Comparing the Performance of Multi-, Inter-, and Transdisciplinary Capstone Groups

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The Mechanical and Industrial Engineering department at Northeastern University has been trying to increase multidisciplinary projects in the capstone design course. Projects incorporating multiple disciplines can involve multidisciplinary students working in series or parallel, interdisciplinary collaboration between disciplines on a common project, or transdisciplinary teams where members need to develop knowledge outside of their own discipline. Examination of past teams involving more than one discipline shows that transdisciplinary teams tend to perform higher on certain metrics compared to multi- and interdisciplinary teams. This implies that projects that require students to gain substantial knowledge outside their discipline can lead to more sophisticated and complete designs, provided expert knowledge and mentoring in the outside discipline is available.

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Introduction

Much work has been done in recent years toward incorporating multidisciplinary experiences into Capstone Design courses. A survey of the literature shows a wide range of multidisciplinary efforts, from combining multiple engineering disciplines to combining engineering and non-engineering disciplines.[1-3] The term 'multidisciplinary' can have a variety of meanings, but Park and Son discussed three distinct forms of interactions between disciplines.[4] Multidisciplinary interactions involve students working within their own discipline and communicating, but not necessarily closely collaborating with another discipline. Interdisciplinary interactions are more collaborative, with students from different disciplines working jointly on a problem. This type of interaction requires students to develop key collaborative learning skills such as positive interdependence and interpersonal skills,[5] but still has them primarily applying the knowledge gained in their own discipline to the problem at hand. Transdisciplinary learning requires students to develop new knowledge in a different discipline in order to build a solution that goes beyond the traditional boundaries of the various disciplines. Students in a transdisciplinary project must be willing to train each other, learn new skills, and seek out expertise beyond their home department in order to successfully accomplish their goals.[4] The goal of the current work is to examine recent capstone groups to determine the type of collaborations present and to determine if certain types of collaborations translate into more effective designs.

Capstone in MIE at Northeastern University

The Mechanical and Industrial Engineering (MIE) department at Northeastern University is, as the department name suggests, inherently multidisciplinary. However the majority of projects have historically been executed by teams with only mechanical engineering (ME) or only industrial engineering (IE) students due to the nature of the projects proposed. Both ME and IE students are required to have a functional solution or prototype as appropriate by the end of the second term in the two term sequence. Projects may be industry sponsored, faculty proposed, or student proposed. IE projects are more likely to be industry sponsored, and range from healthcare problems to industrial problems to nonprofit/service learning problems. ME projects can range from purely mechanical design to mechatronics and robotics, biomedical applications, to heat transfer and fluid mechanics based problems. Faculty load tends to fall on the home department, such that the faculty in the secondary department acts as a client or co-advisor on the team, but the MIE faculty member is the bearer of the official teaching load.

At the beginning of the first term of the two term sequence, faculty members present the list of available projects. Students then form self-selected teams and rank the projects as to their preference. If a project is designed to require students from multiple disciplines, referred to as 'joint' projects, then the advisor specifies that the project must have at least two students from each discipline, and the teams rank the projects accordingly. Projects are assigned to teams primarily with an eye toward giving students their highest ranking project. In some cases, preference is given to students with particular minors. For example, a group with multiple members who are biomechanical minors would be given precedence over other groups for biomechanical related projects. This method of project assignment tends to allow students who truly want a multidisciplinary challenge to bid those types of projects highly. However, the system is not perfect, and some students who are 'odd men out' may be assigned to a non-preferred multidisciplinary project.

Multi-, Inter-, and Transdisciplinary Projects in MIE

There are three general ways in which multidisciplinary projects have been incorporated into the program. One way is by combining multiple disciplines such as ME and IE students on the same team. Teams have also been formed between ME and electrical and computer engineering (ECE) or between ME and non-engineering disciplines such as media design and architecture. This type of group may have one ME or IE advisor, or may be co-advised by professors from each discipline. A second way is to have single discipline teams working in parallel or series. For example, an ME and an IE team, each with 5 students per team, may both be working on a closely related problem. The ME team may be building a physical prototype while the IE team works on simulations involving data gathered from the prototype, but the projects produce two separate final reports. Groups may also work in series, with an ME group, for example, finishing some part of a larger project and passing it off to an ECE team. The third way in which multidisciplinary projects occur is with a team of students from one discipline being advised by an advisor from another discipline. An example of this would be an ME team that was designing something to be used by a chemical engineering (ChemE) researcher, requiring the team to work on a project that was well outside their usual experience and collaborate heavily with faculty outside of mechanical engineering.

Although all of the teams described above incorporate multiple disciplines, the exact type of collaboration depends on some combination of the project, the students, and the advisors. An ideal situation would be for all groups to be truly transdisciplinary, with students learning necessary information from outside their disciplines as needed in order to collaborate with a diverse group. In practice, the projects end up being a mixture of multidisciplinary, interdisciplinary, and transdisciplinary projects. No particular method is used to force the students toward one mode of collaboration or another.

Results from Past Multidisciplinary projects

Table 1 below lists the projects involving multiple disciplines in the ME program since 2008. In this table, 'Student Disciplines' describes the make-up of students on the teams. A project was deemed 'multidisciplinary' if multiple disciplines were required to interact during the same term on the same project in order to accomplish the goal, but students did not generally operate outside of their primary discipline. Multidisciplinary projects included both series and parallel projects. A 'series' project involved one team substantially finishing a well-defined portion of a project before passing it off to a group of another discipline. A 'parallel' project involved two teams, each containing students from only one discipline, working on different aspects of a larger problem during the same term. 'Interdisciplinary' projects required substantial collaboration and interdependence between team members of multiple disciplines. 'Transdisciplinary' projects required team members to learn considerable expertise outside of their core discipline.

The prototype score is based on a rubric outlined in previous work by the authors[6] A score of 10 indicates a complete solution which has been verified by testing at a point two weeks from the end of the term. It is important to emphasize that some groups with low prototype scores did end up developing functional prototypes by the end of term. However, groups that were substantially done two weeks prior to the end of term generally had more complete solutions and exhibited better project management.

The groups with the highest prototype scores tended to be transdisciplinary. In contrast, collaborations deemed multidisciplinary tended to have middle to low prototype scores. Only one group met the requirement for being interdisciplinary, but without completely moving into transdisciplinary behavior. All of the groups that exhibited transdisciplinary behavior were co-advised by professors from multiple disciplines.

Discussion

In general, the groups that were deemed 'multidisciplinary' tended to have groups with team members working in parallel, each focused on their own discipline. For example, the 'Photodynamic Therapy Delivery System' project involved two ME students and three IE students. The idea was to create a medical device that was highly ergonomic with a design focused on human factors. The problem was that the two disciplines could, and did, act as two subteams with little collaboration. The ME students worked on the physical build after some initial input from the IE students, but did not incorporate extensive human factors concepts. The IE students discussed and researched the need for human factors and safety considerations, but did not force the issue of incorporating these ideas into the physical build. The students had the idea that this 'alpha prototype' just had to work, and the ergonomics could be improved in the next prototype. Unfortunately, the term ended before they could get to a second prototype, and the result was two halves of a project that were disconnected. This points to a need for positive interdependence to be built into the project from the beginning.

The 'Exercise Effectiveness and Muscular Activation Tracking' project was an excellent example of students working in an interdisciplinary mode. The ME students created a wearable device that incorporated sensors in order to track muscle activation during weight lifting. Although this could be completed by the ME students without any collaboration, they realized that to truly make a marketable device some sort of user feedback was needed. They decided that a Smartphone application which sent information to a web database would provide the ability to track progress, but realized that they lacked the expertise to create more than a rudimentary application. They therefore teamed up with students from the Media Design department, who were tasked with creating the application and website. This did require collaboration, so that both sets of students knew what inputs were needed, what form the data would take, and could agree on how best to present the data to the user. However, it did not require the students to learn skills outside of their discipline – the ME students did not need to learn how to develop applications in order to successfully complete the projects. This project became interdisciplinary due to advice from the ME advisor, as well as the initiative of the students who sought out the Media Design team to partner with.

An excellent example of transdisciplinary synergy was the 'Urban Façade Thermography' project. This project involved building a quad copter drone that would take infrared images of the outside of a building. These images would then be stitched together to make a map showing where energy was leaking from the building. The ME students were tasked with building the drone. They quickly learned that they needed to know a lot about how to wire and program the drone, what sort of camera would be necessary, and what sort of memory requirements needed to be supported. Much of this they learned through consultation with the ECE advisor and ECE team members. The ECE students, in turn, needed to learn what drones could and could not do, how the sensors and camera gimble could work, and what the weight limits were. In particular, weight limits both dictated the drone design and the software and data acquisition design, forcing both groups to learn the necessary language to communicate the ideas to each other. Although the ME group primarily worked on the prototype for one term, followed by passing it off to the ECE group in the subsequent term, it was not possible to complete either portion of the project without constant interdependent collaboration. This was a function of the project design, but was strongly supported by the effective collaboration of the advisors. The students also were extremely proactive in learning new information and seeking each other out to achieve a unified design that was effective in both the mechanical and electrical aspects.

A pair of projects, both involving Biomedical Microfluidic Devices, illustrate the difference in performance between a multi- and a transdisciplinary group approaching a similar problem. In both cases the problem was to fill a microscale lab-on-a-chip with precisely controlled reagents in an automated device. The first group to work on the device in 2011 concentrated very heavily on traditional ME concerns such as fluid mechanics, pumps, and pressure monitoring. Although their client was a chemical engineering professor, they did not spend time learning about the chemicals involved, leading to difficulties in designing for fluids with disparate properties. The second group continued the work in 2012, but started with the acknowledgement that they needed to have a complete understanding of the reagents involved. Because the students educated themselves about the chemical engineering needs of the design, they were able to generate a much more complete prototype at an earlier stage than the first group. In this case the advisors were the same both times, but the initiative of the students in seeking out new information made the difference in the final product.

Conclusions

ABET student outcome d) requires students to learn to function on multidisciplinary teams.[7] It is clear from the experience at Northeastern that although forming teams from multiple disciplines is relatively easy, there is a wide range of outcomes that result. Students with the self-awareness to understand the need to expand their expertise reap the benefits in terms of effective project outcomes. Going forward, it is clear that structuring projects to require more positive interdependence, and mentoring students about the need to expand beyond their disciplinary comfort zones is needed to move toward truly transdisciplinary, high quality outcomes.

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Table 1: Review of MIE Interdisciplinary Projects since 2008

Project	Term	Student Disciplines	Advisor Disciplines	Collaboration Type	Prototype score
Interactive Bicyclist Accident Prevention System	Fall 2013	ME/IS	ME	Multidisciplinary	4
Photodynamic Therapy Delivery System	Spring 2012	ME/IE	ME/IE	Multidisciplinary	4
Biomedical Microfluidic Devices Automated Filling System	Fall 2011	ME	ME/ChemE	Multidisciplinary	4
Classroom Laboratory Flexible Manufacturing System	Spring 2008	IE/ME	IE	Multidisciplinary	4
EC Window Energy Optimization	Spring 2013	IE	IE	Multidisciplinary, Parallel Project	6
Energy Efficient Room	Spring 2012	IE	IE	Multidisciplinary, Parallel Project	6
Electrochromic Window Energy Testbed	Spring 2012	ME	ME	Multidisciplinary, Parallel Project	6
Microalgae Panels for Carbon Mitigation and Biofuel Production	Fall 2013	ME	ME/ChemE	Transdisciplinary	9
Electrochromic Window Test Bed for Energy Efficiency	Spring 2013	ME	ME	Multidisciplinary, Parallel Project	9
PhASE – PhotoAcoustic Schlieren Elastography	Spring 2013	ME	ME/ECE	Transdisciplinary	9
Exercise Effectiveness and Muscular Activation Tracking	Fall 2011	ME/Media Design	ME	Interdisciplinary	9
Urban Façade Thermography	Fall 2013	ME/ECE	ME/ECE	Transdisciplinary, Series Project	10
Biomedical Microfluidic Delivery System	Fall 2012	ME	ME/ChemE	Transdisciplinary	10
e3Co System	Spring 2010	ME	ME/ Architecture	Transdisciplinary	10