirschner et al., 2006). This call supports the development, implementation, and evaluation of rigorous projects that position the learning environment in line with the technology and science literacy necessary to energize a crucial knowledge base and sustain a fertile environment for new and revitalized industries and the well-paying jobs they bring. (ITEA, 2000). CADCAM prototype pedagogy is inquiry-based learning and recognizes that science and engineering are essentially a question-driven, open-ended process and students must have personal experience with scientific inquiry to understand the fundamental aspects of science and technology (Edelson et al., 1999; Puntambekar et al., 2007).

Inquiry-based exercises, like making prototypes, focus on a process rather than a problem enabling students to define their own exploration and fostering authorship and ownership of issues explored through prototyping exercises. A premise of this paper is that teachers' competence in inquiry-based instruction and students' inquiry abilities evolve gradually out of their current instructional competence (Bonnstetter, 1998). The essential contribution of professional development is to anticipate the transitions that teachers and students navigate when adopting inquiry-based teaching and learning strategies, and to provide supports that are essential to ensure that these transitions are successful. Evolutionary teaching model that first provide structured experiences that help students and teachers evolve along an inquiry developmental continuum. Movement from traditional "recipe driven" projects to inquiry-based projects will set the stage for activities that are more student-directed and that promote students' endogenous cognitive development. Table 1 illustrates this model as an evolutionary process.

TABLE 1. Inquiry as an Evolutionary Process (Abstracted from Bonstetter, 1998).

	Traditional Hands-on	**Structured**	**Guided**	**Student Directed**	**Student Research**
Topic	Teacher	Teacher	Teacher	Teacher	Teacher/Student
Question	Teacher	Teacher	Teacher	Teacher/Student	Student
Materials	Teacher	Teacher	Teacher	Student	Student
Procedures/ Design	Teacher	Teacher	Teacher/ Student	Student	Student
Results/ Analysis	Teacher	Teacher/ Student	Student	Student	Student
Conclusions	Teacher	Student	Student	Student	Student



Inquiry- based projects designed to recognize this evolutionary model support student growth from Exogenous to Endogenous cognitive development. Prototype making itself involves many stages of design inquiry to solve the complex problem at hand. In our model, students start with a traditional hands-on recipe in their effort to recreate through 3D modeling software of a working prototype. As they gain confidence in their abilities with the software and familiarity with the object they model, students move to the next phase and re-design the prototype to improve or alter its functionality. Through abstracting the original prototype into something else, students gain more control over the process allowing them to focus on their own self-motivated discovery.

Various supports are offered along the way to aid a student development. In the prototype making exercises, students work during lab class times with technical support from teaching assistants who help guide their initial prototype making, their prototype re-design and then their preparation for fabrication. Additional on-line and in-class tutorials related to each development phase are provided. Following the completion of the prototype making process physical prototypes are produced from either a 3d printer or a laser cutter to give students hands-on feedback into their prototype design. This exercise is one of several to introduce students with no prior computer or much design experience to 3dimensional modeling.

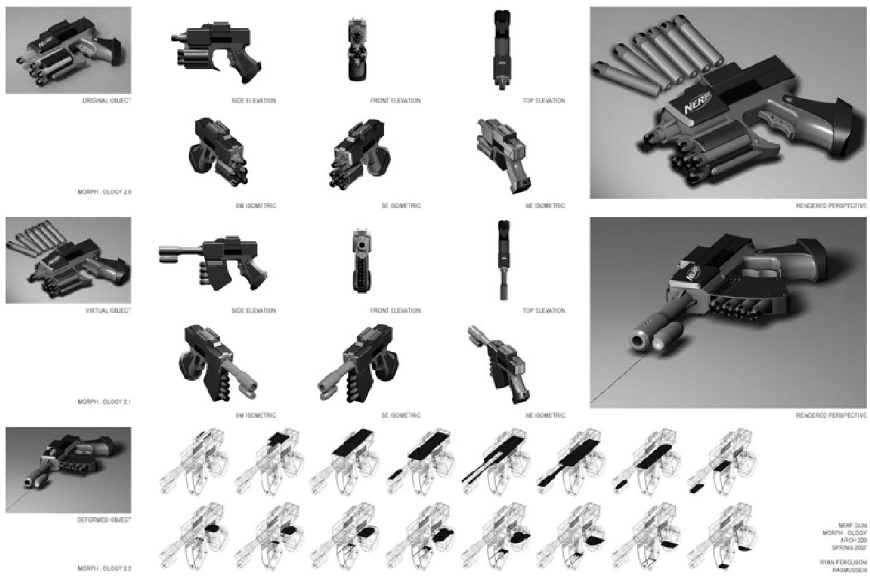


Figure 2. Prototype design exercises by student.

The 5E teaching model we have adopted provides a structure for CACAM pedagogy helping both the teacher and his/her students evolve in their implementation of the inquiry-based investigation process (Trowbridge and Bybee, 1996). The 5E model involves: 1) *Engagement* (motivational and pre-assessment); 2) *Exploration* (time for students to develop language and facilitate student discussion); 3) *Explanation* (teacher lead discussion to clarify inquiry experience); 4) *Elaboration* (students apply and connect science concept knowledge gained); and 5) *Evaluation* (authentic assessment of student achievement). Moreover, all instruction will be embedded within a broad goal of developing scientific literacy: "Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NRC, 1996). Through this combination of the 5E model with CADCAM fabrication, students and teachers in the design of prototypes we hope will develop critical thinking skills through cutting-edge prototyping CADCAM technology.

Adapting the 5E teaching model to CADCAM fabrication will encourage students: 1) *Engagement* with the problem at hand through a prototyped solution;

2) *Exploration* with CAD to design prototype and to collaborate with other students, teacher and mentors; 3) *Explanation* by teacher, mentors and through learning modules or further instruction; 4) *Elaboration* in the refinement of engineered prototype, and 5) *Evaluation* of manufactured (CAM) prototype to test and evaluate solution. Figure 3, describes the various parts involved in the inquiry-based prototype design process.

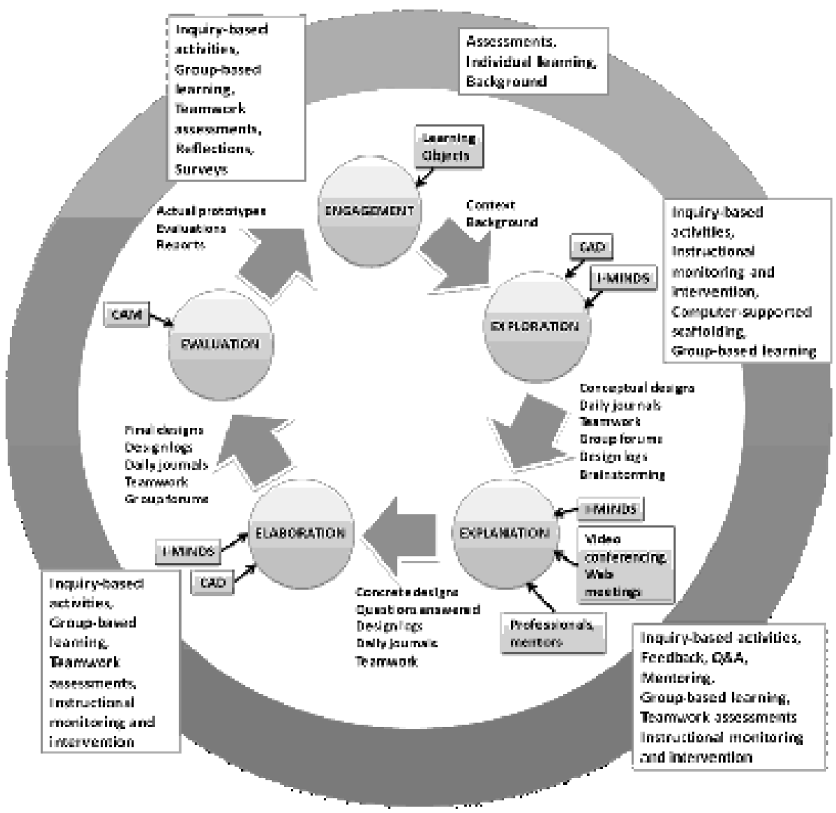


Figure 3. Prototype Design Activity Diagram

Given the nature of open-ended design problems, the 5E inquiry model is ideal and the foundation of the prototype making activity with CAD/CAM software combined with other activities utilized, including group-based learning supported by I-MINDS (a computer-supported collaborative learning system), and learning objects. The latter not discussed in this paper, has had great success in a variety of other research-funded projects (Soh et al., 2008).

4. Conclusion

The goal of this paper and the pedagogy model is to integrate many aspects of contemporary design processes (computer-aided design, digital fabrication or CADCAM) into a comprehensive inquiry-based model for design education. The CADCAM pedagogy proposed builds on the inquiry-based scaffolded instructional content delivered to aid students' learning, for more detail see (Soh et al., 2008), using prototype design (CAD) and fabrication (CAM) tools to design, test, and evaluate potential solutions. The 5E teaching model proposed as the framework for education is a cyclical exploration, similar to the design process proposed by Peter Szalapaj which integrates the physical model (prototype) with the computational (CAD), (Szalapaj, 2005). The work of Frank Gehry is one architectural example that demonstrates the seamless integration of the CAD model and physical model into the design process. We believe that the 5E inquiry-based science foundation provides clarity and the need to solve the problem drives learning on multiple levels, integrating interdisciplinary ideas into the problem and solution. CADCAM and the prototyping problem interlocks disciplines through inquiry knowledge building in team exercises. Finally, the prototype design process encourages diversity and flexibility by allowing students to look at problems from multiples perspectives and points of view.

Future explorations are required to test the full-scale application of the intelligent inquiry education component of this project. Both the Colleges' of Architecture and Engineering have utilized CADCAM design methodologies in the classroom. Early stereolithogogy machines, CNC milling and lathing equipment, 3D printers, and laser cutters have been widely successful in the design and testing of prototypes. Combining this history with the inquiry-based 5E model and an intelligent I-MINDS collaborative environment, we feel offer a new teaching model preparing students with a fully integrated, intelligent design education in architecture, engineering and science. Such an environment will facilitate tighter interactions between students and teachers in the virtual, global community, which will in turn support the actual, local communities. The impact of this project lies in the transformative education/ technology curriculum model developed for this project through the tested engineered-prototype CAD/CAM fabrication design process.

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