Supporting Students' Technical Innovation in Capstone Design: Insights into the Human Connection*

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Educating and guiding undergraduate engineering design teams that perform at a high technical level in innovative design projects can be accomplished by using a hierarchical coaching model. The coaching model discussed in this paper incorporates the use of graduate students as coaches to mentor successful design teams. This paper discusses the results of a study performed on undergraduate engineering design teams and their graduate student coaches during two consecutive years of a capstone design course. The results of this study reveal two underlying themes that can be attributed to the successful execution of this model. One theme is the development of human connections between the coach and undergraduate design team. Another theme that arose was the need for mentorship of the graduate student coach, especially on technical management skills. Both themes enable the design team and coaches to become involved in the design project for reasons beyond that of just understanding fundamental engineering concepts and solving complex problems.

Keywords: coaching; capstone design; teams and teamwork in design; design pedagogy; engineering design; technical management

1. Introduction

A coaching model has been developed to address the issue of technical depth in fostering the culture of innovation in undergraduate education by utilizing graduate student coaches. Traditionally, coaches differ from team leaders in that coaches do not hold a stakeholder position in the design process. Stakeholders are typically preoccupied with project outcomes and can include the instructor, client, team leader and members. Instead of being concerned about project outcomes, coaches are primarily focused on the design process and keeping the team on-track [1].

This coaching model was instituted in a junior-level undergraduate capstone materials design course taught at Northwestern University. The design projects in the course ranged from externally-funded academic, graduate-level research to industrial-sponsored projects. In this particular study, a common theme among the graduate student coaches was their interest in pursuing industrial careers. This theme was identified and then used to develop leadership and coaching programs focused on technical management, thus creating a greater personal connection between the graduate student coach and their design teams.

This paper will also discuss the critical role of interpersonal relationships in developing successful design teams. This enables the team to become involved in the design project for reasons beyond that of technical understanding. It is believed that this creates a comfortable environment that fosters divergent thinking. Analysis will be performed by evaluating and contrasting the coach's and design team's perception of critical coaching activities, having coaches critique their own coaching behaviors, and finally, defining the role of motivational forces in supporting technical innovation in capstone design teams.

In order to fully assess and interpret the personal nature of coaching, this paper will provide an overview of the current coaching literature, a detailed description of the context in which the study was performed and analysis of survey data, and follow-up activities that were undertaken to enhance the efficacy of the model.

2. Literature on coaching design teams

The majority of research about coaching is related to training and focuses primarily on individual skill acquisition [2]. Although very little has been published on coaching design teams, there are some exceptions. In the existing literature, studies [1, 3] have clearly suggested that a major coaching function that facilitates the proper development of design teams involves addressing interpersonal

issues. Studies by Reich *et. al* [1] suggest that coaches not only assist the team in problem solving issues but they also provide moral support. A similar relationship was described by Ekwaro-osire [4] in which teachers/facilitators develop a close, mentoring-type of relationship with a capstone design team. Since mentoring has traditionally been used to describe a one-on-one relationship, the relationship described by Ekaworo-osire was coined the term 'pan-mentoring' to describe the multiplicative, 'one-on-team', nature of this particular type of mentoring. The typical tasks of a pan-mentor include scheduling frequent meetings and acting as a reassuring, encouraging, and knowledgeable sounding board to promote self-regulated learning. A pan-mentor is basically a unique mix between a personal advisor and knowledgeable sounding board.

The personal nature of coaching design teams was revealed in a previous qualitative coaching study [3]. Our research determined that the role of coaching runs deeper than just technical mentoring and helping the team with time management issues, it was discovered that motivation also plays a key role in facilitating efficient and effective innovative design teams. The results from the study suggest that coaches play a critical role in motivating the design team through constant encouragement. It was shown that encouragement occurs through several mechanisms such as recognition and establishing confidence. This allows the students to feel free to express their ideas, concerns and questions while receiving feedback and instruction in an informal and supportive environment. It was concluded that coaching capstone design teams goes beyond the technical issues and that a personal connection plays an important role. The specific details about this coaching study are beyond the scope of this paper and additional details can be found elsewhere [3, 5].

3. Coaching model

The model used for coaching design teams can be found in Fig. 1 [3]. The structure of the model and
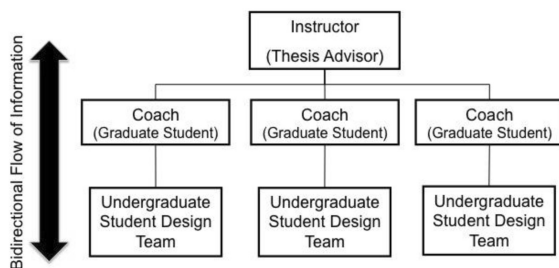

Fig. 1. Hierarchical model used in the study for coaching design teams [3].

relative positions of the key players (instructor, coaches and design teams) are ordered to reflect the nature of the knowledge levels (expert, intermediate and novice) at the initial stages of the project. At the highest level of the model is the instructor. Information initially flows from the instructor to the lower levels of the hierarchy. However, as the project progresses, the technical knowledge levels of the design team increases and information is then fed back up through the branches of the model. This bidirectional movement of information reduces the rigidity of the structure as the model morphs into a horizontal arrangement where the technical level of the undergraduate design team approaches that of the coach. Additionally, it is critically important to distinguish this model from one that utilizes teaching assistants at a similar hierarchical level as the coaches in the model. An important, distinguishing characteristic of the coaches in this model is the relationship between the thesis research of the graduate student coach and the topic of the design project. Previous results [5] indicate that the undergraduate students benefit from having a coach that is a technical expert on the project. As for the graduate student coaches, the benefit to coaching students on a topic related to their thesis work is that it allows them to explore smaller side projects related to their thesis that they may not necessarily have time to work on. Furthermore, since the coaches are already technically versed in the rigors of the project, it removes the need to spend a significant amount of time on background research or other activities typically associated with learning a new project.

This coaching model can be related to the instructional theories such as Schon's teaching model of 'reflection-in-action' [6] and Collins *et al.* [7] 'cognitive apprenticeship model of instruction.' 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 cognitive apprenticeship, the teacher models effective practice then observes and coaches students while they perform a similar task. The unique characteristics of Collins' model that distinctively define the hierarchical coaching model include scaffolding, reflection, encouragement, modeling and feedback.

4. Course description

The coaching model described in this paper was used in a junior-level capstone materials science and engineering course called Materials Design. The course is offered in the spring quarter at Northwestern University and is comprised of lectures, computational labs, homework, exams, and a final

design project. The primary goal of the course was to teach design practices grounded in materials science through active learning in a four to five member group design project. A detailed description of the typical design projects offered in the course is given by Olson [8, 9].

Prior to the beginning of the quarter, the instructor determines the design projects that will be offered in the course. The design projects represent ongoing government- and industry-funded university programs. After project selection, the instructor assigns graduate students who are currently performing research in an area related to the design project, as a project coach for that particular team. Thus, the design projects relate directly to the thesis work of the graduate student coach. This allows the team to be coached by a person who has technical expertise on the project. The high level of research expertise offered by the graduate student coach facilitates the elevation of undergraduate design education to a technical level of that which mirrors the graduate student coach.

This particular study assessed coaching and team behaviors during the Spring 2008 quarter. Prior to the start of the quarter, all of the design team coaches participated in a coaching workshop. The goal of the workshop was to provide the coaches with a solid mechanistic framework for implementing coaching strategies during the quarter. The graduate student coaches that participated in the workshop included those with previous experience, coaching at least one design team, and those with no prior coaching experience. During the workshop, the coaches were first familiarized with the hierarchal coaching model, which included providing the coaches with hierarchical coaching literature from Manuel *et al* [3], and then through group discussion, the graduate student coaches were asked to provide recommendations for activities that could be used in the course to facilitate the success of their design teams. From this discussion the main common strategies proposed by the graduate student coaches were: 1) early team formation/early coaching assignments; 2) reading previous team's reports; and 3) brainstorming sessions. Each strategy was then systematically executed during the quarter. Further details of this study can be found in Manuel *et al* [5].

5. Research methodology

At the conclusion of the Spring 2008 quarter Materials Design course, graduate student coaches and undergraduate design team members were asked to complete a survey instrument developed by the authors. Additionally, graduate student coaches were interviewed to determine the effect of their coaching experience on their long-term career goals, a self-assessment of their performance as a coach, and the efficacy of the coaching workshop.

The purpose of the survey that was given to both graduate student coaches and undergraduate design team members was to study the response of both the coaches and design team members when asked to characterize the importance of specific coaching activities. For the graduate student coaches, one additional set of questions were asked to gauge the importance of motivational forces, outside of that provided by the course instructor, in coaching undergraduate design teams. Motivation appeared as a critical role in the Spring 2007 study [3], thus these specific survey questions sought to further define these forces. Scores for each activity were measured on a four-point scale and were studied through the means and standard deviations. The scores 1, 2, 3 and 4 were used to analyze the relative importance of various activities by the coaches and design team members, with 1 = 'Not Important', 2 = 'Somewhat Important', 3 = 'Important', 4 = 'Very Important'. To analyze the data, sample means were calculated for both groups, the coaches and design team students. The data includes responses from 23 undergraduate students and 3 graduate student coaches.

At the end of the survey, the undergraduate students were asked one free-response question to allow the students to specify activities that were not asked in the earlier part of the survey that they deemed to be important to the success of the design team. Specifically, the students were asked:

(1) What other course activities are important to the success of your design team? And why?

For the graduate student coach's survey, two additional free-response questions were asked regarding their post-graduate school career plans. The purpose of these questions were to evaluate one of the themes from the previous Spring 2007 study that indicated that the coaching experience provided a means for professional development [3]. In particular, that coaching provides an avenue for gradate students to experience the role of supervising other researchers. Each coach was asked the following questions:

(1) Please indicate your post-graduate school career goals.
(2) Did your career goals change as a result of coaching a design team?

Lastly, the goal of the graduate coach's interviews was to gain deeper insight into the coach's perception of their performance during the quarter while providing feedback for future coaching workshops.

Table 1. Summary of questions asked during the interview with graduate student coaches

Question Order	Question
1	What were your goals as project coach? How, if at all did your goals differ from the instructor's goals?
2	When you started the course, how confident were you that your project would be successful?
3	Do you feel that you are meeting the expectations of the design team? Why or why not? Are there things that have hindered your ability to do this?
4	Do you feel that you are meeting the expectations of the instructor? Why or why not? Are there things that have hindered your ability to do this?
5	What if anything, did you get out of the coaching workshop?
6	Do you have any suggestions that would enhance the content of future workshops?

A total of 3 graduate student coaches participated in the study and each response was evaluated to identify common themes. The method for analyzing the qualitative interview data was derived from the grounded theory approaches of Glaser and Strauss [10] and the strategies of analysis of Miles and Huberman [11]. Table 1 summarizes the types of questions that the coaches were asked during the interview.

6. Results and discussion

One objective of the study was to characterize the importance of various coaching activities, both from the perspective of the graduate student coa-ches and the undergraduate design team members. Fig. 2 shows participant responses.

Analysis of the quantitative survey resulted in the identification of four coaching activities that indicate significant, statistical differences between the mean scores of the graduate student coaches and the undergraduate design team students at an alpha level of 0.05 (these activities are indicated in Fig. 2 by the double asterisks **). These were the accessibility of the coach, commitment level of the coach, coach's computational or analytical knowledge and personal connection with the design team. Of those four activities, personal connection with the design team was the only coaching activity that was rated higher by the undergraduate design team students
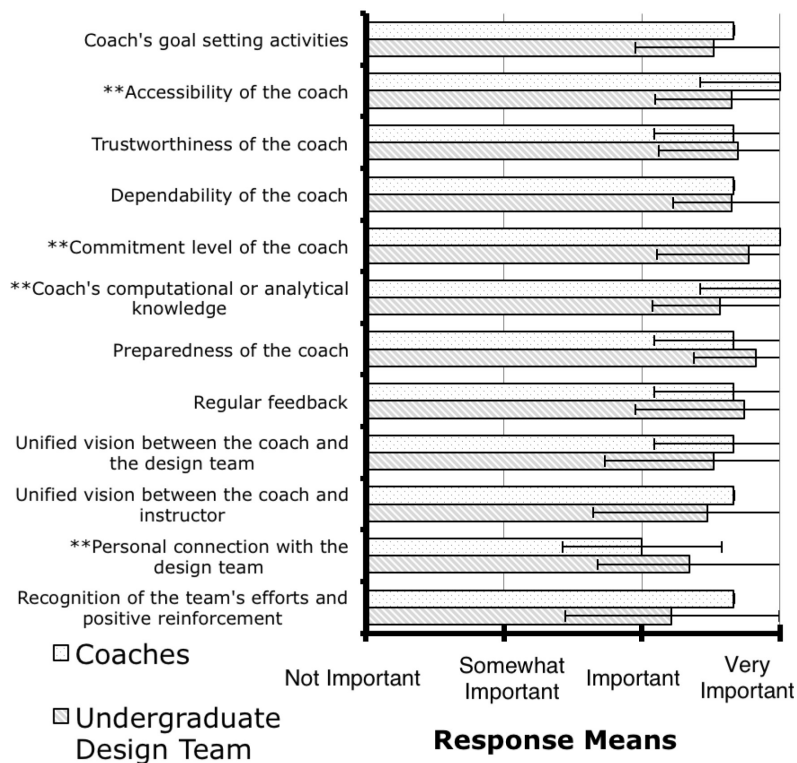

Fig. 2. Response means from graduate student coaches and undergraduate design team members. The asterisks (**) indicate questions in which there were statistically significant differences between the mean scores of the undergraduate design team members and graduate student coaches (t-test, $\alpha = 0.05$).

(mean = 3.4) than the graduate student coaches (mean = 3.0). This may be an indication that the undergraduate design team students are looking for an academic experience that goes beyond gaining technical knowledge and skill, and includes interpersonal relationships.

Without further and additional studies, the results from this study are not conclusive. One possible issue affecting the results relates to the statistically low number of coaching participants in the study (n = 3). Increasing the sample size may affect the normality of the population, changing the validity of the t-test. However, it is important to acknowledge that the purpose of the study is to understand how various attributes of the coaching model affect learning and team performance, not to find statistical significance.

Another issue is that the survey only analyzes how the participants perceived the activity in question. The survey does not analyze if the activity was implemented in an effective manner. This may lead the participants to under- or over-rate a particular activity if not performed effectively. This issue may be avoided in future studies by allowing the students to participate in activities involving personal reflection.

When evaluating the free-response question on the undergraduate design team survey, a number of students indicated avenues and modes of communication as an activity important to the success of their design team.

Responses included those, such as:

[Student 1] 'Group coaching sessions.'
[Student 2] 'Frequent team meetings.'
[Student 3] '(Weekly meetings) outside of class— keeps progression of project on track . . . In-class meetings served the same purpose . . .'
[Student 4] 'Good communication.'
[Student 5] 'Meeting with advisors to stay on track with project objectives.'
[Student 6] 'Frequent team meetings . . .'

Although future studies will need to be performed, the evidence does indicate that interpersonal relationships between the coach and design team play a vital role in facilitating efficient, innovative design teams. In connection with the responses provided in Fig. 2, it appears that undergraduate students are looking for an experience that is more than just an academic exercise, that emotional intelligence also plays a significant role.

Another objective of this study was to characterize the role of motivational forces in an individual's commitment to their team. For example, in addition to evaluating specific coaching activities, each coach was asked to quantify their motivation for participation in the course. Coaches were asked to rate the relative importance of the following three reasons that may have motivated them to serve as a graduate student coach: connection of the project goals with their graduate thesis, their personal career goals, and the need for teaching experience. The need for teaching experience ranked the highest (mean = 3.7) followed by connection of project goals with their graduate thesis (mean = 3.3) and then by personal career goals (mean = 3.0).

Although, the ranking of 'the need for teaching experience' appears high, when asked on the same survey about their post-graduate school career goals, only one of the three coaches indicated 'academia' as a pathway of interest. The other two coaches indicated an interest in industry or an industrial career in a non-engineering related field. Additionally, when asked if their career goals changed as a result of coaching, two graduate students indicated 'no' and one student indicated no response. Initially, from the Spring 2007 study [3] and the ranked survey responses, it appeared that the graduate students, based on their coaching experience, were looking to model an academic career. However, it now appears that the graduate student coaches are looking more for a managerial experience. This has been further solidified by Feinberg [12] who noted the sensitive interplay between coaching and technical management. His study of 20 design teams at Northwestern University noted that during the execution portion of the design process, coaches focus primarily on establishing order while monitoring data and results. This occurs concurrently with coaching activities such as delegating tasks, motivating the team to carry out the design plan, and troubleshooting problems. This was highlighted by the authors as a significant theme across all of studies of Northwestern design coaches and was then used to institute technical management workshops for coaches in the following years.

Lastly, analysis of the interview responses from the graduate student coaches further solidified the common theme of strong interpersonal relationships and the need for teaching managerial skills in future coaching workshops. One coach noted their inability to manage the teams to promote research independence:

[Coach 1] '. . .the team seems to be too dependent on me to do things. Learning that guiding students to be more independent is part of the process.'

The other coaches remarked on the use of managerial tools, to facilitate the success of their design team:

[Coach 2] 'I have created schedules and timelines and made lists of what I expected from the team

and they have asked me questions and delivered everything (I) asked for in a timely manner.'

[Coach 2] 'I realized the need to reinforce project goals over and over to make sure students understand what/why they are doing certain things for the project. I tried harder to relate to them on a personal level.'

[Coach 3] 'My team meets at least once a week, every week. I believe these meetings are crucial to their understanding of the material as it gives (the students) a chance to ask me questions about any part of the project and they take advantage of it.'

7. Summary

This paper presents quantitative and qualitative data collected from both undergraduate student teams and graduate student coaches. The data suggest there are several activities that lead to effective coaching from both the undergraduate design team's and coach's perspective. Specifically, students and coaches equally agreed that setting goals, providing feedback, and being dependable are important. However, we found that students rated having a 'personal connection' with the team/coach significantly higher than the coaches, thereby suggesting the importance of the human connection for students when working on advanced engineering design capstone projects. It is also interesting to note that students rate behaviors such as trustworthiness and commitment level even more highly than the coaches' technical or computational knowledge. The responses from this study provide insights into emotional undertones that support students when developing technically challenging and innovative solutions in capstone design teams. Having strong interpersonal skills as well as coaches seeking managerial experience suggest the need to provide opportunities to support the development of these skills. Based on our prior findings we implemented specific classroom instruction and a workshop to help develop proper communication and relationship skills. Communication, teamwork, and interpersonal skills are important attributes that undergraduates and graduate students will use throughout their careers. Furthermore, based on our findings these same attributes are important for mentoring undergraduate engineering student design teams on technically challenging capstone projects.

References

1. Y. Reich, G. Ullmann, M. Van der Loos and L. Leifer, Coaching Product Development Teams: A Conceptual Foundation for Empirical Studies, *Research in Engineering Design*, **19**(4), 2009, pp. 205–222.
2. J. R. Hackman and R. Wageman, A Theory of Team Coaching, *Academy of Management Review*, **30**(2), 2005, pp. 269–287.
3. M. V. Manuel, A. F. McKenna and G. B. Olson, Hierarchical Model for Coaching Technical Design Teams, *International Journal of Engineering Education*, **24**(2), 2008, pp. 260–265.
4. S. Ekwaro-Osire, 'Pan-Mentoring' as an Effective Element of Capstone Design Courses, *International Journal of Engineering Education*, **19**(5), 2003, pp. 721–724.
5. M. V. Manuel and A. F. McKenna, The Role of Coaching in Facilitating Computational Materials Science Education, *The Minerals, Metals and Materials Society (TMS) Annual Conference*, San Francisco, 2009.
6. D. A. Schon, *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*, Jossey-Bass, San Francisco, 1987.
7. A. Collins, J. S. Brown and A. Holum, Cognitive Apprenticeship: Making Thinking Visible, *American Educator*, **6**(11), 1991, pp. 38–46.
8. G. B. Olson, Brains of Steel: Designing Materiallurgists, *Advanced Materials & Processes*, **7**, 1997, pp. 72–79.
9. G. B. Olson, Brains of Steel: Mind Melding with Materials, *International Journal of Engineering Education*, **17**(4–5), 2001, pp. 468-471.
10. B. G. Glaser and A. L. Strauss, *The Discovery of Grounded Theory: Strategies for Qualitative Research*, Aldine Publishing Company, Chicago, 1967.
11. M. B. Miles and A. M. Huberman, *Qualitative Data Analysis: An Expanded Sourcebook.* 2nd ed, Sage Publications, Thousand Oaks, 1994.
12. Z. Feinberg, *Leadership by Design*, Thesis in the Center for Creative Leadership, Northwestern University, Evanston, 2011.

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