Teaching Interdisciplinary Collaboration: Learning Barriers and Classroom Strategies

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Abstract – Educators have known for some time that simply putting students in teams is not sufficient to teach teamwork; instead, students need explicit instruction and guidance in teaming to work effectively. A similar principle applies to interdisciplinary teamwork: putting students in interdisciplinary teams – an increasingly common practice in engineering education – is not sufficient to teach interdisciplinary collaboration. Nor are traditional teaming skills alone enough to enable students to work effectively across interdisciplinary boundaries. This paper addresses this gap in teaching practices by first briefly identifying barriers to students successfully engaging in interdisciplinary collaboration and defining corresponding measurable learning outcomes. It then focuses in detail on teaching practices designed to help students achieve the learning outcomes. These findings have been developed from a multi-case study of interdisciplinary collaboration in a green engineering program that draws students from multiple engineering disciplines as well as business, industrial design, and related fields.

Keywords: interdisciplinary, teamwork, learning outcomes, teaching strategies, disciplinary egocentrism

INTERDISCIPLINARY COLLABORATION IN ENGINEERING EDUCATION

In recent years, engineering has begun addressing challenges that cannot be addressed by any single field. For example, efforts in sustainability, such as developing alternative energy sources, managing with global climate change, and providing potable water, all require the skills and knowledge of professionals from multiple engineering fields as well as fields as diverse as ecology, political science, management, sociology, and economics. To develop solutions to these challenges, these individuals will need to collaborate in complex ways by integrating the knowledge and perspectives from all the disciplines involved. This interdisciplinary mode of collaboration differs from the "divide-and-conquer" approach inherent within multidisciplinary collaboration, in which experts work in their own domain and then pass work off to the next expert; instead it requires individuals to cross disciplinary boundaries to synthesize new knowledge through a dynamic exchange of ideas and information.

The need for interdisciplinary collaboration goes beyond issues of sustainability. Research in the areas of neuroscience, terrorism, and nanotechnology, for example, also draw from a wide array of disciplines to further scientific and technical knowledge. In all of these contexts, the government has expressed a need for engineers to engage in interdisciplinary collaboration through several government reports, including *Facilitating Interdisciplinary Research* [1] and *Rising Above the Gathering Storm* [2]. These reports, as well as the National Academies of Engineering's *Educating the Engineer of 2020* [3], recommend introducing undergraduates to interdisciplinary learning. These recommendations challenge the field of engineering education to support the development of engineering students' interdisciplinary skills, thus creating professional engineers prepared for the complexity of the current as well as future issues.

The importance of these kinds of interdisciplinary collaborations is reflected in the inclusion of criteria "(d) an ability to function on multidisciplinary teams" and "(h) the broad education necessary to understand the impact of

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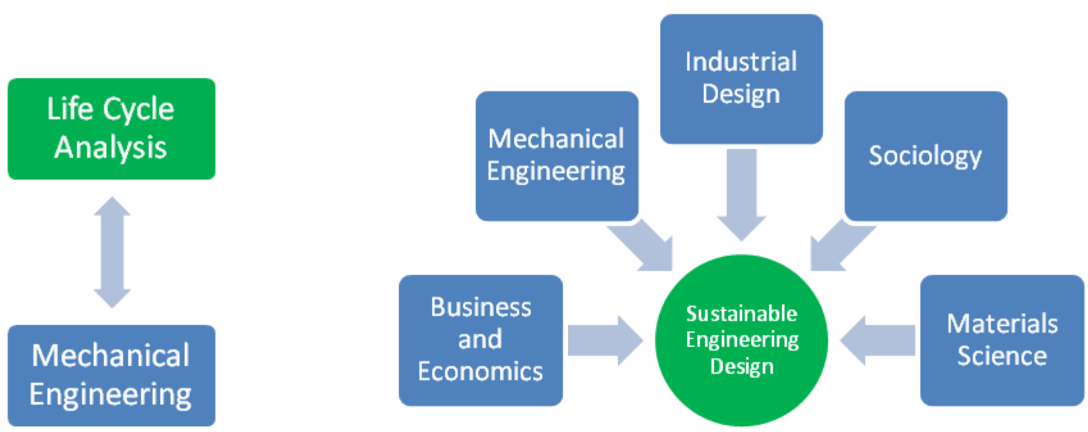
engineering solutions in a global, economic, environmental, and societal context" [4] for ABET accreditation. By developing measurable learning objectives surrounding these two criteria, programs can present assessment data of students demonstrating the skills and knowledge required to fulfill these criteria.

To identify the current state of interdisciplinarity in engineering education, Richter [5] and Richter and Paretti [6] performed a review of the literature, including a detailed content analysis of papers presented at the 2007 ASEE conference. The papers presented a broad spectrum of interdisciplinary efforts, ranging from individual projects to entire curricula. By focusing the analysis on those papers that reported on interdisciplinary courses, the authors identified a lack of measurable learning objectives and teaching strategies faculty use to promote student development of the skills required for interdisciplinary collaboration.

Yet research on interdisciplinarity suggests that meaningful measurable learning objectives can be developed. For example, to demonstrate that how theories of interdisciplinarity can applied to an educational setting, Borrego, Newswander, and McNair developed eight measureable learning objectives by applying the theory of cognitive flexibility [7]. Similarly, learning outcomes can be identified to address the challenges students encounter when engaging in interdisciplinary collaboration. As we have identified previously [5, 6], findings from other studies [8-12] on interdisciplinary development and barriers to interdisciplinary collaboration call for students to be able to:

- "identify the contributions of multiple fields to a given complex problem;
- value the contributions of multiple fields;
- identify the information needs and constraints of experts in other disciplines to insure effective collaboration;
- integrate approaches and expertise from multiple fields in a synthetic way;
- learn from both the methods and content of other disciplines to both contribute to the project and inform future work" [6].

To further investigate the challenges students encounter in interdisciplinary settings, we performed a case study of an interdisciplinary green engineering course; a detailed description of the study is provided elsewhere [5, 6]. From this study, the beginnings of a theory of "disciplinary egocentrism" emerged to identify key cognitive barriers students face and suggest possible teaching interventions. Disciplinary egocentrism is defined as the inability to think outside of one's disciplinary perspective; "relatedness" refers to the connections between the discipline and the interdisciplinary topic, while "perspective" pertains to the relations across disciplinary boundaries (see Figure 1).



(a) Relatedness (b) Perspective

Figure 1: Connections between an interdisciplinary topic and traditional disciplines exemplifying (a) relatedness and (b) perspective in interdisciplinary contexts [6].

Using this perspective on the challenges students face in interdisciplinary settings, we have developed the following critical learning objectives for interdisciplinary collaboration. Students in interdisciplinary teams should be able to:

- "Create structures (physical and virtual) that foster interdisciplinary collaboration
- Communicate their expertise to collaborators
- Describe the disciplinary approaches and expertise of their collaborators
- Recognize and describe the value of contributions from their own fields as well as from their collaborators
- Engage in shared problem definition and specification from multiple perspectives
- Identify appropriate opportunities for disciplinary depth" [13].

To assist students with overcoming disciplinary egocentrism, faculty need to produce specific interventions to achieve these objectives, preferably with a focus on transferable skills students can utilize in other interdisciplinary contexts. The remainder of this paper presents specific teaching strategies faculty can employ in interdisciplinary contexts.

TEACHING STRATEGIES

Since disciplinary egocentrism may result from the lack of exposure to other disciplines, providing different disciplinary perspectives through lecture provides a starting point, but students may not transfer the lectures of different disciplines to other interdisciplinary settings. Discussion- and reflection-based interventions can provide students with transferable skills to successfully participate in interdisciplinary contexts; faculty also can develop interventions that enable students to work with technology to promote interdisciplinary collaboration. These interventions draw from literature on writing to learn as well as design education, among other theories of student development, to address the learning outcomes listed above. The interventions were developed from observational data from a year long interdisciplinary design course, and systematic investigation of their effectiveness is currently underway.

Discussion and Reflection Exercises

The following topics can be used as topics for informal reflective writing and/or as prompts for class discussion. Faculty can begin to engage students in discussion through carefully constructed guided questions to promote detailed explanations of the disciplines.

Disciplinary design processes: To promote design thinking and expose epistemological differences, faculty may ask students to produce a description of the design process according to their discipline. This description should not only include the specific tasks or factors taken into account when designing but also the relative importance of each task or factor. After reading through the students' responses, the faculty member(s) can lead a discussion, which draws from student responses, focusing on comparing and contrasting "design" across the disciplines, identifying terms or concepts that could lead to misunderstanding or conflict, and discussing the final artifact (product, process, or system).

Survival scenarios: The web offers a number of survival-based scenarios that ask participants to rank items needed for survival in situations such as a plane crash, desert, or wilderness, (e. g. http://wilderdom.com/games/descriptions/SurvivalScenarios.html). Each participant is asked to produce his or her own ranking privately, and then small groups come together to negotiate a group list. The exercise is particularly useful in promoting interdisciplinary collaboration because it can highlight the ways in which different areas of expertise provide necessary insights. Reflection/discussion prompts can specifically target the ways in which negotiated group knowledge yielded stronger results, and can ask students to reflect on what areas of expertise they would want to have in such situations. These scenarios can also be used as prompts to discuss topics such as

- The differences between single-discipline and multidisciplinary teams
- The difference between "multidisciplinary" and "interdisciplinary"
- Circumstances in which to use a "divide and conquer" approach rather than an integrative one

- Contributions individuals bring to collaboration beyond their disciplinary expertise
- Distribution of work for interdisciplinary teaming

To develop a more engineering-oriented design-based scenario, the authors have drawn on scenarios used in design education research at the Center for Engineering Learning and Teaching. Specifically, we have adapted the Mississippi River flood problem [e.g., 14, 15] as a tool both to promote and assess interdisciplinary collaboration through the following exercise:

1. Over the summer the Midwest experienced massive flooding of the Mississippi River. The firm you work for has just been asked to design a retaining wall system (e.g., a levee) for the Mississippi. You are responsible for putting together a team to study and develop solutions for this issue. What team members and/or characteristics would you include on the team?
2. Which team member(s) or characteristic(s) would be the most important and why?
3. What difficulties do you foresee the team members having in working with each other? (Please list the most important first.)
4. What strategies would you use to resolve these difficulties?

Again, this scenario can be used as a reflective homework assignment and/or as a prompt for discussion. To promote metacognition, it can be used at the beginning and the end of the course to help students identify changes in their answers based on their experiences in the interdisciplinary team.

Use of analogies and metaphors: Work by Kakar [16] and McNair and Paretti have demonstrated the ways in which explicit instruction in the use of analogy and metaphor can help students bridge disciplinary divides [17]. Exercises that invite students to create analogies or metaphors to explain core concepts in their field that pertain to the design work at hand can help promote integrative collaboration among team members.

A-disciplinary problem definition: Faculty can also foster integrative collaboration by intentionally postponing the point at which students bring their area of expertise to the design project. In the initial phases of a project, faculty can help students define the problem and produce requirements and constraints without resorting to disciplinary divisions of work by requiring all students to conduct open-ended literature reviews, interview stakeholders, and brainstorm ideas. Creating an integrative approach to problem definition can help students take ownership in the project (even if their area of expertise might not initial be seens as “necessary” until a later phase) and stimulate cross-disciplinary thinking.

Technology

Where discussion and reflective exercises can help promote students metacognitive understanding and actual performance in interdisciplinary collaborations, interventions associated with technology are equally important in supporting those collaborations. Often interdisciplinary teams lack the same kind of shared physical space within-department teams may have, such as student lounges or common study areas, and conflicting course schedules can make it more challenging to schedule out-of-course meetings [5, 6, 13]. These challenges are similar to those encountered in many contemporary workplaces, and faculty can greatly benefit students by helping them develop virtual collaboration skills. Introducing tools such as common server spaces for file exchanges, chats or online discussion forums for meeting minutes and collaboration, and providing neutral central locations for teams to meet can be invaluable in promoting successful collaboration.

CONCLUSIONS

Interdisciplinary teams are increasingly crucial in enabling engineers to engage productively with experts across not only science but business, social science, and humanities disciplines to address the challenges confronting us in the 21st century. Putting engineering students into interdisciplinary teams during their undergraduate curricula is one important step towards helping these students gain critical collaboration skills. But, as the research presented here suggests, simply putting these students into interdisciplinary teams is not itself sufficient to teach transferable skills in interdisciplinary collaboration. Faculty who wish to support student learning in this critical area can adopt meaningful learning outcomes associated with interdisciplinary collaboration and incorporate small, but significant reflective exercises and technological tools to address those outcomes.

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