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Hierarchical Model for Coaching Technical Design Teams*

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A new design education model has been developed to address the issue of technical depth in undergraduate design education by utilizing graduate students as coaches. This model has been implemented in a junior-level capstone materials science and engineering design course. The model allows the graduate student coaches to experience supervision of other researchers while serving as a technical resource and role model for the undergraduate design team. Meanwhile, the instructor serves as an expert who oversees the instruction of the course and the graduate student coaches. With reduced responsibility, the instructor can focus on the quality of research performed while influencing a greater number of design teams. This paper provides an overview of the model, its characteristics and execution, and presents findings from interviews with the graduate students coaches and undergraduate design team members. Results from our study suggest that the model provides benefits for all participants in the hierarchy.

Keywords: Engineering design; coaching; design education; pedagogical strategy

COACHING MODEL

DESIGN WORK IN INDUSTRY is typically done in teams. However, some speculate whether work done in undergraduate design teams embodies the same level of technical depth that one would see in industry. We implemented a design education model to address the issue of technical depth by utilizing graduate students as undergraduate design team coaches. This model aims to bring undergraduate design education to the level of graduate engineering research.

The hierarchical model used for coaching design teams can be found in Fig. 1 below. The hierarchical arrangement of the instructor, coaches and design teams acknowledges the hierarchical nature of the knowledge levels (expert, intermediate and novice). Those with the greatest technical expertise are placed at the top of the hierarchy. Initially, information flows in a downward direction to the undergraduate design team. As the design team progresses through the project they feed information back up through the branches of the hierarchy, reporting to the coaches and in turn the coaches relay the information to the instructor. The complex and iterative exchange of information that occurs between all the levels of the hierarchy leads to a bi-directional movement of information, consequently the structure of the hierarchy is no longer rigid but becomes more compliant as research progresses. As the course progresses, the hierarchal arrangement shifts as the technical level of the undergraduate design teams approaches that of the coaches.

At the beginning of the course, design projects are posed to the undergraduate students by the instructor. Students form four to five member teams in which each team is coached by a graduate student who is selected prior to the start of the course. The design projects relate directly to the thesis work of the graduate student. This allows the team to be coached by someone who has technical expertise in the project and helps guide the team through the design process. It is this interaction which facilitates the elevation of undergraduate design education to a higher technical level similar to that of funded graduate student research.

The coaching model was used in a junior-level capstone course on materials design detailed in [1]. A similar model was also used in an upper-level interdisciplinary design project course [2] where the faculty serve as ‘mentors’ and coaching occurs concurrently, as opposed to the hierarchical manner discussed in this paper. The details and

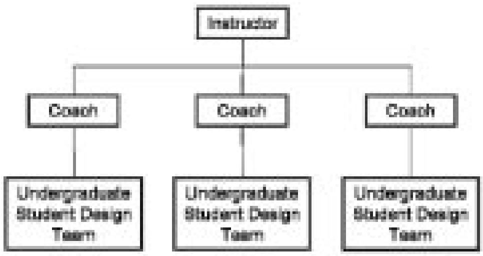

Fig. 1. Hierarchical model for coaching design teams.

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characteristics of the coaching model used in the interdisciplinary design course are reported elsewhere [3]. All students enrolled in both of these courses have been exposed to engineering design through a first-year required design and communication course which they take in their freshman year [4].

The hierarchical coaching model can be related to instructional theories such as Schon's teaching model of 'reflection-in-action' [5] and the 'cognitive apprenticeship' model of instruction [6]. That is, Schon's model suggests that teaching consists of a dialogue between the coach and student where understanding is developed through communication and reflection about the design itself. In addition, the cognitive apprenticeship model of instruction suggests a process of modeling, coaching, scaffolding, reflection and exploration. In cognitive apprenticeship, the teacher models effective practice then observes and coaches students while they perform a similar task. The coaching model described in this paper presents a multiplicative approach of these two educational theories. The involvement of graduate student coaches enables the instructor to influence a greater number of undergraduate students. These theories highlight the advantages of using a hierarchical coaching model in engineering design education.

MODEL IMPLEMENTATION

The materials design course is comprised of lectures, computational labs, homework, a midterm and a final design project. The homework and midterm evaluate the students' understanding of what has been taught in the lectures and labs, and constitutes 40 per cent of the final grade. The primary goal of the course is to teach design practices grounded in materials science through active learning in a group design project and, therefore, 60 per cent of the final grade is derived from a composite final design project grade. To determine this grade, students submit a project proposal midway through the course and deliver a final project presentation and report at the end of the course.

All undergraduate students participating in the class must be enrolled in the lecture. The lecture provides fundamental technical understanding of the concepts and principles of the materials design methodology used by practicing engineers. It also serves to engage and prepare students for the computational labs and design project. Case studies are presented to analyse the process of arriving at possible design solutions in the context of the undergraduate design projects. The case studies highlight industrial-orientated design projects and enhance the relevancy of the scientific principles learned in the lecture to solving real-world design problems. The lecture is prepared and taught by the instructor, and classroom assessment is performed through the use of a midterm. The lecture emphasizes key concepts and enables interaction between the instructor and undergraduate design teams, although the principles learned in lecture are commonly reinforced by the graduate student coaches.

The computational laboratory allows students to apply theoretical concepts learned in lecture in an active, hands-on environment. The goal of each laboratory session is to familiarize students with computer applications commonly used in materials design for future use in their respective projects. Software packages include the Cambridge Engineering Selector (CES) developed by Ashby [7, 8], ThermoCalc software system developed by the Royal Institute of Technology [9] and Computational Materials Dynamics (CMD) developed by QuesTek Innovations. Lab work is done individually by the student and the level of understanding is evaluated using homework. Laboratory instruction is primarily provided by a graduate student fulfilling the dual role of a teaching assistant and graduate student coach. It is the course instructor who is charged with the responsibility of coordinating coherency between the lectures and laboratory sessions.

During the quarter, the instructor assesses the progress of each design team in meetings with the graduate student coaches. Meetings provide a venue where the technical details of the project can be discussed between the instructor and graduate student coaches. The coaches in turn meet their design teams to discuss the technical details, thereby following the multiplicative/hierarchical nature of the model. Meetings between the coaches and design teams take place in and outside class.

Approximately one class a month is devoted to in-class coaching sessions where the undergraduate students are separated into their respective design teams with their coach. These sessions provide an informal, supportive atmosphere where information from the instructor can be passed to the design teams via the coach. The coach provides a clear assessment of the team's progress and encourages questions, roundtable discussions and participation by all members of the undergraduate design team. The coach also sets clear, attainable goals and deadlines to keep the team on schedule. This helps the team to set a good pace so that the team does not run out of time at the end of the course. In-class meetings are typically followed by a series of outside meetings amongst the undergraduate team members.

The final assessment of design teams occurs at the end of the quarter. Each team makes a 30-minute presentation which is accompanied by a final report. The instructor evaluates the team's performance and issues a team grade.

DESIGN PROJECTS

Descriptions of two design projects used in the materials design course are listed in Table 1. These

Table 1. Examples of design projects

Project Name	Project Goal
Blastalloy	Design a high performance steel for anti-terrorism blast protection.
Terminator 4	Design a high specific-strength self-healing magnesium-based alloy composite for UAV applications.

projects also represent ongoing government and industry funded programmes. Each team was coached by a graduate student who is performing research in that area. This allows the course to leverage the existing computational and human infrastructure available at the university.

The goals of the Blastalloy project were based on the CyberSteel 2020 project focused on developing ultrahigh toughness plate steels for blast-resistance naval hull applications. The project was funded by the Office of Naval Research (ONR) 'Naval Materials by Design' Grand Challenge. In collaboration with freshmen and upper-level interdisciplinary students, an undergraduate design team coached by a graduate student designed and built a pressurized water blast testing chamber based on numerical blast simulations performed by a design team in the previous quarter.

The Terminator 4 project leveraged an ongoing research project utilizing a graduate student coach funded by the National Aeronautics and Space Administration (NASA) to develop a high specific-strength magnesium-based alloy composite for aerospace applications that can self-heal. Utilizing computational thermodynamics software, the team designed a high performance magnesium-zinc-aluminum alloy with thermodynamically compatible shape memory alloy (SMA) wires that demonstrates yield strengths greater than a commonly used magnesium-based alloy, AZ91. The team performed interfacial testing to characterize the effects of reinforcement surface modifications and demonstrated the feasibility of adding yttrium to the matrix for self-fluxing.

This successful implementation of this model in the undergraduate curriculum has led to national recognition. The students participating in the Blastalloy and Terminator 4 design projects were the winners of the 2004 and 2005 national TMS-AIME (The Minerals, Metals and Materials Society of the American Institute of Mining, Metallurgical and Petroleum Engineering) undergraduate design competition. These experiences reflect and represent the elevated knowledge level and problem solving skills that can be developed with the implementation of this model.

Method

The purpose of our data collection was to understand the project and learning needs of upper-level undergraduate design teams and to characterize the nature of guidance necessary to effectively implement the hierarchical coaching model. We used a qualitative approach for collecting data to determine the impact of our coaching model, and to understand the mentoring experience from both the students' and coaches' perspective.

We interviewed six of the graduate student coaches and two undergraduate students to obtain feedback on the role of the coach, the challenges that each side faced and strategies that were utilized to move the project forward. The coaches were asked the following questions:

- What has been your experience as a coach?
- What has been challenging about coaching the design teams?
- What help do students seek from you?
- How might coaches be better prepared to coach the undergraduate teams?

The undergraduates were asked similar questions but they were tailored to the design team experience. The questions were selected to elicit general details about the mentoring/coaching process and to reveal any issues faced by graduate/undergraduate students in order to better inform our coaching model. Responses from this exploratory study provide insights into how the hierarchical model was implemented, and how it may be improved for future applications.

The responses to each of the questions were reviewed in order to characterize the types of responses the students and coaches generated. All responses were read to identify common themes. This method of analysing qualitative data reflects the iterative tradition of qualitative research corresponding with the grounded theory approach of Glaser and Strauss [10] and the strategies for analysis of Miles and Huberman [11].

Results

The study presented in this paper is preliminary, focusing mainly on responses from graduate student coaches on their coaching experience in the materials design course during the Spring 2007 quarter or earlier.

The following subsections provide representative responses regarding two broad categories that are directly relevant to the model. The first category, 'mentoring to achieve a high technical level', presents general comments about the mentoring process specific to our model and the second category, 'motivation', is a main theme that emerged from the data. The quotes preceded by a 'C' are from the coaches while those preceded by a 'U' are from individual undergraduate materials design team students.

Mentoring to Achieve a High Technical Level

It has been previously stated that the high technical level of undergraduate design team is fostered by the graduate student coach who is considered to have technical expertise on the project. This can be seen in the following responses by undergraduate design team members and a graduate student coach:

(U) ' . . . [projects in the materials design course] which are very sophisticated and hard to understand, it is really necessary to have a mentor [coach] because most of us [the undergraduate design team] . . . didn't know what to do. The mentors [coaches] really helped us try to figure out the whole goal of this project.'

(U) ' . . . at first, because we [the undergraduate design team] didn't know anything, our mentor [coach] guided us . . . but once we knew what we were trying to do, everyone [the undergraduate design team] was self-motivated to figure out the models . . . equations . . . and data for the system, and now it seems like the mentor [coach] is almost useless . . .'

(C) ' . . . by the end, they know as much as we do . . . their learning curve is always very steep . . . by the time they [the undergraduate design team] end their project, they are at such a good level. They are so confident about the project that is it amazing at how much they learned in such a short period of time.'

Furthermore, while commenting about the elevation of the undergraduate design team experience to graduate level research, a graduate student coach indicated that the flow of information during the project is bi-directional, benefiting multiple participants in the hierarchy.

(C) 'A lot of times the students [undergraduate design teams] are able to work on smaller side projects that you [the coach] may not necessarily have time to work on or it may not be the main objective of your thesis research. Sometimes on the smaller projects, the undergraduates find interesting phenomenon or some scientific thing that maybe needs to be further looked into and that helps out the coaches in their research and kind-of provides feedback on where they should go with their [the coaches] own research.'

One interesting finding is the critical role that the instructor plays in the hierarchical model. Our original assumption was that the instructor's role is minimized through the use of graduate student coaches. The data reveals that the graduate instructor's role is minimized through the use of graduate student coaches. To advance the project, quite often the existing technical knowledge threshold must be increased. This forces the graduate student coaches to expand their knowledge and expertise. As one coach stated,

(C) ' . . . [the projects] push the boundaries of the coaches' knowledge.'

Our findings suggest that the coaches look to the instructors, who are considered technical experts, as mentors for technical advice on how to meet the specific project goals that are outside of the area of their expertise. This need for mentorship is captured in these comments by graduate student coaches, who stated:

(C) '[The instructor] has a vision that is not available to the graduate students.'

(C) 'There are a lot of things I need to know. It is all in [the instructor's] head, I feel like [the instructor] knows it's possible but I don't . . . I need to get to that point before I could explain to other people what it is all about.'

This technical knowledge is then translated and transferred to the undergraduate design teams.The following statements were made by four graduate student coaches in response to question about the needs of the undergraduate design teams.

(C) 'I think that they [the undergraduate design team] really just want to know step-by-step, what do I do, where do I start, what am I looking for?'

(C) ' . . . they [the undergraduate design team] know that coaches are pretty much critical to the success of your project.'

(C) ' . . . we [the coach] tell them how, what machines you [the undergraduate design team] need to use and how to use them. We teach them, we train them on that 'cause they have to use it.'

(C) 'I [the coach] think a lot of it relies on coaches to explain new concepts.'

Motivation

In addition to the instructor's critical role in the hierarchy, motivation also plays a vital role and occurs through several mechanisms. One mechanism is the connection of project goals with a societal need. Project goals demonstrate the significance and relevance of the project in a broader context and shows that what is being learned is worthwhile and intrinsically valuable. The following quotation was from an undergraduate materials design student working on a project to improve the fatigue performance in shape memory alloy stents. Their comment is in reference to a team trip to a local hospital to see a surgeon deploy a stent in a patient.

(U) ' . . . we [the team] were all standing around and we could see like X-ray vision, how the stent alloy goes in and expands and like it opens up the blood vessel . . . First of all it was cool, second of all, wow, we are actually working on a project that could be used in a surgical room. That motivated all of us to like just work on this and try to improve the fatigue limit which is our project for this quarter.'

Another mechanism is the relationship of the project goals to the thesis research of the graduate student coach. This provides motivation for the graduate student coach to advance the knowledge level of the project which will in turn help them to complete their thesis. The following quotations are from graduate student coaches who have served as coaches on several design teams. These statements were in response to a question asking them to explain their coaching experience.

(C) ' . . . we [the coach and the undergraduate design team] have the project that I'm working . . . is directly related to my own Ph.D. thesis so it is much easier for me.'

(C) ' . . . it is really easy for me to guide students [the undergraduate design teams] because I'm more knowledgeable, I guess, at different things they need to know for their project.'

Meanwhile, graduate students interested in pursuing academic careers are motivated by the teaching experience as seen in the following quotations by two graduate student coaches.

> (C) 'I think it is a good teaching experience, mentoring experience, it does take a significant amount of time but if that is your goal and your are interested in teaching and mentoring, I think it is a satisfying experience.'

> (C) ' . . . it's what I want to do after research, after industry, is working like, be a high school teacher, just to be like 50 year old crazy high school teacher that blows up things in the chemistry lab. . . . I [the coach] find myself teaching a lot, I think a lot of it like intimate teaching experience.'

On the other hand, this experience provides an impression of graduate school for undergraduate students. This was observed in the following two quotations from a graduate student coach and an undergraduate materials design team member, both of whom participated on separate design teams.

> (C) ' . . . a lot of times they [the undergraduate design team members] ask me about grad school, what is grad school like, is this typical of a grad student that they have to learn with undergrads . . .'

> (U) 'One of the girls [an undergraduate design team member] was talking about how it must be hard for the grads [the coaches], like she doesn't want to be a graduate student because it is like, they can try all these different directions and you work on a project for four years and like it is not even complete . . .'

The graduate student coaches also play a critical role by motivating the undergraduate design team through the use of constant encouragement. Encouragement can occur through several mechanisms such as recognition and establishing confidence but also through a personal connection between the coach and the team. This sentiment is reflected in the following comments by an undergraduate design team member and various graduate student coaches:

> (U) ' . . . [the coach] is needed there for guidance issues and trying to figure out what we [the undergraduate design team] need to do but to do that effectively, I think . . . for the mentor [coach] to be more friendly to us and like act as a friend versus a grad. student who is just doing this for like payroll or something like that . . . I think that personal connection is really important for a mentor [coach] to have . . . "We [the coach and undergraduate design team member] play soccer together . . . that is pretty cool." '

> (C) ' . . . getting them [the undergraduate design team] passionate and interested in what is going on and actually understand what is going on is really the difficult part.'

> (C) 'I think the most important thing, the part of success, is to bond really well with the team members and from the very first I [the coach] make sure that they [the undergraduate design team] are comfortable . . .'

> (C) ' . . . a lot of it is motivation because I [the coach] think . . . people work better, design better when they understand the motivation of their project . . . because motivation itself is a way to get people excited about doing it [the project] . . . it is a way to get them [the undergraduate design team] to feel like they are doing something worthwhile.'

DISCUSSION

Benefits occur at each level in the model. Minimizing the interaction between the instructor and undergraduate students gives the instructor more time to focus on the lecture and thorough assessment of design projects, meanwhile influencing a greater number of students. The undergraduate students benefit by having a technically knowledgeable project coach whose expertise directly relates to the design project. The coach can provide greater individualized attention: teaching hands-on experimental techniques, providing access to resources and a sounding board for design ideas. Meanwhile, the coach can help the team set realistic goals and help the students with time management. Undergraduate students can feel free to express their ideas, concerns and questions while receiving feedback and instruction in an informal and supportive environment. Since work of the undergraduate design team is closely tied to the thesis work of the graduate student, progress of the project can provide valuable information on specific aspects of their research. Graduate student coaching also provides the opportunity for modelling academic career paths for those undergraduate students interested in pursuing a graduate degree.

Coaching provides a means of professional development for the graduate student. Graduate students receive sound mentoring and feedback from the instructor on the technical aspects of the project and developing effective coaching skills. Furthermore, coaching can provide graduate students with experience in supervising researchers. To enhance the professional development of gradate student coaches, workshops focusing on the skills needed to be an effective coach could be implemented. In addition to providing support, the workshop would encourage and reinforce the use of sound coaching and teaching practices.

CONCLUSIONS AND FUTURE WORK

The hierarchical coaching model presented in this paper suggests a method to increase the level of technical depth in undergraduate design teams through the use of graduate student coaches. A graduate student coach whose thesis research directly relates to the design project creates successful design teams while minimizing the need for personalized attention from the instructor. While providing a good role model for undergraduate students, graduate student coaches gain valuable experience in teaching and supervising researchers. The successful use of the hierarchical coaching model can be beneficial to faculty, students and institutions.

Since the involvement of graduate student coaches is vital to the effectiveness of the hierarchy, we will study the potential impact of including features such as coaching workshops for graduate student coaches. This will provide a solid framework to build a coaching model which will benefit all participants in the hierarchy.

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