A chemist, engineer and environmental scientist walk into a classroom…

Outcomes from an interdisciplinary project-based course

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Introduction

Educators have highlighted the importance of working beyond the confines of a single discipline to solve complex challenges as diverse as sustainable development, establishing new business ventures and providing effective health care (Lehmann, Christensen, Du, & Thrane, 2008; Lüthje & Prügl, 2006; Thistlethwaite, 2015). Many institutions are preparing students for this through open-ended project-based learning, where students from various disciplines practice the skills of collaboration to combine the perspectives and expertise of different disciplines, reduce the complexity, uncertainty and ambiguity to workable concepts, and create value for an enterprise or customer (Kamp, 2018). Interdisciplinary teamwork requires studying the problem from the perspective of each discipline, generating and sharing insights from each and then using the new shared knowledge to create solutions. Testing the solution and evaluating the learning process itself are integral to learning outcomes for each disciplinary team (Newell, Wentworth, & Sebberson, 2001).

In this paper, multidisciplinary working will be characterised as two or more experts coming together to work on a problem, each bringing their own expertise. There is limited exchange of information or increased knowledge of the other discipline, as if the expertise areas have been ‘patchwork-quilted’ together (Borrego & Newswander, 2008; Porter, Roessner, Cohen, & Perreault, 2006). Conversely, true interdisciplinarity is a fully integrated approach, where experts work closely, combining knowledge to work towards a solution. This kind of working changes a person, altering their view of the world or how they work.

Interdisciplinary learning can be difficult to achieve and sustain due to intrinsic differences in epistemologies, traditions, knowledge and culture of each discipline. Bradbeer (1999) asserts three key challenges in achieving interdisciplinary learning: working across, working in and synthesising different disciplines. These are characterised into three phases: issues with working in multi-disciplinary ways as students move from one discipline to another, moving towards interdisciplinarity through understanding what the other disciplines have to offer, and working truly interdisciplinarily through synthesising information from other disciplines. A key barrier to moving through these stages is self-awareness and adaptability of learning styles.

Self-awareness is a key attribute of effective interdisciplinary learning. Awareness of oneself to question and understand the ‘how’ in learning, as compared to just the ‘what’, which is required for truly interdisciplinary collaborations. Helping students increase self-awareness and reflexivity can assist in becoming proficient interdisciplinary learners and gain the most from an interdisciplinary experience (Bradbeer, 1999).

The intended learning goals for interdisciplinary project courses tend to be the same for all team members, and focus on professional skills such as interdisciplinary thinking, research and design capabilities, collaboration and communication, self-adjustment and reflection. Students are expected to use their discipline knowledge in addition to understanding and appreciating other disciplines. However, in multi-disciplinary teams, members are only expected to bring disciplinary expertise to the team. Thereby, the intended learning outcomes include enacting their discipline effectively within a team. In this case, it is appropriate that each member of the team be assessed against intended learning outcomes appropriate to their discipline role (Taajamaa, Westerlund, Liljeberg, & Salakoski, 2013).

For engineers to solve complex global challenges, they will need to exhibit many of the skills and challenges faced in interdisciplinary teams: agility, resilience, flexibility, the ability to frame problems in socio-technical contexts, work across disciplines and collaborate effectively with multiple stakeholders (Daly, Mann, & Adams, 2008; National Academy of Engineering, 2004). Project-based learning in engineering curricula is helping to foster some of these skills, but explicit interdisciplinary collaboration has not been investigated.

A key feature of interdisciplinary projects is the knowledge and processes each discipline provide, that together can achieve an outcome not possible alone. In this research, environmental science, engineering and environmental chemistry academics identified an opportunity to develop an interdisciplinary student project based on research investigating mercury contamination arising from small-scale artisanal mining in rural Indonesia. Seven final year undergraduate engineering students worked with one final year Masters of Climate Change student over a semester, mentored by an interdisciplinary team comprised of engineering, environmental science and environmental chemistry academics. This research also involved students from an intensive water science summer course in an initial interdisciplinary workshop. The aim of this research was to understand experiences of students in an interdisciplinary project in order to improve future interdisciplinary experiences. This paper outlines key factors of collaboration across communication, logistics and assessment, and makes recommendations for establishing effective interdisciplinary student projects.

Context and Approach

The project focused on the deployment of a newly created limonene polysulfide with mercury-absorption properties (Crockett et al., 2016; Worthington, Kucera, & Chalker, 2017). The environmental researcher saw a potential application of this for remediation of mercury contaminated water in rural Indonesia. An interdisciplinary approach was required as the chemistry of the polymer, environmental impact of the polymer and engineering deployment techniques are integral to investigate to ensure suitability and appropriateness.

The advisory team proposed and facilitated this project in a final year project-based engineering capstone subject. However, it was recognised that the engineering student team would need to be augmented with environmental science expertise. Consequently, a Masters student was invited to participate in the project through a research project in an environmental science subject. The engineering capstone subject has intentionally flexible assessment, focusing on traceability and client requirements, and a similar arrangement for incorporating the Masters student was sought.

The academic team acted as clients and were heavily involved in scoping the project. The project team was tasked with developing and testing concepts for deployment of the polymer. To complete testing and deployment, a closed rural gold mine 60kms from the university, with known mercury seepage in waterways was used as a field site. Water from the site could be tested on campus, with the use of the environmental chemists' laboratory.

The engineering team (referred to as participant group B), was assembled based on an interest in humanitarian engineering. Prior to the start of the teaching period, the interested students were invited to participate in a portion of a co-badged second year coursework Water Science summer intensive course taught by the environmental science and environmental chemistry advisors. The engineering students were invited to participate in the lectures and field trip relating to mercury and associated environmental and health impacts. After a visit to the field site, the students in the water science course (A) and four of the project team (B) were involved in a workshop framing the group project, facilitated by the engineering advisor. Throughout the semester, the team met regularly with the academic team (D) and Masters student (C) and completed three stage-gate assessment pieces for their course, as well as a poster at the conclusion of the project. Table 1 provides an overview of the other key learning activities undertaken by the participant groups.

Table 1 Overview of learning activities with respect to participant group

Student groups	Learning Activities	Timing
Water Science students (A)	Mercury lecture, trip to field site, interdisciplinary workshop	Before semester
Engineering team (B)	Mercury lecture, field site visit, interdisciplinary workshop (3/7 team members).	Before semester
	Client meetings	During semester
	Lab inductions	Week 3
	Capstone course tutorials and presentations	Week 4, 6, 11
	Visit from sulphur-limonene expert Dr Justin Chalker	Week 6
	Poster presentation	Week 12
	Visits to field site	Throughout semester
	Field site testing and lab testing	Final 6 weeks of semester
Environmental science Masters student (C)	Mercury lecture, trip to field site, interdisciplinary workshop and full Water Science course	Before semester
	Lab inductions and performing lab tests	Week 6-7
	Visits to field site	Throughout semester

Method

A mixed-methods approach was taken to understand student experiences and perceptions of the interdisciplinary project. This is a common approach for project-based learning that provides flexibility in application of research techniques and triangulation of data (Lee, 2010; Martínez et al., 2006; Rouvrais et al., 2006). Surveys, focus groups and observation were the primary data collection methods. Table 2 shows the methods of data collection with respect to the participant group and timing of the collection. All data collected is in alignment with an approved human ethics protocol at the institution. Research work was undertaken by an independent research assistant who was not involved with delivery or assessment, with support from the academic coordinators.

Table 2 Data collection methods with respect to participant group and time of data collection

Participants	Form	Timing of collection
Water Science class (A), three engineering team members (B), environmental student (C)	Pre/post surveys	Before project commencement
Project team (B, C)	Observations	Throughout semester
Environmental student (C), engineering team (B) academic team (D)	Interviews and focus groups	Completion of project

At the conclusion of the Water Science mercury lecture and prior to the interdisciplinary workshop, students (A,B,C) were invited to complete a pre-survey on their beliefs about their field of study and experiences working outside of their discipline. After an introduction to the project, students worked in discipline groups to brainstorm what information or skills would be needed for the project. These students were then placed in interdisciplinary groups and to compare and contrast their discussions. The students were then invited to complete a post-survey based on their experiences in the workshop.

The first few weeks of the project involved scoping the project and intended outcomes with the help of the advisory team. Team meetings and visits to the pilot testing site were observed and ethnographic field notes taken. Finally, at the conclusion of the teaching period, the engineering students (B), the Masters student (C), and advisory academics (D) participated in focus groups and interviews. These allowed the various groups to express their perspectives about the project and their personal experiences. The line of questioning focused on the interdisciplinary aspects of communication, logistics and assessment, as it was not focused on the course or cohesion of the individuals as a team.

Results and Discussion

The survey results, observations, interview and focus groups were used to understand the project team, academic team and water science student's beliefs and experiences of interdisciplinary learning. The survey data was independently analysed, while the observations, focus groups and interviews' results were triangulated during analysis. All results were then combined to generate outcomes. The interviews were transcribed and coded based on emerging themes throughout the semester or previous interviews.

Student background (A,B,C)

Pre-workshop survey

Table 3 shows the demographics of the students who participated in the pre-survey for the interdisciplinary Water Science course workshop. The response rate was high at 87% n=35.

Table 3 Pre-survey demographics, n=35, 87% response rate

Demographic	Raw response	% (n)
Gender	Female Male Non-binary NA	51 (18) 40 (14) 6 (2) 3 (1)
Enrolment	Full-time Part-time Depends NA	86 (30) 9 (3) 3 (1) 3 (1)
Student type	Domestic International NA	29 (10) 66 (23) 6 (2)
Age	18-22 23-25 26+ NA	49 (17) 31 (11) 17 (6) 3 (1)

Table 4 shows the degrees or majors of students involved in the class workshop. Due to students undertaking double degrees, more than the n=35 value is represented. The largest group were those undertaking environmental science degrees or majors (43.9%). Only 12.2% of the students were studying engineering, meaning any results from these surveys may not be representative of engineering students' beliefs more broadly.

Table 4 Interdisciplinary workshop session participant degrees and majors

<table>
<tr><th>Degree</th><th>n=35</th><th>Combined</th><th>% of n</th></tr>
<tr><td>Science (chemistry, physics, biochemistry, earth science, biology, biomedicine, mathematics, psychology)</td><td>15</td><td>15</td><td>36</td></tr>
<tr><td>Environment (UG) (environmental science, water science, resource and environmental management, land management)</td><td>10</td><td rowspan="2">18</td><td rowspan="2">44</td></tr>
<tr><td>Environment (PG) (environmental science, climate change)</td><td>8</td></tr>
<tr><td>Engineering</td><td>5</td><td>5</td><td>12</td></tr>
<tr><td>Non-Science (accounting, finance, sustainable development, geography, economics, criminology)</td><td>5</td><td>5</td><td>12</td></tr>
</table>

Beliefs and feelings

Initially, the Water Science class survey responses showed students believed the most significant factors in achieving the project aims were a mixture of communication skills, better understanding and factors related to their discipline. For example, chemistry students were more likely to focus on the properties of the material, engineering students on the deployment technique and environmental students on the potential environmental impacts of the polymer. This is to be expected, as students apply their own knowledge and discipline understanding to the problem.

The science and engineering students' beliefs about their disciplines differed in key areas, as shown in Table 5. Students were asked to rank beliefs from 1 (strongly disagree) to 5 (strongly agree). Percentage agreement is based upon the percent of responses of 4 or 5, agree to strongly agree.

On average, science and engineering students reported that they had experience outside of their discipline, but a larger portion of the science students had such experiences, 64% compared to 33% of the engineering students. Science students also identified they had been taught to work in multi or interdisciplinary groups (86%), more than the engineering students (33%). This may be due to science students taking multiple majors, taking subjects that contribute to multiple majors within science, having greater choice and flexibility in their degree, or having greater exposure to interdisciplinary studies or students in those subjects. At the university, there are 25 different majors and 43 minors or specialisations available to science students, while engineering provides 6 major/minor options. Science students have more opportunity to engage in various sub-disciplines within science than engineering students. However, as the engineering response rate was so low, it is hard to draw conclusions. Interestingly, a slightly larger percentage of the engineering students (40%) were completing a double degree with a degree outside of engineering, compared with the science students (32%).

Table 5 Significant belief differences between science and engineering students, n=35, 1=strongly disagree 5= strongly agree

	Science Beliefs Avg	**Eng Beliefs Avg**	**Δ**	**Science agree (%)**	**Eng agree (%)**
Experience outside discipline	3.86	3.33	0.52	64	33
Taught to work in multi/cross-disciplinary groups	4.29	3.50	0.79	86	33
Comfortable outside of discipline	4.57	4.33	0.24	100	67
Take leadership role in projects	3.86	3.00	0.86	64	33
Importance of research skills	3.29	4.00	0.71	29	100
Importance of interdisciplinary knowledge	3.50	2.67	0.83	57	0
Importance of ethical practice	3.21	4.00	0.79	57	100

In regards to students' perceptions of important factors for their discipline, students reflected the focus of their university experience as shown in Table 5. 100% of engineering students believed research skills were important, compared to 29% of science students. Science students' comfort in interdisciplinary situations is also seen in 57% of respondents believing interdisciplinary knowledge is important, while none of the engineering students perceived it as important. This may be because engineering students feel discipline knowledge is central to the role of an engineer, and the curriculum does not encourage or promote interdisciplinary learning. Ethical standards of engineering are specified by Engineers Australia through a set code and competencies. Potentially this emphasis was seen in 100% of the engineering students believing ethical practice to be important, while only 57% of science students believed it to be important.

Creating effective teams (B and C)

Team configuration (maturity, selection, formation)

The engineering project team were all students in their fourth year or above (double degrees are five years in total) of study and had completed group projects in previous courses. Selecting students based on their interest in the topic enabled a mixture of engineering majors and experience. This variance in work-experience and maturity in managing teams and working with clients became apparent during the semester, and was exacerbated by the Masters student's numerous years of industry experience. Throughout the project, the gap in understanding of professional communication, deadlines and processes were apparent.

Two team members were unable to attend the Water Science course or the first week of semester, creating delays, mismatched expectations and understanding of responsibilities. A formal commencement or primer session with all students and academic supervisors may have created a more cohesive unit, and established expectations from the beginning. One student remarked,

> *"…we missed the opportunity to sit down all together and work out what we expected… it was a broke*[n] *up process…* [meeting] *could have helped get everyone on the same page better."*

The lack of team cohesion could also be seen when interacting in meetings or at the trial site. Certain team members would congregate or discuss topics together, while others engaged more readily with the Masters student or took leadership roles.

Expectations

Lack of clear expectations also meant the Masters student's role was unclear, which was intensified by differences in maturity. For the first few weeks, the Masters student tried very hard to connect with the team and create momentum. They felt the expectations from the engineering team was not clear. Their role also changed throughout the semester, initially collecting and testing water samples but progressing to sending emails on the team's behalf. This was also difficult, as the Masters student was not enrolled in the same course as the engineering students and had a different assessment schedule.

Assessment

The engineering students' assessment, as dictated by the capstone course, entailed three stage-gate presentations throughout the semester, a poster and an individual reflection. This is similar to other capstone projects such as Skates (2003).The Masters student was required to complete a research project and submit a final report.

The separation of assessment between the Masters student and the team appeared to suit them. They were able to set the scope for their project independent from the engineering team, running in parallel but not relying on the work of the engineers. The student said,

> "*From past work experiences, I didn't want to have to rely on* [the engineering team] *… in the last weeks of semester when everyone is stressed… and not have vital information"*.

However, this separation increased division between the team and limited the interdisciplinary capacity flowing both ways. It created more of a multidisciplinary learning experience where the engineers relied on the environmental science expertise to help them, but in doing so, did not enable the Masters student to also learn.

Interdisciplinary work (B, C, D)

Understanding discipline-specific approaches

Terminology or knowledge is often used across disciplines with specific meanings, depending on the context. This became apparent throughout the semester with specific language and understanding of concepts such as 'testing'. One student commented,

> "*…I would have liked to go to the water science course… to fill in knowledge I didn't have. Or a technical session with people at the beginning. Without technical understanding it's hard to make good decisions and we were making a lot of decisions at the start*".

One course convenor remarked, "[the engineering students] *were after a number, instead of thinking about the analytical part… I think they were thinking in a single discipline way instead of multi-disciplinary way*". The engineering students were seeking a number for the effectiveness of the sulphur-limonene concentration they were deploying, but the results required further interpretation which is a key aspect of environmental chemistry.

This could be attributed to the engineering students relying heavily upon the Masters student for testing and interpretation of results. It was in part the team's approach, but was reinforced by limited lab access and inexperience with the mercury testing equipment. High-consensus fields with well-defined terminology such as engineering and environmental science can enable a multidisciplinary approach such as with the testing, which arises from one discipline's knowledge of apparatus or analysis (Borrego & Newswander, 2008; Lodahl & Gordon, 1972).

Instruction in interdisciplinary work

A primer workshop could have been used to introduce interdisciplinary techniques or required knowledge, like at Plymouth University, alongside a comprehensive student handbook (Skates, 2003). This may ensure the cultural traditions and key cognitive differences or knowledge gaps between the disciplines can be explored. Through a primer and open discussion, students can reflect on their own discipline and what differences they need to understand and work within to create a successful collaboration.

Further to discipline knowledge, the students were not equipped with interdisciplinary skills to guide them through the learning journey. While some may have been more self-aware than others, the skillset was not explicitly supported. One academic team member said

> *"…in hindsight, what we did is a fairly classic, let's put people from different disciplines in a room and hope they work out working in a multi-disciplinary team is important and what that means. One of the biggest takeaways is we need to prepare students for what that looks like."*

Further, one of the academic team noted academic cultural norms that the students were perhaps not aware of, such as courtesy and laboratory protocols. The engineering students were not aware their testing prevented others from completing testing, influencing others work. By helping students develop their self-awareness, their learning, experiences and maturity can be enhanced.

Recommendations and future work

Interdisciplinary projects encounter a range of challenges. To help combat these and improve student experiences and outcomes, recommendations from this project are:

- consideration of team configuration and formation
- clear expectations and planning – induction primer, creating plans
- communication and knowledge sharing – assessing skills and strengths
- assessment – negotiation and alignment of assessment

Future work would be in implementing these recommendations in a similar course and evaluating the experiences and observations in comparison to this research. Through engaging engineering students in interdisciplinary projects, they are exposed to various epistemologies, ideas and perspectives that will help them solve complex problems.

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