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Interdisciplinary Design Course Structure: Lessons for Engineering Instructors from a Capstone Design Course

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Dr. Olsen has been a member of the WSU faculty since 2009 and is an committed to developing innovative and effective teaching methods. He has taught a diverse section of coursework and is very active in developing ways to improve the undergraduate education at Washington State University. He uses innovative teaching approaches and is extremely receptive to student feedback. His enthusiasm for engineering courses is contagious. Students witness a professor who truly loves what he does. Part of what makes Dr. Olsen such a successful teacher is his joy at working in tandem with the students. He has been involved in developing the curriculum for several classes in the Civil & Environmental Engineering Department as well as continuing to modify the curriculum and teaching methods for currently established courses. Dr. Olsen is passionate about interdisciplinary education and actively collaborates with students and faculty in civil engineering, mechanical engineering, architecture, and landscape architecture. He has a breadth of understanding across multiple disciplines that allows his to engage with students on a large variety of topics.

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Beyreuther conducts built environment research and teaches interdisciplinary design studios under the WSU Institute for Sustainable Design (ISD) in areas of integrated building and infrastructure systems design. Beyreuther is the Director of the WSU Integrated Design Lab (IDL) that performs research and development activities with industry and professional practice partners. Since 2009, he has co-developed the WSU Integrated Design Experience (IDX) studio that teaches design collaboration around large-scale, complex real-world projects to undergraduate and graduate students of architecture, engineering, and construction management. Prior to joining Washington State University in 2008, Beyreuther practiced as a structural engineer in Seattle, WA and is a licensed Professional Engineer in the State of Washington. He has also taught at the University of Washington in the College of Built Environments. Beyreuther received a Bachelor of Civil Engineering from the University of Minnesota and a Master of Architecture from the University of Washington.

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Michael Wolcott is a Regent's Professor in the Department of Civil and Environmental Engineering, a member of the interdisciplinary Materials Science and Engineering faculty, and director of Washington State University's Institute for Sustainable Design. He holds a Ph.D. in materials engineering science from Virginia Polytechnic Institute & State University and BS/MS in wood science and forestry from the University of Maine. A member of the WSU faculty since 1996, he previously served as an associate professor at West Virginia University's Division of Forestry.

Tamara Laninga, University of Idaho

Dr. Tamara Laninga is an assistant professor in the Department of Conservation Social Sciences and the Director of the Bioregional Planning and Community Design program (BIOP) at the University of Idaho (U-Idaho). She is the University of Idaho PI for the Northwest Advanced Renewables Alliance (NARA). She is an IDX instructor and also works closely with the outreach and environmental preferred products (EPP) teams. Dr. Laninga has over seven year experience aiding communities with sustainable land use planning. Specifically, she has facilitated student/community partnerships that have resulted in comprehensive plan updates; land use ordinance revisions; housing site and waterfront development conceptual designs; public engagement workshops; rails to trails and regional trail plans; and regional asset mapping, supply chain analysis, and conceptual designs for wood-based biofuels supply chains in the Pacific Northwest. Dr. Laninga teaches planning history and studio courses in the award-winning BIOP program and public involvement and social science theory in the CSS Department. Her research interests include community economic development, site selection for biofuels supply chains, the social acceptability of wood-based biofuels, and sustainable land use planning approaches.

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Abstract

This paper provides lessons learned from 6 years of developing and delivering an interdisciplinary undergraduate capstone and graduate course titled the Integrated Design Experience (IDX) at Washington State University and the University of Idaho. The IDX course addresses real-world problems with the aim of finding sustainable solutions in the built environment. Students and faculty from engineering, design, and community planning disciplines collaborate with industry, governmental, and professional practice stakeholders to research and develop innovative solutions to complex problems that demand multi-scalar and multi-disciplinary approaches typically outside the range of any single stakeholder. This paper describes the evolution of interdisciplinary curriculum strategies and expansion of disciplinary involvement and project topics.

Introduction

The multifaceted nature of the built environment, and the growing demand by future employers for graduates with innovative and collaborative skills, necessitates establishing interdisciplinary learning environments [1]. To respond to this need, the Washington State University Institute for Sustainable Design (WSU ISD) – a collaboration between a civil and environmental engineering department, a design and construction school, and a material science and engineering research center in the WSU Voiland College of Engineering and Architecture – developed the Integrated Design Experience (IDX) undergraduate capstone and graduate course in 2009. IDX is a teaching, research, and outreach vehicle for students, faculty, clients and mentors to analyze complex natural and built environment problems and design innovative solutions in interdisciplinary teams. In the IDX model, students and faculty are mutual learners, working collaboratively to achieve both teaching and research outcomes [3]. In this environment, faculty are less likely to be the sole providers of information and students the sole consumers of the provided information [2]. Specific objectives of IDX are twofold: 1) deliver an interdisciplinary educational experience for students and 2) foster faculty development and collaboration between diverse disciplines.

Course Overview

The IDX course addresses sustainable design challenges faced by municipalities, government organizations, and university research groups. Interdisciplinary teams provide unique environments to address the challenges from multiple viewpoints. An overview of the original course is described in the article, "Model for Faculty, Student, and Practitioner Development in Sustainability Engineering through an Integrated Design Experience" [3] illustrated in Figure 1.

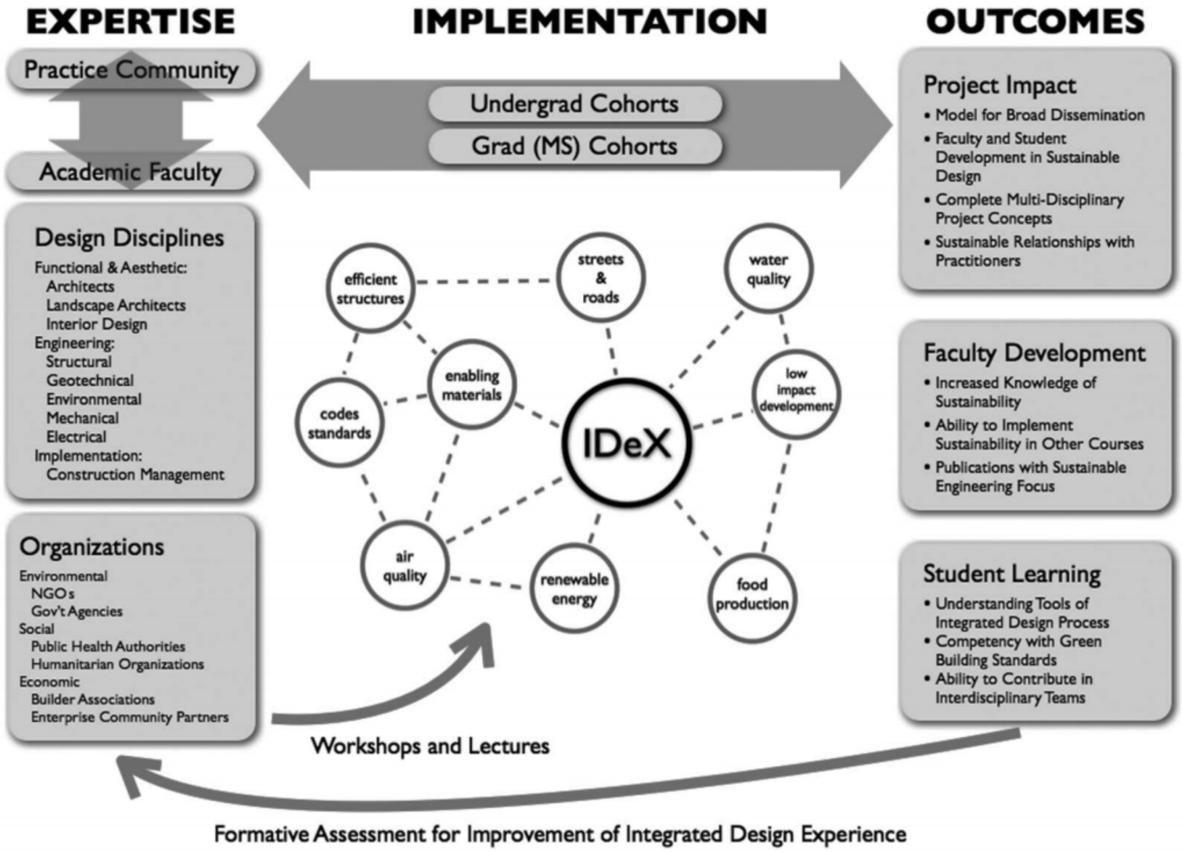

Figure 1. Course Overview [3]

Each project is scheduled for a full academic year as shown in Figure 2. The project scope and objectives are established in the summer prior to the fall semester by the IDX faculty. The students participate in the Fall and Spring semesters focusing on analysis and design phases respectively. Finally, faculty are responsible for dissemination of material during the following summer.

Profile (faculty) Summer	Analysis (students) Fall	Design (students) Spring	Dissemination (faculty) Summer
• Problem Statement • Background Information/Data	• Literature Review • Resource Flows • Site Selection/ Analysis	• Schematic Design • Design Development • Construction Documents • Sustainable Analysis	• Reporting • Development • Grant Writing • Journal Articles • Conference Papers

Figure 2. IDX class outline

What projects did IDX use in it's classes?

IDX was launched in 2009 with seed funding from the NSF and the Washington State University Institute for Sustainable Design (ISD) using a gift from Weyerhaeuser. As of the Spring of 2015, the IDX course has been involved in 8 projects over 6 years. These projects have been dispersed between municipality contracts, state agency contracts, university service centers, and university research projects. The class has one project per year except for the 2011/2012 and 2014/2015 academic years where two projects were run in parallel. The following briefly summarizes the IDX projects conducted to date:

2009-2010: Smart Farm Project

The objective of the Smart Farm project was to provide a sustainable design for the WSU organic farm. Specifically the design would provide a model for organic agricultural processes that incorporates technology, comfortable living spaces, educational opportunities, and compassion and connectivity to the surrounding community with net zero water and energy usage. The project was funded with $40,000 by a seed grant from the NSF and a gift from Weyerhaeuser to the WSU ISD for developing the class. The designs from the Smart Farm project have informed the current buildout of the new 30 acre organic farm on the WSU campus.

2010-2011: City of Auburn

The objective of the Auburn project was to partner with the City of Auburn to develop innovative stormwater strategies, improve community access in the city, and design integrated structural solutions pertaining to the city. The project was funded by a $90,000 contract from the city of Auburn. At the end of the project two of the student designs were built out by the city including a Low Impact Development (LID) boardwalk in the Auburn Environmental Park and the use of pervious concrete for stormwater in the city center.

2011-2012: Washington State Ferries

The objective of the Washington State Ferries (WSF) project was to design a sustainable transportation plan, develop sustainable design standards for stormwater treatment and building materials, and use Low Impact Development (LID) techniques to control and treat stormwater. Student designs were developed on 4 separate terminals in the Puget Sound. The project was funded by a $100,000 contract from the Washington State Department of Transportation (WSDOT). The analysis and designs for the WSF project were used to launch further research collaboration between WSF and WSU pertaining to stormwater treatment.

2011-2016: NARA Biofuels

The objective of the NARA Biofuels project is to conduct education and outreach activities for the Northwest Advanced Renewables Alliance (NARA) in their goal to provide stakeholders, interested in creating a forest residuals to bio-jet industry, with regional solutions that are economically viable, socially acceptable, and meet the high environmental standards of the Pacific Northwest (WA, OR, ID and MT). Specifically, students have been tasked with identifying ideal locations in the Pacific Northwest for site infrastructure along the supply chain, site design of various types of site infrastructure, and researching processing methods to optimize the efficiency of the supply chain. The project is funded for 5 years by a $100,000 grant per academic year through the NARA program funded by the USDA. The research performed by the IDX students has been presented at international conferences and used to further the NARA project.

2014-2016: Mass Timber

The objective of the Mass Timber project is to advance the engineering and design of cross-laminated timber structures in high-performance buildings. Specifically the students collaboratively developed baseline parametric building models that respond to site, climate, program, and structural patterning in pre-design. Engineering students developed parametric analysis tools for evaluation of iterative structural decisions. The project aligns with a USDA Forest Product Research grant, a pending US Forest Service Wood Innovation grant to develop pilot supply chains for mass timber in the Pacific Northwest, and a USDA Tall Wood Building competition.

<u>What types of students are represented in IDX?</u>

Over 6 years of IDX courses there have been 15 separate majors represented. A majority of students are engineering, design, and planning students, however, students from other disciplines are included to assist in specialized aspects of a given project including organic agriculture, law, and accounting. Figure 3 shows the distribution of students during each IDX year.

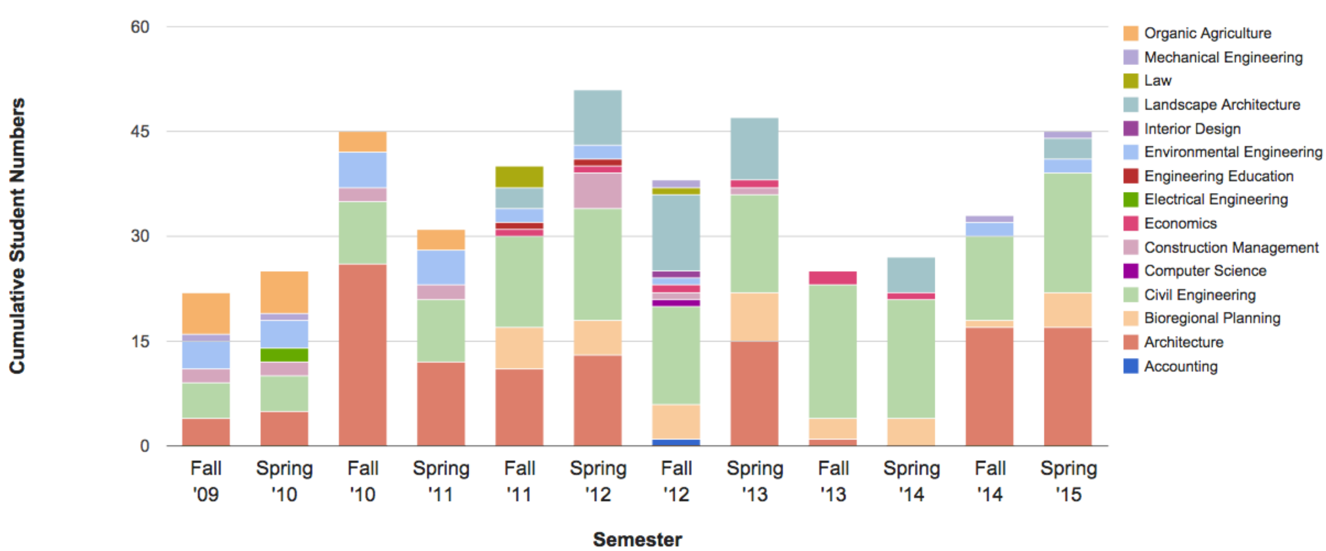

Figure 3. Student Demographics by Major

IDX integrates undergraduate, masters, and doctoral degree students (see Figure 4) in each project. The predominant degree represented is undergraduate students, but also includes an average of 22% master students and a few doctoral students since the fall of 2011.

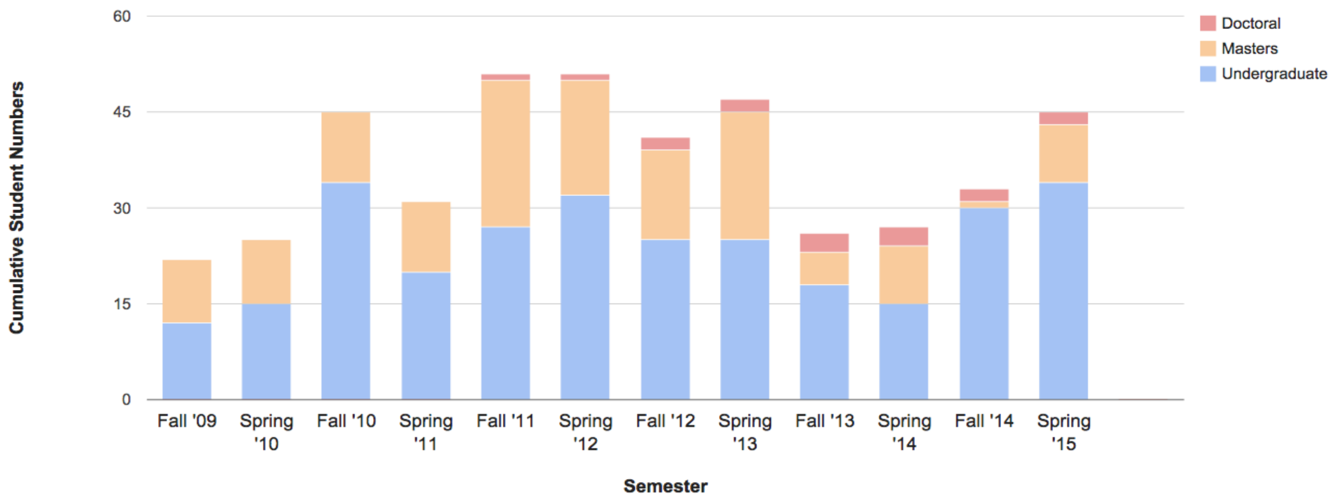

Figure 4. Student Demographics by Degree

<u>How many faculty are represented on each project?</u>

Providing an interdisciplinary capstone course requires significant faculty resources. The number of faculty represented in each project is displayed in Figure 5. The figure represents all faculty appointments to the class including lead faculty and mentor faculty. Lead faculty primary responsibility for the class, including curriculum development, representation at all lecture and studio hours, and final grading. Mentor faculty are provided to assist with advising students in given areas of expertise, providing direction and feedback during each semester.

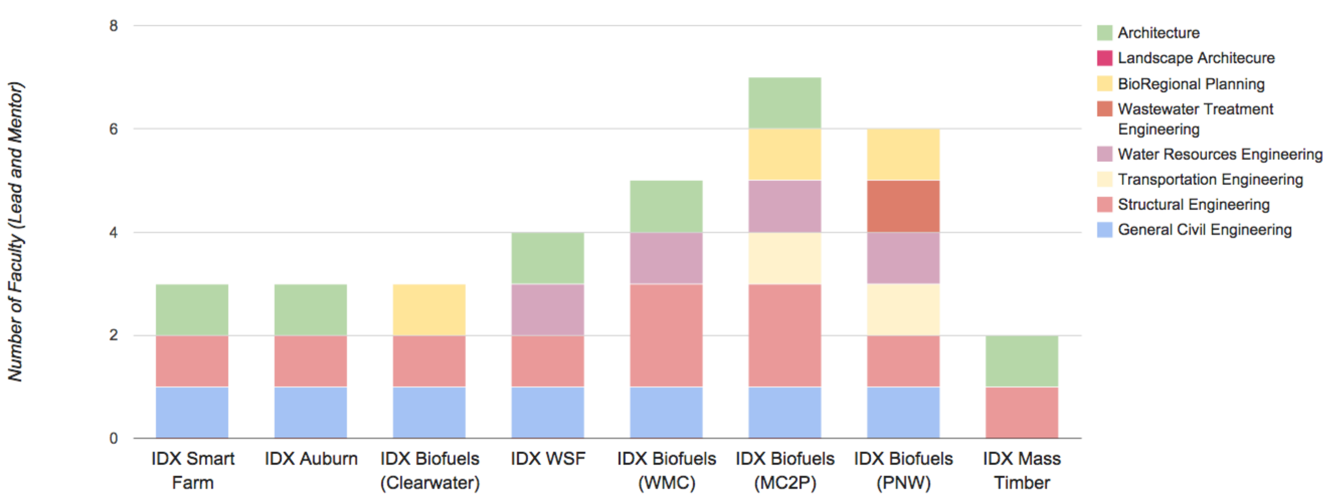

Figure 5. Faculty Disciplines per project.

Where did the funding for each project come from?
Currently the IDX course has been funded by university institute funds, government contracts and research grants. The funding for each project is listed in Figure 6, with an average of $92,500 per project. These funds cover faculty appointments, travel for students to visit sites and present to clients, student fellowships, and miscellaneous goods and services.

Figure 6. Project funding per project.

The majority of the funding for IDX goes to support faculty appointments. These appointments by FTE are represented in Figure 7. Each project lists funds by type including, ISD funds, contracts, grants, and allied state funds. Allied State funds represents other capstone design courses that are partnered with the IDX studio. These classes are funded by specific departments and are not included in the budget. Currently there are no direct state funds apportioned to the project.

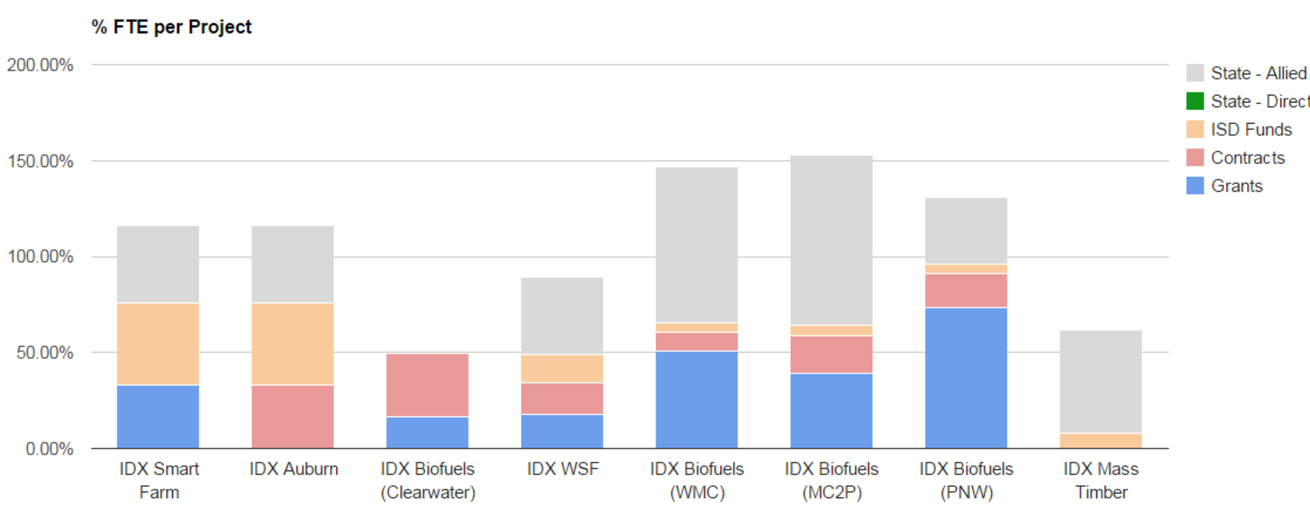

Figure 7. Faculty Appointment per FTE

What are the barriers to success for an interdisciplinary capstone design class?

Creating an effective interdisciplinary class provides numerous challenges. Unless these challenges are addressed the quality of the course significantly decreases. The barriers outlined below are the primary challenges that were faced in the 6 years of IDX to date.

<u>Differences in student disciplines</u>
The interdisciplinary nature of the class tends to naturally create conflict due to the variety of disciplinary backgrounds, learning styles, and problem solving methods. It has become evident that engineering students approach problems in a completely different manner than design students. Engineers are typically linear and rigid thinkers while designers are iterative and flexible in their time and solutions. These differences were visible early on in the program, and prompted the development of a peer evaluation system to confirm the specifics of the conflicts.

<u>Students without faculty representation</u>
During the first few years of the IDX course there were students whose discipline was not directly represented by the lead faculty on the project. The student disciplines that were not represented would be more likely to develop frustrations with the class. This was brought to light through student evaluations administered at the end of each semester. For example in the first year during the Smart Farm project the three faculty on the project represented Civil Engineering, Structural Engineering, and Architecture, however one third of the students were from the Organic Agriculture Department. Throughout the course of the semester, the frustration expressed by the Organic Agriculture students during class discussions and was confirmed in the student evaluations.

<u>Difficulty recruiting and maintaining faculty for the project</u>
Recruiting and maintaining faculty is difficult due to the nature of the course. In a typical college class the faculty has full control over the curriculum, but for an interdisciplinary design class with multiple lead faculty creating curriculum, making decisions, and assessing students becomes more complex. In the first two years of the project each decision was made in a weekly faculty meeting by consensus. Due to differences in faculty perspectives this process would take significantly longer than decisions made by one faculty member.

Lessons Learned
Through the 6 years of the course, solutions to the barriers mentioned above have been brainstormed and approached with some trial and error. Below are the methods that have been successful in improving the program and building it to its current state.

Identify Team Problems through Peer Evaluations

Peer evaluations have been implemented in an attempt to identify potential conflicts in student groups and address them directly before they expand and propagate. After each group assignment an online peer evaluation form is distributed to students to complete. The form responses are then summarized using a custom script to identify the potential problems, or problem students. Figure 8 shows an example output of the summary of the student form.

Submissions	# of Surveys	Quality of Work		Timeliness of Work		Support		Interaction		Attendance		Responsibili		Involvement		Initiative		Overall Performance	
24	68																		
Submitted	3	4.83	5	4.83	5	4.83	4	4.83	5	5.00	5	4.83	5	4.83	5	4.83	5	4.83	5
Submitted	2	5.00	4	4.25	4	4.75	4	4.75	4	4.75	4	4.75	4	4.75	5	4.75	5	4.75	4
Submitted	3	4.67	5	4.50	5	4.50	5	4.33	5	4.50	5	4.67	5	4.50	4	4.50	4	4.50	5
Submitted	3	4.83	5	4.83	5	4.50	4	3.83	4	5.00	5	5.00	5	4.83	5	4.83	5	4.67	5
Submitted	3	4.83	4	4.83	4	5.00	4	5.00	4	5.00	4	5.00	4	5.00	4	4.83	5	5.00	4
Submitted	3	4.83	5	4.67	4	4.67	5	4.67	4	4.83	4	4.83	5	4.83	5	4.83	5	4.83	5
Submitted	3	4.67	4	4.83	5	4.50	5	4.83	5	5.00	5	4.83	5	4.67	5	4.33	5	4.67	5
Submitted	3	5.00	4	4.67	5	5.00	5	5.00	5	5.00	5	5.00	5	4.83	4	4.83	5	4.83	5
Submitted	4	5.00	5	4.38	5	4.63	5	4.38	5	5.00	5	4.38	5	4.25	5	4.13	5	4.38	5
Submitted	2	2.50	4	2.50	3	2.50	2	2.25	3	2.25	5	2.50	4	2.75	4	2.50	4	2.50	3
Submitted	6	4.50	5	3.75	5	4.17	5	4.33	5	4.58	4	4.33	4	4.33	4	4.67	4	4.58	5
Submitted	3	4.50	4	4.33	4	4.33	4	4.67	4	4.83	4	4.67	4	4.50	4	4.33	4	4.50	4
Submitted	4	3.50	5	3.63	5	3.38	5	2.88	5	5.00	5	3.88	5	3.00	5	3.25	5	3.63	5
Not Submitted	0																		
Submitted	3	4.50	5	4.50	5	4.17	5	4.00	5	4.83	5	4.67	5	4.33	5	4.33	5	4.33	5
Submitted	3	4.67	5	5.00	5	4.67	5	4.67	5	5.00	5	4.33	5	4.67	5	4.83	4	4.67	5
Submitted	4	4.00	5	3.75	5	3.25	5	4.25	5	3.75	5	3.63	5	3.13	5	3.88	5	3.50	5
Submitted	4	5.00	5	5.00	5	5.00	5	4.88	5	5.00	5	5.00	5	5.00	5	4.88	5	5.00	5
Submitted	2	5.00	5	5.00	5	4.75	5	5.00	5	4.75	5	4.75	5	5.00	5	4.75	5	5.00	5

Figure 8. Example of Student Evaluation Form

In the form each student is directed to assess their own work as well as the work of each group member. The colored cells represent an average of the scores from team members and the adjacent white cell represents the self evaluation score. The color coating of the cells then allows the faculty to easily identify students that are creating conflict in the teams. The form also summarizes comments about each team member so faculty can read about the specific details of the conflict. Once a conflict student is identified they are asked to meet a faculty member in the office to discuss the issue and given a mandate to improve on specific areas. Students that do not show improvement are removed from group work and focused on other projects.

Multiple faculty w/ specific objectives

Making the decision making process for faculty more efficient is important for reducing workload. This reduction allows faculty to provide time for high quality curriculum development, timely project analysis and design feedback, and quality class interaction. A simple method of determining job descriptions for each represented faculty became important for streamlining the workflow. An example of the job descriptions for the Washington State Ferries project is listed in Figure 9. This allowed faculty to focus their attention on specific portions of the class and minimize the "decision by committee". It is important to note that collaborative between faculty is still imperative for the class to be successful, but providing responsibilities for given sections of the class does make the process more efficient.

Job Descriptions for IDX Faculty:

Faculty #1

Internal Organization, Internal Communication, Tutorial (ArcGIS, Civil 3D)

- Google Apps website
- Creating/Posting Assignment Sheets
- Calendar of events
- Grading spreadsheet/distribution
- ArcGIS and Civil 3D Tutorials
- Student communication (via e-mail)

Faculty #2

Engineering/Ag Mentor Communication/Faculty Expert/Grading

- Meeting Agendas
- Communication with Mentors
- Water Resources Expertise on projects
- Grading coordinator

Figure 9: Example of Faculty Job Descriptions

Faculty mentors - Student Evaluations

One of the most beneficial improvements that was made in the IDX class was including faculty mentors into the project. Faculty mentors are added for all student disciplines that are not represented by lead faculty in the class. They are able to give direction and feedback to the students and agree to a 1-2 hour per week commitment as well as attending all reviews during the semester. Faculty mentors are given a 5% FTE appointment to the class, minimizing the cost for each project while providing a vital opportunity for the students.

Allied classes

The largest budget item for the course is the faculty component. The student to faculty ratio is much less than a typical capstone class based on the need for a minimum of two lead faculty and a typical class size of 20-30. To minimize the faculty budget partnerships with other capstone classes are considered to reduce the cost. These partnerships are called "allied classes", where the partnering department pays for the appointment of the faculty for the allied class. Developing strong relationships with departments represented in the interdisciplinary course is vital to create these beneficial partnerships. Once a department agrees to collaborate, it is still important to work through the logistics of scheduling, ABET requirements, and teaching and accreditation expectations for the allied courses. Fulfilling each of these challenges lays a foundation for providing a legitimate interdisciplinary course at a lower cost.

Outcomes

One of the most important metrics of our program is the outcomes from the projects. During the 6 years that IDX has been operating at Washington State University and the University of Idaho, there have been significant outcome successes to the program including curriculum improvements, strong university and government agency partnerships, high demand for our graduates, and even buildout of some IDX student designs. A student group in the City of Auburn project developed boardwalk for the Auburn Environmental Park. The boardwalk implemented low impact development techniques to minimize the impact on the wetlands area in the park. The City of Auburn then used the boardwalk design, including the low impact footings, and constructed the boardwalk in 2011.

Additional faculty development outcomes include scholarly conference presentations and proceedings, juried journal articles, and funded grant proposals. These scholarly activities range from research about the pedagogy of IDX to research building off of concepts developed by faculty and students collectively in IDX. In the latter, IDX serves as an incubator for faculty research ideas leading to innovation-based grant proposals. In the process of teaching innovative concepts to students through iterative questioning and ideation design methods, faculty research ideas evolve and develop.

Conclusion

This paper introduced a model for interdisciplinary faculty and student teaching, research, and outreach course called the Integrated Design Experience (IDX) through a course overview with participation and funding statistics, examples of previous course projects, lessons learned, and outcomes achieved. The authors conclude that IDX has been a successful model at Washington State University and the University of Idaho because of an appropriate balance between autonomy from and integration with disciplinary departments at the universities. This balance enables the flexibility required to frequently evaluate metrics and to adjust delivery of the course quickly in response to underperforming methods or to unanticipated barriers related to real-world projects. Overall, the IDX course is a unique experience that is has tremendous potential for scaling and replication to deliver high-level interdisciplinary courses for students, foster interdisciplinary faculty development, and drive market diffusion and technology transfer outreach activities to clients and stakeholders.

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[2] Steiner, Gerald, and Alfred Posch. "Higher Education for Sustainability by Means of Transdisciplinary Case Studies: An Innovative Approach for Solving Complex, Real-world Problems." *Journal of Cleaner Production* 14.9-11 (2006): 877-90. Print.

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