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Creating a pipeline to engineering for women through an interdisciplinary data-driven and cyber-infrastructure enabled course

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Abstract

Academics have become increasingly interdisciplinary while at the same time, the sciences, engineering and research in general are increasingly data driven. Most higher education curricula, especially in Engineering are, however, still rooted in more traditional, discipline bound curricula and make little use of the vast amounts of data available. We describe an experimental course that address this and aims to include women from non-engineering fields. The interdisciplinary course took a data driven approach to the intersection of women's issues, water rights, and workers' rights, taught by faculty from Civil Engineering, History, American Studies, Earth and Planetary Sciences, Geography, and Informatics. We provide an analysis of how students adapted to this novel approach and what impact it may have on female students' career choices, especially in engineering. The course familiarized students with the use of cyber-based tools (e.g., shared databases, internet portals, monitoring devices/sensors, visualization, data collection and analysis tools) to gather, depict, compare and/or reuse data.

Keywords: *Women in engineering, Water data, Women data, Work data, Interdisciplinary teaching, Informatics, Cyber-Infrastructure*

1. Introduction

Academics, especially the STEM fields, have become increasingly interdisciplinary while at the same time, the sciences, engineering, and to a lesser extend the humanities, are becoming increasingly data driven and data has become increasingly democratized and accessible. Just as fewer women enter engineering programs in the Unites States (US), they are also less prevalent in these emergent areas. Most higher education engineering and STEM curricula are still rooted in more traditional, discipline bound teaching and make little use of the vast amounts of data available and the power of interdisciplinary collaboration to involve more diverse student bodies.

We describe a grant-funded, experimental course focused on taking an interdisciplinary, data driven approach to the intersection of women's issues, water rights, and workers' rights. The major objectives of the grant were to:

- Provide opportunities for female and ethnically diverse undergraduate and new graduate students from any discipline to do course work based on engineering and data sciences
- Expose students to team science based on inter-and trans-disciplinary groups
- Enable students to find and work with secondary and tertiary data sets
- Teach skills to evaluate, integrate, and the re-analyse diverse data sets
- Familiarize students with cyber-infrastructure enabled tools
- Provide opportunities for women from many fields to envision careers in engineering and the data sciences

The growing importance of interdisciplinarity and diversity in US universities is undeniable. The evolving needs to manipulate and extract meaning from “big data” made possible by cyber-infrastructure and data management tools have been well documented. The science of team science is taking research to a new level. All of the above were used to inform the organization and content of the course syllabus.

1.1. The importance of Interdisciplinarity and Team Science

Breakthrough solutions for large scale engineering problems and global scientific challenges, such as climate change, will require scientists and researchers trained to work on diverse interdisciplinary teams. They will need the technical skills to use collaborative science platforms, be familiar with cyber-enabled data management systems, and the ability to work with international partners from more than one discipline. This context and such skills are generally not taught at universities and especially not in engineering schools. Yet, future work will rely “on teams from many different fields working together and sharing data and insights in a systematic way over a long period of time, with many researchers entering and leaving the project without effecting overall performance” [1]. This process is challenging, for instance, McCausland and Martin showed that trans- and interdisciplinary research teams operate in what they call ‘VUCA’ contexts [2]. This refers to conditions that are *volatile*, *uncertain*, *complex*, and *ambiguous*. Such research is “*volatile* in that voluminous information and datasets may be available for any particular problem but it is rarely precisely the right information and new information is constantly appearing from many directions; *uncertain* because many scenarios of collaborative research could potentially be relevant and it is unclear which scenarios would be the most beneficial to investigate; *complex* because an effective research team is an evolutionary product that leads to emergence of shared objectives; and *ambiguous* because until a team evolves into a cohesive group with shared objectives, it is not clear initially how they can collaborate in meaningful ways” [3] [4]. Our premise in developing the course was that past and current generations of scientists and engineers are not likely to have been socialized into collaborative interdisciplinary work. It behoves future educators to make this a priority and begin to expose their students early to the principles, challenges, and benefits of team science. The challenges in constructing the course and creating the teaching team turned out to be as complex as it is in real world intra-disciplinary research teams! Mezirow refers to this process as “transformative learning” [5]. Transformative learning theory highlights three key stages that lead to radical change: a disorienting dilemma, critical reflection, and reflective discourse [6]. As we will show below, the course encountered all of these. Clearly, engineering and science programs need to develop a new generation of scientists and engineers that is better than our own at collaborating on

inter- and trans-disciplinary research teams and that is more inclusive of women and minorities.

1.2. The importance of Women in Science and Engineering

“The absence of women from STEM education and careers affects more than the women; it is a missed opportunity for those fields”[7]

The statistics of women in science and engineering in the US is discouraging, especially compared to those in European and other countries. Active interventions to improve entry and retention are urgently needed. Women should be prepared for their fair share of STEM jobs, as a U.S. Department of Commerce report from July 2011 shows that, over the past 10 years, growth in STEM jobs was three times as fast as growth in non-STEM jobs, even in difficult economic times. STEM workers also command higher wages, earning 26% more than their non-STEM counterparts [8]. In 2007, females made up 58% of two-year college enrolment in the US; however, in 2006-2007, females received only 15% of the A.S. degrees in engineering technologies [9]. In 2010, only 18.1% of four-year engineering degrees went to women [10]. In the 2008-2009 survey, the percentage of women receiving degrees in other areas was also low. For instance, only 17.8% women graduated with computer science degrees [11]. As mentioned above, US women comprised 18.1 per cent of total undergraduate completions in engineering in 2010. Canadian women graduating from undergraduate engineering degrees decreased from 21.8 per cent in 2003 to 18.9 per cent in 2007 [12]. In the UK, the percentage of females graduating in engineering was 15.5 per cent in 2005-6 [13]. However, in all three of these countries the percentage of females graduating in engineering is much lower than other European countries. In some non-English speaking countries the percentage of women graduating with engineering degrees is significantly higher than in the English-speaking countries, although in no country is the female percentage graduating in line with overall population, or of the female percentage of university graduates [14]. Central and Eastern Europe are generally considered to have the highest proportion of female engineers in the world but, due to political changes, these percentages have decreased in recent years. For example in Russia, this percentage has declined from 58 per cent in 1995 to 30 per cent in 2002. It is therefore likely that “the percentage of female engineers graduating across all countries will remain stationary in the range of 15 per cent to 30 per cent at best for the near future”. [14] This lower participation rate in engineering in the US is generally attributed to negative messaging combined with a perceived female-unfriendly workplace reality. Studies by Huang et al [15] and Adelman [16] on the persistence of females in S & T programs in the US show that, relative to men: women in engineering programs are not poorly prepared, but they face difficulties of a largely psycho-cultural nature, nor do women perform poorly. Thus there is no fundamental reason for females not participating and succeeding in engineering programs.

2. Course Development and Teaching

Keeping the goals of both the grant and the course in mind (interdisciplinarity, team science, engineering and data science pipeline for female students, using Cyber-infrastructure enabled tools), the PI looked for areas of strength at UNM to invoke in

constructing the course. UNM has nearly eighty affiliated faculty working in some area of women studies, a well-known master of Water Management program in the Civil Engineering department, and a strong Data Sciences academic program in the University Libraries. Most importantly, the course was based on principles found in the various works by our college Deanna Pennington [3] discussed above and summarized in her group's latest work [4] as "... the critical *human foundations* of trans-disciplinary, transformative research are team members with

- 1) a shared commitment to finding a solution to the problem;
- 2) deep knowledge in different fields of expertise;
- 3) a shared ethic and value system for collaborative engagement within the research team;
- 4) placement within highly connected knowledge networks;" et cetera.

To do this, we had to assemble a group of well known, visionary, and inspiring women faculty from the humanities, social sciences, natural sciences and engineering. We had to build trans-disciplinary awareness, team formation and group cohesion among the faculty so that they could evoke meaning in the course from their own experiences and their struggles to find common ground and shared purpose. This process was more difficult and time consuming than expected, in fact, all the concepts of the VUCA concept discussed above, came into play! The most challenging for the professors was the insertion of an emerging field unfamiliar to most of them; that of cyber-infrastructure enabled data sciences. The female faculty came from Civil Engineering, Earth and Planetary Sciences, History, and American/Women Studies. The faculty trained together and shared their ideas about the use of cyber-based tools (e.g., shared databases, internet portals, monitoring devices/sensors, visualization, data collection and analysis tools). During the fall semester the group began to develop the interdisciplinary course. This process, we were told repeatedly, also informed and transformed the research of the participating faculty. The course was taught the following spring semester. It was offered as both a senior undergraduate class and first year graduate class and was unexpectedly popular. The students came from 17 areas or majors: History(5,one with Anthropology), Secondary education(2); Criminology(1); Geography(2); Mathematics(2); American Studies(2); MS in Water Resources(6); Spanish(1); Civil Engineering(6); Chemical Engineering(3); Journalism(1); Environmental Science(3); Business Management, minor in sustainable studies(1); Biology(1); Psychology(1); Interdisciplinary Film & Digital Media(1); Earth & Planetary Sciences(2). Seven of the students were Hispanic and two were Native American. Only four students were male and the rest female.

2.1. Teaching the course

Technology, transparency, and team work were essential principles of the class. We explained the outline and unique structure of the course and the expectations for virtual and physical team work. The course website and several special class presentations also gave students a hands-on introduction to digital information management tools and methods. While initially, some students were apprehensive about the unique course structure and a number of them reported feeling "lost," as the semester progressed, the students became increasingly comfortable in this environment. With so many teachers from such different fields, coherence of course structure was extremely important as were evaluation and marking issues. For the final project, each team created a poster

presentation addressing a research question using data from data sets (global and national) regarding women, water and work. The groups used statistical and data management tools to integrate the data and present findings. The students were encouraged to participate in related extracurricular events such as the NSF Cyber-Infrastructure Day held annually in the past six years at UNM.

2.2. Technology, Tools and Challenges the course

Contemporary research is driven by information technology, so it was deemed important to provide the students with some experience with both desktop and online data collection and manipulation tools. However, because there was quite a variance in the levels of technology skills and proficiency among the students, it was determined that a phased approach should be taken that gave them several levels of introduction to software tools and applications. The first technology presentation included a survey of desktop and Web 2.0 research tools (e.g., Mendeley, Zotero, Del.icio.us) that students could use to manage general research information. Later on, students were given an assignment using the Water Footprint Network's online calculator (<http://www.waterfootprint.org>), which uses a questionnaire to determine an individual's annual water consumption. The experience with this tool provided students, particularly those with limited technology experience, a basic foundation upon which later assignments could be based. The primary technological resource for the class was the custom *Drupal 7* website which served as the locus for class activities and provided a "web enhanced" learning experience. The site enabled students to communicate with instructors, participate in online blogging and discussions, and turn in their various homework assignments online. More importantly, Drupal provided a data management platform for the class, in particular for students' water diary assignment, which was the most intensive data-centred activity in the course. This assignment required each student to track their own personal water usage and then through analysis determine any patterns or common characteristics of water use across all of the students in the class. At the beginning of the assignment, students were asked to collaborate as a group and design a water diary data schema; together they determined the protocols for collecting diary entries and identifying the specific data elements that each student needed to record. Emphasis was placed on creating a functional data model that could then be packaged as an easy to use data entry form for the students. During the next stage of the assignment, each student was asked to log on to the Drupal site each day to record their personal water activities and levels of consumption. The data collection period lasted for several weeks, after which students were given another demonstration that showed them how to extract the collected data from the Drupal site for analysis. Each student downloaded the complete water diary data set from the website, and had to perform several conversion operations to move the data into Microsoft Excel for analysis. In the final stage of the assignment, students performed some basic analytical functions on the data, and reported on their results in class. The practical experience students received using various data management, collection, and manipulation tools formed an effective component of the course learning experience. There were several challenges to delivering these assignments. Most prominent, with such a diverse class population, with students coming from the humanities, social and natural sciences as well as engineering, was getting them all to a common level of technological dexterity. It took

much more time than anticipated in the initially design. This resulted in some of the more advanced students seeming bored with the early assignments, and the less adept students feeling overwhelmed with the later assignments. The instructional team did however take away valuable experience for future iterations of the course - particularly how to better design technology experiences for students with differing levels of expertise. It should be noted that none of the subject instructors had ever used *Drupal* prior to the course, so introductory training had to be scheduled for them as well as the students. Instructors also needed additional technology support with, for example, creating spread sheet specifications for the water diary analysis assignment, and digitizing images and video for class lectures. Several major changes had to be made to the course lecture and assignment content while the course was in progress. There was definitely a sense that the website was being “designed as we go” for the first half of the semester. Outcomes strongly indicate that the effective use of information technology, given that the students came from such differing levels of technological literacy and diverse subject backgrounds, depends greatly on the amount of “adaptive structure” that can be embedded in the design of technology-based assignments.

3. What Worked and What Would we do Differently?

The usual obstacles with interdisciplinary projects were encountered such as different use of language and tools, differing expectations for student learning and phasing of foundational concepts from all fields. The professors struggled with marking and evaluation, especially as we were working with a mix of graduate and undergraduate students. To deal with the uneven preparation of students, a survey was developed and administered at the beginning of the class. This was used by the teaching group to adjust expectations and some of the assignments were re-designed. Another survey was done at completion of the course in order to evaluate change and whether the objectives had been met. The survey concentrated on questions regarding how often students had used technology and data tools and how comfortable they were with them, their mastery of the data analysis and data management tools. There were significant improvements in the post-test over the pre-test. The number of students who felt extremely or very comfortable with technology and engineering concepts went up from 57% to 70% and the number of student who used data extremely or very often went up from 46% to 60%. Finally, there was a short written interview with two questions about how the course influenced the students approach to data and future science and engineering career decisions. Almost all of the students said it had changed their view of data and its impact on every day activities. There were some who felt it would influence their future as data-driven work becomes more important. Most of the undergraduate humanities and social sciences students said that their fear of science and technology academic work has diminished or evaporated. They were more willing to engage in scientific endeavours, and, for non-engineering majors, would consider changing directions. Students and the teaching group agreed that the Drupal CMS was essential to support the team work and for the overall success of the course. The faculty suggested the following changes for a similar course in future:

- Smaller teaching groups, e.g. a data scientist, a humanist, an engineer
- More experience for the teachers with the Drupal CMS functions
- More rigorous learning objectives, without losing the “immediacy” and real-world feeling

- More clearly expressed goals that students are being prepared or encouraged to move into science and engineering fields.
- One professor wanted the course targeted to female students who are most likely to switch to an engineering program.
- They also felt strongly that such an interdisciplinary course need to be required for all engineering students in their third or fourth years.

4. Conclusion

This course made significant inroads into understanding the broad array of human and technological requirements for developing and implementing an effective interdisciplinary course. While both faculty and students felt that it was a valuable experience in and of itself, after careful evaluation the faculty came to realize that this course is but one milestone on the path toward the on-going realization of benefits from active interdisciplinary collaboration in teaching and learning. The most compelling experiences for the teaching faculty and the students were the intra-disciplinary mix of participants and the focus on data and systems informing global challenges. The female participants frequently commented that they enjoyed a predominantly female class. Based on the above, the senior author is working with engineering, biology, economics, and computer science faculty to develop a teaching program that combines technology with the economics of emerging electricity generating systems and various forms of energy storage. Using intermittent energy sources (e.g. solar, wave, and wind) as the dominant supply of electricity in future will require a combination of storage technologies and controls. Ideally, we must combine aspects of device technology, economics, control theory, user behaviour, and statistics. The theoretical premise of the interdisciplinary course(s) will be to explore the similarities between energy and materials flow in engineered systems and in natural (biological) ones, thus improving the “ecology” of proposed artificial systems. Yet again, the main challenge is how such an interdisciplinary course can be constructed to encourage more participation by female students from non-engineering fields?

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