2006-1378: CHARACTERIZING THE MENTORING PROCESS FOR DEVELOPING EFFECTIVE DESIGN ENGINEERS

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Characterizing the Mentoring Process for Developing Effective Design Engineers

Abstract
Several instructional frameworks suggest using a coaching model as a pedagogical approach for open-ended types of academic tasks. These frameworks provide a theoretical foundation for a coaching teaching approach but often do not provide specifics on how to effectively enact a coaching pedagogy in particular academic settings. The current study explores the specifics of the coaching process in the context of mentoring engineering student design teams. The current study provides insight into the types of roadblocks design teams face and how our teaching strategies can help teams overcome these challenges. By aligning our teaching and coaching strategies with the actual learning and project needs of student design teams we are better positioned to produce effective, future design engineers.

Introduction

Design courses emphasize learning-by-doing and applying knowledge and skills to develop feasible solutions to real needs. At a minimum, students are expected to perform the dual task of applying rigorous design process principles as well as utilizing domain specific knowledge to generate, analyze, and evaluate potential solutions. Given this action-oriented approach inherent in design courses, educators are faced with providing a pedagogical strategy that is consistent with the goals of design education. In project-based or design courses instruction often takes the form of coaching or mentoring rather than didactic transmission of information. While many engineering design courses adopt a coaching model it is not clear what is required, or expected, to effectively guide design teams to successful solutions.

The current work is an exploratory study to review the coaching process of several engineering design projects from both the student and mentor perspective. We interviewed several students and project mentors to understand the project and learning needs of design teams and the nature of the guidance provided by the mentors. The current study provides insight into the type of roadblocks design teams face and how our teaching strategies can help teams overcome these struggles. By aligning our teaching strategies with the actual needs of student design teams we are better positioned to produce effective, future design engineers.

Background on the Institute of Design Engineering and Applications

At Northwestern University the Institute for Design Engineering and Applications (IDEA) was formed as a collaborative effort; engineering faculty, the administration, engineering students, and experts from industry worked together to establish learning goals and design project experiences for our design curriculum. In IDEA design courses students work in teams to develop design solutions to real projects for actual clients. Students interact with clients, product users, experts, instructors, and teammates throughout the design process and are required to convey design ideas to multiple audiences[1, 2].

We follow a collaborative and iterative process such that our curriculum conveys that the design process:

- is needs-driven (in contrast to specification-driven or hypothesis-driven).
- is about converting intellectual capital into products and processes that meet societal needs.
- encompasses many phases, and we provide students experiences from design conception to production.

One primary educational feature that is embedded in all IDEA design courses is "relevance". We emphasize relevance in our IDEA courses not only because we seek to develop design solutions to real needs but also because relevance is closely related to motivation in the learning process. For example, Hynd and coworkers explain that persistence and effort are outcomes of motivating influences such as "self efficacy, interest, a desire for good grades and a belief that the information is relevant and useful" (p. 55)[3]. Hynd and coworkers suggest that, in order to support learning at the conceptual change level, instructors should present information by incorporating real life applications or uses so that students see the relevance of the information.

Since all of the IDEA design projects are actual design problems with real clients and users, "relevance" is embedded in the project work. Students consult with clients to define the project goals, meet with users to get feedback on different design ideas, and ultimately create solutions (often working prototypes) that are given to the client to be implemented and used. Through these authentic design activities students see first-hand the impact of their design solutions, and the relevance of their work in a broader context.

Table 1 provides three examples of IDEA projects and the corresponding details of how relevance is embedded in the project. We provide these examples to demonstrate that there is a broad community context to IDEA student design work, and therefore, relevance to the outside world is intrinsic to the projects.

IDEA Project	**Goal of Project**	**Relevance of Project**
Infant Feeder for HIV+ Mothers	Design a milk feeding apparatus that will allow a mother to safely and discreetly feed her child.	Every year, 219,000 new infections result from mother-to-child-transmission of HIV in sub-Saharan Africa. The design has the potential to have significant impact on decreasing the HIV infection rate[4].
NUberwalker	Design a treadmill/body weight support system for in-home use that enables stroke or spinal cord patients to regain normal gait patterns.	In the United States, there are 23,000 people with spinal chord injuries, 4 million have survived a stroke or brain attack and are still living with after effects, 350,000 with multiple sclerosis, and 1.5 million with Parkinson's disease. The design would provide in-home therapy to a significant population of users[5].
Hand Orthosis	Design an orthosis device that will aid hemiparesis	Hemiparesis, a weakness of one side of the body, is a common effect of stroke occurring

	patients in their activities of daily living.	in approximately 80% of stroke patients. Patients who have hemiparesis experience a large loss of motor control in their hand and fingers. The design would enable patients to extend their fingers while allowing flexion and help them perform simple daily tasks[6].

Table 1. Three Examples of IDEA design projects.

Pedagogy of IDEA Design Project Courses

Two interdisciplinary design project courses serve as the backbone to the IDEA curriculum. In these two courses (IDEA 298 and 398) students work in teams to solve problems as illustrated in Table 1. We have adopted a two-part teaching approach for these project-based courses. One component of the course consists of addressing topics we have identified as critical to the design process such as ethics, project management, communication and teamwork. This component of the course is team taught by faculty from both the engineering school and the writing program.

Many of the classes devoted to these topics use a case-based teaching approach and assignments are structured so that students discuss the topics in the context of their design project. By having students connect the learning with their actual project we emphasize relevance not only of the project, but also of the subject matter knowledge that enables productive completion of the project.

The other component of the course consists of carrying out the design project work. For this component of the course student teams are assigned a "project mentor", or coach. Theoretically the project mentor is someone who can help guide the team through the design process and help teams bring the project to completion. This coaching model of teaching has been presented through a variety of instructional frameworks. For example, in problem-based learning (PBL) as applied to medical education, students are presented with a patient case and engage in self-directed discovery of a diagnosis of the problem[7]. In the PBL approach students can seek out information from faculty who serve as tutors or consultants.

Schon describes an architectural studio model where the design process is learned as "reflection-in action"[8]. The teaching model consists of a dialogue between the coach and student where understanding is developed through communication and reflection about the design itself. As Schon states the "dialogue has three essential features: it takes place in the context of the students' attempt to design; it makes use of actions as well as words; and it depends on reciprocal reflection-in-action" (p. 101)[8]. Furthermore, the cognitive apprenticeship model of instruction suggests a process of modeling, coaching, scaffolding, reflection, and exploration[9]. In cognitive apprenticeship the teacher models effective practice then observes and coaches students while they perform a similar task.

Each of these frameworks suggests a coaching model of instruction and provides a theoretical foundation for the educational advantage of this approach. However, as we apply the coaching teaching model to our design project work we are faced with several practical issues that are critical to the successful performance of our design projects. For example, it is not always clear what the right mix of knowledge and skills the mentor should possess in order to guide teams through the design process. At a minimum, we assume that the mentor should possess subject matter expertise related to the project as well as design process knowledge. However, are these necessary and sufficient conditions for characterizing the role of the mentor?

Our motivation for this study is to examine the experiences and interactions between design teams and their mentors in order to better articulate the role of the mentor. By doing so we have a more informed notion of what is required in guiding teams to successful solutions.

Method

Since the current work is an exploratory study we used a qualitative approach for collecting data. We interviewed five project mentors and surveyed eight students from previous IDEA design projects to obtain feedback on the role of the mentor, the challenges that each side faced, and strategies that were utilized to move the project forward. The mentors were asked the following questions:

- What has been challenging about mentoring the design teams?
- What do you think students need to complete the project?
- What help do students seek from you?

Students were asked to submit a written response to the following questions:

- When working on your design project, what kind of help did you most need (or want) from your project mentor?
- Did you receive the help you needed? Why or why not?
- Did your design project experience in IDEA 298 and/or 398 meet your expectations? Why or why not?

The questions were selected to elicit the specific coaching issues faced by students and faculty and to identify any similarities or differences from the two perspectives. Responses from this study serve as a basis for developing a pedagogical framework for effective coaching of engineering design teams.

The responses to each of the questions were reviewed in order to characterize the types of responses students and faculty generated. All responses were read to identify common themes. This method of analyzing qualitative data reflects the iterative tradition of qualitative research corresponding with the grounded theory approach of Glaser and Strauss (1967)[10] and the strategies for analysis of Miles and Huberman (1994)[11]. The process of defining a set of codes or categories that capture the essence of a data set evolves as the study is designed, implemented, and evaluated.

Findings

Based on the student and faculty responses we identified several common themes. The majority of the responses focused on the needs of students' when working on a design project. Both faculty and students discussed in detail what these needs are and three categories emerged from the data: project pacing and goal setting, access to resources, and encouragement. Each is described in more detail below.

Project Pacing and Goal Setting

Every faculty member and the majority of students explained that time management is critical to moving the project forward. This may seem obvious since anyone who has worked on design projects understands the role of project management techniques such as using Gantt charts. However, in addition to basic scheduling issues the data also reveals some interesting nuances associated with project management. Students and faculty describe the challenge of "scoping" a project. Specifically, in an academic setting teams are limited by the academic calendar. Student teams are constrained by the number of weeks in an academic term so they need guidance on what is feasible to accomplish in this time frame. The following student comment accurately conveys this notion.

"From the project mentor I was looking for help regarding setting a good pace for the project. Making sure that my group did not fall behind and run out of time at the end of the project. The mentor should keep tabs on how the project is progressing and making sure the team stays close to the schedule they set out at the beginning of the quarter."

Furthermore, large-scale open-ended design projects go through multiple stages. Students rarely have the perspective or experience to know how to pace a project and how all of the pieces will eventually fit together. Students require help in not only identifying appropriate and feasible goals for their participation on the project but also help in "seeing the big picture." The following student comment illustrates this point.

"The help that we most sought from our mentor was help outlining the scope of our project and where to go next. Because our project was intended for many years it was difficult to figure out a path from one piece of the project to the next."

Faculty responses also confirm the importance of providing students guidance on scoping a project, setting realistic goals, and helping students with time and risk management. One project mentor described his role as a "manager who gives direction, helps set objectives and goals, and keeps the team calm".

Access to Resources

Another consistent theme mentioned by both faculty and students is the need for the project mentor to provide access to resources. Resources include people such as specialists with particular expertise, and "things" such as parts, suppliers/vendors, tools and facilities. In particular, one project mentor said that the number one question he receives from student teams is "Where do I get parts and supplies?"

Finding appropriate expertise is a recurring issue with the coaching of our design teams. IDEA design projects are interdisciplinary in nature and proceed through several design phases ranging from conception to production. The projects therefore, require diverse disciplinary knowledge as well as broad design process skills. For example, the Infant Feeder project requires biomedical engineering knowledge to understand the specifics of how to neutralize the HIV antibodies. In addition, the project also requires detailed understanding of materials and manufacturing processes in order to recommend an effective pouch for storing and dispensing the breast milk.

Our original assumption was that the project mentor should have deep disciplinary knowledge in the domain most related to the project (in the Infant Feeder case this is biomedical engineering). We reasonably based this assumption on the fact that the project coach needs to know something about the engineering fundamentals required of the project. The data bears out this assumption however the results also suggest that students seek out a range of expertise. In fact an interesting finding is that students will ask the mentor to connect them with a disciplinary expert, even when the mentor himself/herself is an expert in the field. As one mentor relayed “even when I know, students don’t assume I know”. This sentiment is confirmed by the following student comment:

“The project mentor should help direct us to specialists in field.”

These findings raise some interesting issues. First, design project work requires a broad (and often deep) range of knowledge and skills. We believe it is essential for the project mentor to have expertise in the field most closely related to the project. However, we recognize that it is impractical for one person to possess all of the knowledge necessary to guide teams in carrying out all of the design work.

Our findings suggest that an effective mentor should not only have disciplinary expertise and design project experience but also have the ability (and expectation) to act as a “broker” between students and outside resources. As one mentor said, he serves as a “technology broker to orchestrate an approach and hook students up with the right tools and people”. An important attribute of an effective project mentor is therefore, having connections to experts in the field, knowledge of appropriate computational/design tools, and knowledge of physical components and vendor sources.

Encouragement

One other major theme we identified is the importance of the project mentor to provide encouragement to the team. To put it simply, IDEA design projects are complex and time-consuming. Even the most talented students hit roadblocks and are challenged by certain aspects of the project work. During these difficulties students are looking for encouragement and outside recognition of the effort that is involved. The following student comment nicely captures this sentiment.

“Once the project got moving the experience was very worthwhile, although very time consuming. I spent more time per week working in this class than maybe any other class I had taken at NU. During this process the most distressing part was every time we made significant advances in the construction it was always looked upon poorly by our mentor. [The mentor] rarely seemed satisfied with our progress, despite the long hours we spent building the machine. I would suggest in the future that [the mentor] try to focus on encouraging the teams on what they have accomplished instead of stressing what needs to be done in the future. That is not to say the "plan" for quarterly progress isn’t important, but it is difficult to motivate the team when after many sweaty hours in the shop all they hear is what they haven’t done yet.”

Similar comments were voiced by the mentors. For example, one mentor summed up his role as someone who "needs to be caring and needs to love the field." This comment was given in the context of understanding the emotional needs of students. Specifically, that the majority of design teams are motivated and want to do a good job. One role of the project mentor is therefore, to help channel the students' motivation and desire to succeed in a way that will produce effective results.

Summary and Future Work

The coaching model has been presented in several instructional frameworks and has been shown to be an appropriate teaching approach for open-ended activities such as problem-based learning and architectural design. Within IDEA students work on open-ended design projects and, similar to these instructional models, require a teaching approach that is less didactic and more one-on-one. While instructional frameworks like cognitive apprenticeship provide a theoretical foundation for the coaching model, they are not prescriptive. That is, instructional theories often do not provide specifics for how to enact a coaching model in a particular domain or setting.

Results from this study shed light on the expectations both engineering faculty and students have about the coaching process. In particular, results from this study suggest three essential areas where student design teams need guidance: project pacing and goal setting, access to resources, and encouragement. These three areas serve as a basis for a framework to characterize a coaching process that encourages "design-engineers-in-training" to work independently and effectively, to proceed at an acceptable and productive pace, and produce effective solutions to real needs.

This study introduces the basis of a framework for characterizing an effective coaching model for engineering design. We plan to conduct interviews and survey additional IDEA 298 and 398 students and project mentors to verify this model and identify any other critical factors that are necessary to include. We also plan to collaborate with several other academic institutions to validate our emerging framework and to explore the coaching model in the context of engineering design teams in more detail.

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