Digital CADCAM Pedagogy Model

Intelligent Inquiry Education

CAD

Education

Evaluation

Timothy Hemsath

College of Architecture, University of Nebraska-Lincoln

Robert Williams

College of Engineering, University of Nebraska-Lincoln

Ronald Bonnstetter

Teaching, Learning & Teacher Education, University of Nebraska-Lincoln

Leen-Kiat Soh

Computer Science & Engineering, University of Nebraska-Lincoln

Pedagogy

Rapid Prototyping

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.

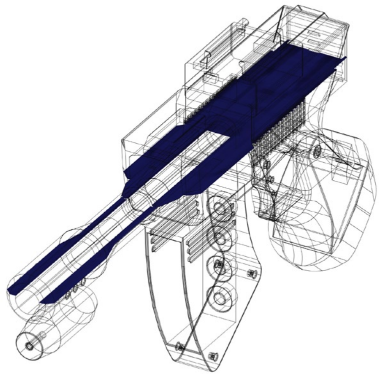


FIGURE 1. CAD PROTOTYPE MODEL (BY RYAN FERGUSON)

1 Introduction

Prototyping CADCAM 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 2005; ITEA 2000).

Many prototyping machines are *computer numerically controlled* (CNC), requiring not *only* basic engineering knowledge to design the prototype, but computer expertise to design, test and execute a successful prototype. In European and a few American high schools students have engaged CNC technology to the 3D challenge, *Formula 1 race car* design competition (Gorman 2007; 3d challenge), which demonstrates students' ability to use elements of advanced engineering-technology in the high school learning environment. However, this competition does not directly expose a great number of students to the manufacturing process or have a plan in place to measure what students are learning. Additionally, the Technology Student Association has several competitions geared to students involving the use of prototypes, CNC technology, and other technical skills demonstrates the ability of students to tackle complex technology problems (http://www.tsaweb.org).

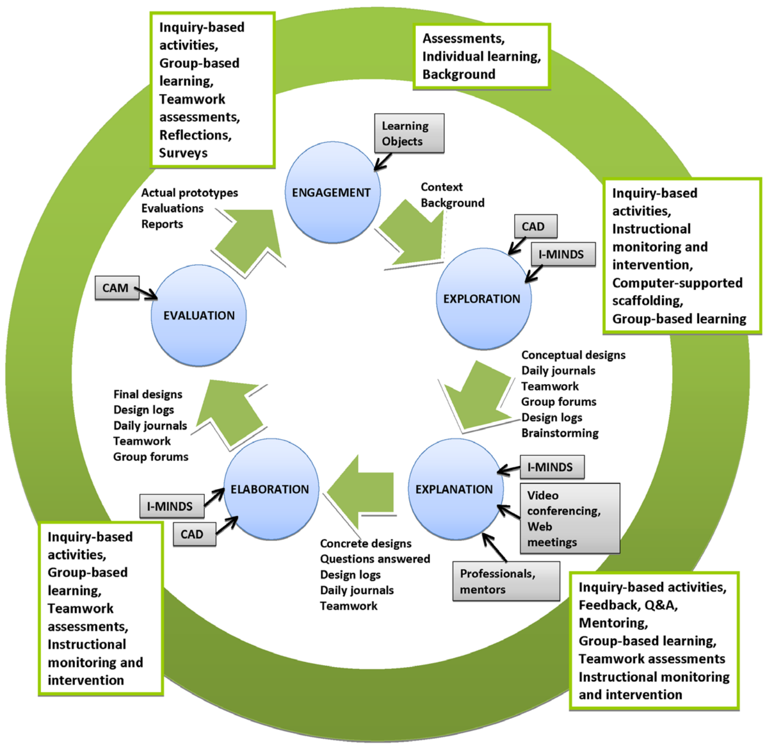
Rapid Prototyping (RP) is a manufacturing technology that utilizes three-dimensional (3D) *computer-aided design* (CAD) models and special hardware to produce a physical model directly from the CAD data. Uses of RP include design verification and visualization, supplier involvement, field testing, and 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.

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 95) 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 UNL's 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 2005; 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 is 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 2007).

Inquiry-based exercises, like making prototypes, focus on a process rather than a prob-



lem 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.

2.1 PEDAGOGY MODEL

The 5E teaching model 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.

FIGURE 2. PROTOTYPE DESIGN ACTIVITY DIAGRAM

	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

TABLE 1. INQUIRY AS AN EVOLUTIONARY PROCESS (ABSTRACTED FROM BONSTETTER 1998)

Adapting the 5E teaching model to CADCAM fabrication will encourage students:

1. *Engagement* with the problem at hand through a prototype solution
2. *Exploration* with CAD design to make prototype and collaboration with other students, teacher and mentors
3. *Explanation* by teacher, mentors and through learning objects described below
4. *Elaboration* in the refinement of engineered prototype
5. *Evaluation* of manufactured (CAM) prototype to test and evaluate solution.

Figure 2, describes the relationship of all the various parts involved in the intelligent inquiry-based prototype design process.

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 discussed next, has not been effectively tested in combination with this particular pedagogy model, but has had great success in a variety of other research-funded projects (Soh et al. 2008).

The proposed CADCAM pedagogy model comprises two primary methods to create intelligent inquiry education and interaction with students online in the CADCAM design process: 1) learning objects, which will be SCORM-compliant and deliverable online using standard learning management systems (LMSs) (i.e., Blackboard, WebCT, etc.), and 2) computer-supported collaborative learning (CSCL) systems (i.e., I-MINDS), which will be characterized by a one-click download and installation on school computers. Participants can then communicate with peers and instructors by accessing the I-MINDS server, synchronously and asynchronously.

2.2 LEARNING OBJECTS

Intelligent Learning Object Guide (iLOG). The long-range goal of iLOG is to augment learning objects with empirical usage intelligence and learn how a learning object should be used, how it has been used, and how it has impacted instruction and learning. The project is currently designing and producing learning objects—which are compliant with the Shareable Content Object Reference Model (SCORM) standard (ADL 2004)—on computer science topics that use active learning (Bransford and Schwarts 1999) and elaborative feedback. In contrast to passively listening to a lecture, active learning requires students to dynamically make decisions and choices, which, in turn, influence the sequencing and instructional presentation. Elaborative feedback is another critical design dimension. Studies of learning, transfer, and development show that feedback is extremely important and that, usually, it should be immediate (Bransford et al 2000; Mory 2004). The value of learning objects as an instructional tool we hope will be realized with the digital CADCAM pedagogy model.

2.3 COMPUTER-SUPPORTED COLLABORATIVE LEARNING: I-MINDS.

To support collaborative learning, across disciplines, we will utilize a computer-supported collaborative learning (CSCL) tool: the Intelligent Multiagent Infrastructure for Distributed Systems in Education (I-MINDS) (Soh et al. 2008). I-MINDS employs a system of intelligent software agents, representing individual students and the instructor (or teaching resource in the case of an asynchronous course or lesson). Briefly, an *agent* is a software module that observes and receives input stimuli from its environment, makes autonomous decisions based on these stimuli, and actuates actions to carry out these decisions, which, in turn, change the environment (Weiss 1999). A multi-agent system, in turn, consists of agents working together to solve joint tasks or achieve global goals. In I-MINDS, each student agent serves a student, profiling the student's behavior in his or her structured and non-structured collaborative activities (Khandaker et al. 2006). The student agents exchange information to form peer groups that are compatible to help students collaborate (Soh et al. 2006). For each group, there is a group agent that provides scaffolding and monitors the progress on accomplishing tasks assigned by the instructor. The instructor is supported by a teacher agent that displays statistics of students and groups, identifies problems in group activities (for example, a student being too dominating or too shy), and manages the Q&A sessions by ranking questions posed by the students. The teacher agent also administers quizzes and supports multithreaded forum discussions. Our educational studies show that agent-mediation can help improve student performance (Soh et al. 2004) and form more effective and efficient groups (Khandaker et al. 2006; Soh et al. 2006).

3 Conclusions

The CADCAM pedagogy proposed builds on the intelligent inquiry-based scaffolded instructional content delivered to aid students' learning, using prototype design (CAD) and fabrication (CAM) tools to design, test, and evaluate potential solutions. Learning objects, because they are stand-alone, modular and relatively small, can be weaved into existing curricula conveniently. The learning objects will also be based on validated strategies that help student learn: active learning and immediate feedback. Further, the learning objects will be SCORM-compliant. The use of the computer-supported collaborative learning system (I-MINDS) is grounded on the necessity of providing online support to each student and teacher at a distance where traditional face-to-face approaches are infeasible, and also on peer-based or group-based learning.

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 the I-MINDS collaborative environment discussed in this paper, offers a new teaching model. 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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