Special Session - Applying Theories of Interdisciplinary Collaboration in Research and Teaching Practice

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Abstract - **Interdisciplinary research is becoming more widespread, and the ability to function on multidisciplinary teams is one of the ABET criteria each engineering student must meet before graduation. But how can faculty more easily bridge the gaps between disciplines for themselves and their students? Through a series of fun, interactive activities, participants will explore their own past encounters with other disciplines, learn about theories that describe interdisciplinary interactions, and begin to apply some of these principles to the design of an interdisciplinary learning activity. The accompanying interactive session description (paper) describes the motivation for this approach, one theory, and one example application to designing interdisciplinary learning activities.**

Index Terms – cognitive flexibility, faculty development, interdisciplinary, theory

INTRODUCTION

Interdisciplinarity has garnered increasing attention in recent years. Within engineering undergraduate education, arguments for interdisciplinarity have centered around national competitiveness arguments arising from increasing globalization. In order to justify their high salaries, reports such as *Educating the Engineer of 2020* [1] and *Rising Above the Gathering Storm* [2] argue, U.S. engineers must be able to work across disciplines to think creatively and strategically. Similar pressures from industry resulted in "the ability to function on multidisciplinary teams" as an ABET engineering accreditation criterion since the year 2000 [3].

While the engineering education literature (including conference proceedings) is an excellent source of innovative teaching ideas, it is severely lacking in the linkages to prior work [4] that are critical to both scientific research in education [5] and building an identity as a research discipline [6]. In reviewing the engineering education literature relevant to the multidisciplinary teamwork criterion, Shuman and coauthors [7] described exemplary classroom-based teaming experiences. They praised programs that gave students explicit instruction in teamwork processes, rather than simply immersing them in the experiences to sink or swim on their own. There was no mention of the disciplines involved, because in most cases all students were from the same discipline. In programs that did cross disciplinary lines, there was no explicit instruction in interdisciplinary interactions because few theories directly apply without some adaptation.

Thus, we argue that in light of the importance of interdisciplinary teamwork and the lack of models to guide instructional design in engineering education, the time is right for conference sessions and publications to introduce the community to theories related to interdisciplinary work. This interactive session summary describes one theory and a related instructional design example guided by the theory. Others will be presented at the session.

LITERATURE REVIEW: COGNITIVE FLEXIBILITY THEORY

To those that distinguish between the terms "multidisciplinary" and "interdisciplinary," interdisciplinary work is the more integrated of the two and the more difficult to achieve [8]. Multidisciplinary work merely pieces together contributions from various disciplines. As a result, the researchers are unlikely to learn from each other or to work together after the project ends [9]. In contrast, true interdisciplinary work integrates the methods and perspectives of multiple disciplines to create new knowledge. The collaborators learn from each other, change their own approaches and perspectives, and are far more likely to pursue interdisciplinary projects in the future [10]. Though the ABET criterion specifies multidisciplinary teams, we believe interdisciplinary approaches would enrich engineering and engineering education research and practice while still meeting accreditation requirements. To help define interdisciplinary teamwork in engineering, we introduce cognitive flexibility theory.

Cognitive flexibility [11] describes the ability of a person's mind to shift among varying (and even seemingly contradictory) ways of knowing, or epistemologies. Epistemology refers to fundamental beliefs about knowledge and knowing, which often guide preferred methods and values. Both situated learning [12] and personal epistemology [13] research have revealed evidence of differences in the ways people trained in various disciplines view a project, problem, and knowledge itself. Cognitive flexibility represents

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a new way of thinking about epistemologies—a cognitively flexible individual is capable of changing his or her "epistemic lens" to suit various contexts; i.e., an engineer is able to think like an educator, and vice versa. The extension we make in applying cognitive flexibility to interdisciplinarity is by *defining interdisciplinary thinking as the cognitive flexibility to mediate between disciplinary viewpoints to enable truly interdisciplinary integration.* Cognitive flexibility is already in practice on a basic level for most faculty members who must switch between the way of knowing that suits him or her as a researcher to a different way of knowing that suits his or her role as a teacher.

The theory of cognitive flexibility emphasizes cognitive training as the main factor in an individual's ability to shift viewpoints according to context. Poor training that oversimplifies content, problems, and solutions can actually inhibit one's ability to develop cognitive flexibility. Instead, Spiro et al. [11] suggest that covering the same content in different ways can increase cognitive flexibility. This provides the environment for students to develop their own knowledge structures and practice restructuring them. "[A]s ill-structuredness increases, the use of rigid knowledge structures (i.e., the same precompiled knowledge structure used for many cases) must be replaced by flexible, recombinable knowledge structures" (p. 380). Fixed knowledge is thus devalued in favor of the "mobilization of potential knowledge" [14]. This aligns with the concept of transferable skills advocated in *How People Learn* [15] and other teaching and learning literature; emphasis is on developing skills and structures for future learning over memorizing specific content and examples.

While cognitive flexibility is largely used as a pedagogical theory focused on individuals, it can also have profound effects for cross-disciplinary teamwork. If engineering students are able to modify their assumptions of knowledge to address the other disciplines involved on a project team, true interdisciplinarity—in which perspectives and methods are integrated to synthesize a synergistic whole—is not only possible, but practicable. Engineers at any level can train themselves to be more cognitively flexible by exposing themselves to different problems and knowledge structures, and by considering a single problem from various disciplinary viewpoints. By stretching their minds—keeping them flexible—engineering students and faculty alike can enjoy productive working relationships that are truly interdisciplinary.

EXAMPLE: DESIGN OF AN INTERDISCIPLINARY LEARNING ACTIVITY

In *Understanding by Design* [16], Wiggins and McTighe describe a "backward" instructional design strategy that ensures assessment evidence is readily available at the end of any unit. Briefly, the steps are to: (1) identify desired learning outcomes, (2) determine what evidence is necessary to decide whether students have met these outcomes, and (3) design learning activities that will give the students the knowledge and tools to achieve on final tests, projects and other assessments. There are many possible learning outcomes associated with interdisciplinary learning at the undergraduate and graduate levels. The following is a partial list of examples that specify measurable student work. As a result of instruction, students should be able to…:

- define key terms from another discipline that are relevant to an engineering project
- develop a common vocabulary with collaborators from another discipline
- describe strategies for learning new content in an unfamiliar discipline
- compare and contrast research approaches and values from one discipline with those in another
- enumerate theories or categorizations for describing interdisciplinary interactions
- select an appropriate approach for organizing an interdisciplinary team project
- summarize current debate in the value and evaluation of interdisciplinary work

The example learning outcome we will work through in this paper is relevant to both undergraduate and graduate students:

- Students should be able to… coordinate multiple disciplinary viewpoints to help their teams successfully complete a multidisciplinary team project.

It should be noted that this learning outcome probably could not have been this well-articulated if not for the theoretical background provided by cognitive flexibility theory described above. In addition to prescribing learning activities, theories also provide clearer *definition* of what it means for our students to be interdisciplinary and provide *explanatory power* for patterns in actual practice [17].

Clearly, students should be assigned a multidisciplinary team project if it is mentioned in the outcome. Evidence of whether students are effectively bridging disciplinary perspectives might include observations of team meetings during class time, reflective essays embedded in project portfolios, and final reports and presentations. Students will be more likely to provide explicit evidence if they are shown the scoring rubric ahead of time, with items such as "explicitly describes how both [mechanical engineering] and [biology] concepts were applied to complete the project."

Following *Understanding by Design*, the next step is to consider what additional learning activities (other than the project assignment itself) students need in order to bridge different disciplinary perspectives. Given a specific setting, an instructor must decide whether students need to be convinced that there are different viewpoints. Perhaps the project assignment itself brings this to light as students begin to work toward completing it. Particularly if time is limited, the instructor might choose to include an initial team activity designed to highlight the different ideas team members can bring to a project based on their past experiences [18-19]. An example of this might be for each student to independently draft a scoring rubric for the assigned project, then synthesize the drafts into a single set of criteria for evaluating the project during a team meeting. This activity is likely to bring to the fore differing views of which aspects of the project are most important to defining success.

Another question instructors might consider is whether students need to know specifically which viewpoints characterize the disciplines involved. This depends to some extent on the grading and assessment tools selected. If, as in the rubric mentioned earlier, students will be asked to describe the viewpoints and how they were applied, then understanding the viewpoints is critical. Class time should then be spent discussing the different approaches. If students have already begun working together, they might have some ideas to offer in class discussion, aided by instructors or guests from the different disciplines and studies by Janet Donald and others [12, 20]. Consistent with cognitive flexibility theory, any instruction on the differences between disciplinary approaches should not be reduced to a few bullet points; gray areas and common approaches should also be discussed.

Finally, and most important to the stated learning outcome, is student practice applying different perspectives. Cognitive flexibility theory advocates practice with multiple complex, interconnected problems and examining these problems from multiple perspectives. Consider an example from an interdisciplinary project course we are just beginning to study. The disciplines involved are industrial design and computer engineering. The policy of the instructors—one representing each discipline—is to “leave your discipline at the door” upon entering the class. During assigned times to sketch potential ideas, no student is allowed to say she is not an artist and skip the activity; everyone sketches. Similarly, when relevant building and safety codes and regulations are investigated at the library, everyone participates in the assignment. In the first weeks of class, when the main problem is still being defined, students are frequently shuffled between groups and tasks to understand different aspects of the project. At no point are students assigned a task because it is typical work for someone trained in their discipline. The only time discipline is used is in assigning the permanent project sub-teams, to ensure a mix of each background is represented but not dominant in any one team.

Cognitive flexibility also has important implications for curriculum design in engineering. Oversimplification as often occurs in introductory college courses incorrectly trains students to expect simple solutions, focused more on memorization than analysis. Students must actually unlearn [21] this style of thinking to appreciate interconnection and ambiguity associated with advanced developmental levels like Perry [22] or Baxter Magolda [23]. To the extent that faculty have control over prior coursework, they should ensure students work with complex examples and problems—including interdisciplinary experiences—from the beginning.

Our research appears to support the working hypothesis that freshmen, who are not yet indoctrinated to a particular disciplinary view, are more open to considering multiple perspectives than their senior-level counterparts [24]. In both cases, engineering students were assigned to work with non-engineers on team projects. Focus groups and surveys were used at the end of the semester to uncover student perceptions of the interactions that had taken place. Engineering senior design students for the most part displayed only irritation at having to explain technical content to teammates and misconceptions about the disciplinary backgrounds of their collaborators, derogatively referring to their work as “marketing” or “spin.” Also, since the two groups completed different assignments for their respective courses (mirroring structures they are likely to encounter in industry), there were ownership issues related to the various products [18, 19].

In the case of the freshmen, engineering students working with both industrial design students and assistive technology (differently-abled) clients made far more reflective comments about the differing viewpoints involved and the value they bring to interdisciplinary projects. For example, the views of freshman engineering students changed over the course of their interdisciplinary design projects: in the beginning they were more concerned with functionality in terms of “what’s on the inside” versus what they viewed as aesthetic (“what’s on the outside”); by the end of the project they acknowledged that aesthetic form can be integral to functionality. Since neither group was given much explicit instruction in what to expect from their team interactions, a logical conclusion is that freshman students are more amenable to considering and valuing multiple viewpoints in their work. Consistent with recommendations from cognitive flexibility theory, we should further capitalize on this willingness with increasingly complex, interconnected, ill-structured and interdisciplinary engineering projects in the freshman year.

ACKNOWLEDGMENTS

This work was supported in part by National Science Foundation grant EEC-0643107. We also wish to thank Dr. Wendy Newstetter for helpful theoretical conversations and Shawnette Adams and the instructors for discussions about ongoing studies of interdisciplinary student team project courses.

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