Facilitating an Integrated Graduate Research Team in a Complex Interdisciplinary Domain: Preliminary Findings

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ABSTRACT
The ability to work in independent and interdisciplinary teams is increasingly demanded by industry. However, research on interdisciplinary teams in academic settings, whether focused on learning or research, remains scarce. The purpose of this study was to understand how one interdisciplinary graduate research team functions, with the aim of eventually providing recommendations for facilitating similar teams. As part of an ongoing study, this paper presents preliminary findings on the ways in which several bodies of literature on teamwork can be used to understand graduate research teams. Empirical data consist of observations and interviews. Positive interdependence, a team mental model, and team empowerment were found to be necessary for success of this interdisciplinary team. Literature from industry and undergraduate settings provides recommendations on how to develop these features; however, the graduate education context complicates those recommendations and entails tensions and tradeoffs.

Keywords
Interdisciplinary, graduate, teamwork, team mental model, positive interdependence, team empowerment

1. INTRODUCTION
Around the world, the ability of engineering graduates to work in independent and interdisciplinary teams is increasingly demanded by industry (Borrego & McNair, 2009; Curtis & McKenzie, 2001; Patil & Codner, 2007). Interdisciplinarity and independence are important because the global business environment now demands the ability to work across multiple borders with flexibility and adaptability (Borrego & McNair, 2009) and to do so with increasing autonomy (Wageman, 1997). The trend toward autonomy is bolstered by studies showing greater creativity (Williams & Yang, 1999) and stronger competitiveness (Cohen, Ledford, & Spreitzer, 1996) as outcomes for more independent teams. Consequently, interdisciplinary and autonomous teamwork is increasingly identified as an important new direction for both undergraduate (McNair, Newswander, Boden, & Borrego, 2011; Zafft, Adams, & Matkin, 2009) and graduate education (Golde & Dore, 2001; Nerad & Heggelund, 2008; Nyquist & Woodford, 2000; The Woodrow Wilson National Fellowship Foundation, 2005; Wulff, Austin, & Associates, 2004).

There are many challenges to realising this ideal, however. Due to the complexity and diversity of skills required, engineers are not yet sufficiently trained to work in teams at either the undergraduate or graduate level (Shuman, Besterfield-Sacre, & McGourty, 2005). Interdisciplinary teams pose additional challenges, due in part to conflicts between interdisciplinarity and current university structures. Particularly in the United States (Abbott, 2001), the boundaries between traditional disciplines stand as a barrier to both professor (Amey & Brown, 2004; Borrego & McNair, 2009; Committee on Facilitating Interdisciplinary Research, 2004) and graduate student (Holley, 2009) participation in interdisciplinary research and teaching. Universities are organised along traditional disciplinary lines (Gumport, 1993, 2005), and graduate students are socialised to the norms of these disciplines in order to ensure their career success (Turner, Miller, & Mitchell-Kernan, 2002; Walker, Golde, Jones, Bueschel, & Hutchings, 2008). Furthermore, tensions over the ideal level of independence are keenly felt by graduate students (Gardner, 2007), and teamwork, which is so highly valued in engineering and science (Borrego & Cutler, 2010), adds an important but underexplored facet to those already existing tensions.

One high-profile effort to innovate in interdisciplinary graduate education is the U.S. National Science Foundation’s IGERT funding initiative. Its objective is to establish
“innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries” (NSF, 2010). The team observed and analysed for this paper, which was part of an IGERT grant, represents an important and innovative attempt to incorporate interdisciplinary team research into doctoral work. Large interdisciplinary projects are very complex contexts to study as well as to work in. The team described here is working very hard to innovate and succeed in uncharted terrain.

This analysis presents preliminary findings that are part of an on-going research project. Other findings have been reported elsewhere (Beddoes, Borrego, & Jesiek, 2011). The broad questions guiding our work are: 1) What factors promote or detract from student satisfaction, degree attainment, and interdisciplinary integration of an interdisciplinary graduate research team? 2) What recommendations can be reached for faculty behaviour and practices? 3) How can the constraints imposed by the graduate education context be successfully negotiated to develop graduate students as independent, interdisciplinary researchers and team members? The purpose of this preliminary analysis is not to comprehensively answer each of these questions, but rather to present findings on how we have begun to address them by incorporating several key bodies of literature on teamwork. There is a large body of literature on teams in management that is of relevance to engineering education, and we use several strands of it to illustrate its usefulness in addressing these questions.

2. METHODS
This study was conducted at a large public research university in the Southwestern United States. IRB approval was obtained at both the researchers’ and participants’ institutions. The team observed was part of an interdisciplinary graduate program that spans several traditional departments as well as a new interdisciplinary degree program and is funded in part by IGERT. The team was part of a research unit that focused on a research and development project for physical rehabilitation of stroke patients using mixed media technologies that incorporated audio and visual feedback into physical therapy.

Participants included six doctoral students, two post-doctoral research assistants who recently graduated from the PhD program (referred to as “post-docs”), and two professors who also held administrative positions in the interdisciplinary unit. The six doctoral students (three men and three women) had backgrounds in and were located in departments of engineering, computer science, media arts and sciences, and music. They were in their first, second, third, and fourth years of graduate school at the University.

Data collection consisted of one month of participant observation and interviewing (Fetterman, 2010; Glesne, 2005) in September and October, 2009. One author temporarily relocated to the other university and participated in research group activities for several hours each day. Data collection included observation of team meetings, work at a project test site, and informal work time at the student offices/design studio. Data collection also included approximately 17 semi-structured and informal interviews with graduate students, post-docs, and faculty. Each student was interviewed formally at least once using a semi-structured protocol, which typically lasted between 30 and 60 minutes. Students were also interviewed informally several times a week, in the course of their normal, daily activities. For instance, after a group meeting, the researcher would enquire about what a student thought of something that had just happened in the meeting.

Additionally, the researcher had many opportunities to ask the students questions while they conducted research at their research site. The two post-docs were each interviewed once, for approximately one hour each. Interviews with students and post-docs were not recorded. The researcher took detailed notes. The two faculty members were interviewed together twice, for approximately one hour each time. These interviews were recorded.

While collecting and analysing the data, the authors began with a broad focus on how the team operated, specifically how their interdisciplinary values impacted their behaviours and team processes. Literature on teams from both industry and academic settings was reviewed in order to analyze and illuminate the data. Three particularly relevant topics that helped explain the data were positive interdependence, team mental models, and empowerment. In trying to construct a coherent narrative to describe the observations, the authors realised that there were many divergent team mental models, and students felt disempowered by frequently changing goals. Additional literature on positive interdependence was then included to more fully explain this complex team and to translate the industry-based literature to an educational context. This literature is referenced in the appropriate sections below.

To increase the validity of our results, triangulation (Fetterman, 2010) was used to test sources of information against each other, to collect evidence of team mental models, and to verify information. We also had significant background based on two prior interview visits to the site (Boden, Newswander, Borrego, & Beddoes, 2009; Newswander & Borrego, 2009.) Finally, all participants were given the opportunity to review and comment on this analysis prior to its submission for peer review. There was no disagreement with our results.

3. FINDINGS
In the current paper we draw primarily on three bodies of literature to illuminate some important aspects of our data, namely positive interdependence, team mental models, and team empowerment. While these three concepts do not explain everything that we observed, they were each revealed to be important, and, moreover, they are particularly relevant for this team because of their connections to the faculty members’ goals for this team.

3.1 Positive Interdependence
Johnson, Johnson, and Smith explain that positive interdependence,

exists when students perceive that they are linked with other members of a group in a way that they cannot succeed unless the other members do (and vice versa) and/or that they must coordinate their efforts with the efforts of others to complete a task (1991, p. 16). Although they did not use the term, the faculty members wanted students to develop positive interdependence. They repeatedly said they wanted the students to believe that their work was inseparable from the other team members’. The term they used to describe this outcome was “systems thinking.” As one faculty member explained, he warned students not to make the mistake of thinking they could “solve one problem and solve it all the way without thinking about the whole system because all parts depend on each other.” Elaborating in a follow-up interview on the difficulties of achieving this goal, however, the other faculty member said
that, “It’s normal that [the students] want to get one piece of the project because systems level thinking isn’t taught at [the] undergrad level.” In the case of this team, positive interdependence, or systems thinking, was closely connected to the interdisciplinarity of the team.

Despite faculty members’ aims, however, positive interdependence had not been wholly achieved among all students. Students were asked if they believed their own work could be successful if others’ work was not successful. Four evidenced positive interdependence by replying “no.” One first year student said that yes, it would be possible, and another first year said s/he was not sure. Therefore, students asserted varying levels of positive interdependence. This gap between faculty aims and student beliefs suggests that merely telling students how they should think about their work is insufficient, and other strategies should be used to promote positive interdependence.

3.2 Team Mental Model

Part of the explanation for a lack of positive interdependence can be attributed to the lack of a team mental model. Team mental models (TMM) are shared knowledge structures that enable a team to form accurate explanations and expectations of the task, to coordinate their actions, and to adapt their behaviour to demands of the task as well as other team members (Cannon-Bowers, Salas, & Converse, 1993; Edwards, Day, Arthur, & Bell, 2006; Kozlowski & Ilgen, 2006; Langan-Fox, 2003; Langan-Fox, Anglim, & Wilson, 2004; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Mathieu, Heffner, Goodwin, Cannon-Bowers, & Salas, 2005).

During individual and small group interviews, students and post-docs were asked to draw a diagram of the research project, identifying who was involved and how or where they fit in. There were significant differences among the diagrams. For example, some were missing team members, not all diagrams included all three teams that comprised the research unit, and some were divided into research teams while others were grouped by technical specialties. Not only were the diagrams significantly different—both in terms of who was included and where they were located—but most students seemed uncomfortable with or confused by this exercise. This suggests that they were not accustomed to thinking about the team or larger research unit in which they were situated.

Additional evidence for the lack of a TMM comes from the fact that much confusion and disagreement among the team was observed over who the student team leaders were (or, indeed, if there even were student leaders), how they had been chosen, and what their roles and responsibilities were. This is not surprising given that in an interview the faculty said they never explained these items to all students.

As another example, observations at a group meeting revealed that different students were operating with significantly different assumptions about the direction of the design of the media feedback. Tensions arose because some students thought the media feedback would be screen-based, while others had been working under the assumption that they were moving away from screen-based feedback to other types of interactive feedback. These two divergent beliefs about the feedback meant that the team had been working towards different—and clearly incompatible—goals and expectations regarding the development of the system. Several engineering students thought the feedback mechanism would remain similar to what it had been in the first version of the system. The media students, on the other hand, wanted to produce a different type of sensing mechanism for the feedback, and they believed that the other team members were also interested in this plan. Because one aspect of a team mental model concerns a team’s goals and tasks, this misunderstanding among students can be understood as an instance where the lack of a team mental model caused conflict.

3.3 Empowerment

The lack of a TMM certainly had a negative impact on the team’s empowerment. Empowerment is defined as “increased task motivation resulting from an individual’s positive orientation to his or her work role” (Kirkman & Rosen, 1999, p. 58). It includes beliefs about effectiveness, meaningfulness, autonomy, and impact of one’s work. The faculty were observed trying (but not always succeeding) to give autonomy on the level of day-to-day research and students’ formulation of their research goals, but not on the level of broader goals, decisions, and responsibilities stemming from external pressures such as funding and publishing. To the extent that they delegated responsibilities, goal setting, and decision making to the students it tended to be empowering, and the opposite was true as well.

One example that supports this finding comes from an assignment given by one of the faculty. After a group meeting in which one faculty member became convinced that students needed more guidance, the other developed and sent to students an example of what he called a “scenario” to guide their next research and development steps. The students did not understand the point of the scenario and most decided not to complete it. They reasoned that it would have required more work and they were already satisfied with the direction they were pursuing. This was an instance in which students were disempowered, in terms of motivation and comprehension, by having a goal imposed by the faculty members. It should be noted, however, that the students showed some autonomy by choosing to ignore the assignment. This example represents, in part, a larger frustration felt by students when the faculty intervened with directions, assignments, or goals on a time scale that students perceived to be “after the fact.”

Further evidence of the significant role that empowerment can play came from an interview with one of the post-docs. An outside faculty member had indicated that the team had a reputation within the program as highly functioning and productive. When asked in an interview what he would attribute their high functioning, the post-doc said that, ...at the beginning they didn’t have a lot of faculty guidance, so they evolved a self-functioning structure and a flatness of structure, not a hierarchy, and had not a lot of external constraints. So the direction of the project was under their control, which led them to be motivated. So they had to find a way to converge and work together. Usually the projects are more controlled and directed by professors and there is more pressure and control, which is a detriment to group cohesion.

It can be concluded that students had greater comprehension of the tasks as well as more motivation to complete the responsibilities when they set their own goals because those tasks had meaning for the students. On the other hand, when faculty made research decisions or set assignments, students...
often did not always understand the point and were not motivated to complete them.

4. DISCUSSION
The data reveal that while the faculty had ambitious and innovative goals regarding positive interdependence and empowerment for their interdisciplinary graduate research team, those goals were not fully realised. This can in part be explained by the lack of a team mental model. Given the recommendations from the literature referenced in this paper, strategies can be identified that – if utilised more fully – would likely help accomplish those goals. The strategies include cross-training, peer evaluation, obtaining student input, and group processing. However, because the relevant literature does not come from graduate education settings, there are tensions: implementing these recommendations in graduate education settings can be challenging - given time, disciplinary, and university pressures - and will likely require tradeoffs based on individual faculty’s goals. Such tensions and tradeoffs will be discussed more fully in future work.

High levels of team empowerment correspond to highly productive, happy, and loyal teams (Kirkman & Rosen, 1999), and productive, happy, and loyal students are important for the success of undergraduate and graduate programs, universities, and, indeed, for a field as a whole. The presence of positive interdependence and a team mental model corresponds to effective and successful teamwork, which is important for preparation to work in industry and to solve the challenges of today’s complex world. It is imperative, therefore, that educators and administrators take seriously efforts to increase team positive interdependence, mental models, and empowerment as they advocate the importance of teamwork and interdisciplinarity more generally. As our findings reveal, the absence of positive interdependence, a team mental model, and empowerment leads to team conflict and student dissatisfaction.

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6. REFERENCES


