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Sustaining Interdisciplinary Projects in Green Engineering: Teaching to Support Distributed Work*

MARIE C. PARETTI, DAVID M. RICHTER and LISA D. MCNAIR
Department of Engineering Education, Virginia Tech, E-mail: mparetti@vt.edu, richterd@vt.edu, lmcnair@vt.edu

Design projects associated with sustainability efforts often require interdisciplinary student teams to address technical, social, and environmental concerns. While educators are increasingly seeking to understand and actively teach interdisciplinary collaboration skills, less attention has been given to the structure and context of such teams. In this paper, we draw on prior research to analyze interdisciplinary teams as sites of distributed work. Using frameworks that identify key characteristics of co-located and distributed work, we identify key factors in interdisciplinary design teams that may inhibit collaboration. We conclude with strategies for faculty to help sustain such teams through concrete course management practices and through explicit learning outcomes that can help students transfer teaming skills learned in this environment to new projects.

Keywords: design education; distributed work; interdisciplinary teams

1. INTRODUCTION: GREEN ENGINEERING AND INTERDISCIPLINARY COLLABORATION

'SUSTAINABLE DESIGN' reflects the broad commitment to creating artifacts and processes that 'meet the needs of the present without compromising the ability of future generations to meet their own needs' [1, p. 54]. In this paper, we examine one particular dimension of sustainable design as it is practiced in engineering. 'Green engineering projects,' which emphasize life-cycle analysis, are one important dimension of sustainable design because they focus on wise use of materials and energy, beginning with the raw materials and ending with product disposal. Such projects often require experts who can integrate knowledge and methods from fields such as materials science, mechanical engineering, biological sciences, industrial design, human factors, natural resources, and sociology. To better prepare undergraduates for professional practice in this area, many universities are increasingly turning to green engineering projects in capstone or other design courses [2, 3]. Here we address how such projects can themselves be sustained and supported through effective pedagogy.

Learning outcomes for such courses typically include not only technical competence, but, increasingly, skills associated with collaborating across disciplinary boundaries. Traditional multidisciplinary collaboration often relies on a divide and conquer approach, in which experts work within their own domain and then exchange or 'hand off' their part of a project. The kind of intensive interdisciplinary collaboration required of most green engineering projects, in contrast, often relies on an integrated approach in which experts learn deeply from one another in terms of both information and approach, and synthesize their expertise to create new knowledge and generate new ways of working [4–6]. In previous work, we have reported findings from case studies of interdisciplinary collaboration to first identify the cognitive barriers individuals face when they seek to engage in such work and, second, define appropriate learning outcomes for interdisciplinary collaboration [3, 7, 8]:

- '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.' [7, p. 34]

But these outcomes, though important, represent only one dimension of the challenge of interdisciplinary work. In this paper, we turn from cognitive concerns regarding how students value and integrate multiple disciplines to structural concerns regarding how students establish and maintain productive collaborations. Specifically, we argue here that interdisciplinary collaborations represent *distributed work environments* that differ markedly from within-discipline teams that are more likely

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to operate as co-located environments. Distributed collaboration is generally more reflective of the professional environments most students will experience when they enter the workplace. Sustaining these collaborations, however, requires not only a different set of management practices on the part of course faculty but also a set of collaboration skills on the part of students that reach beyond traditional teamwork approaches such as forming, storming, norming, performing; identification of team roles; use of personality profiles; or creation of Gantt charts or similar management tools.

2. CO-LOCATED VERSUS DISTRIBUTED WORK

As noted above, addressing cognitive or epistemological distance among team members is one important dimension of sustaining successful teams. Addressing spatial, temporal, and contextual distance is, in many cases, no less important. In general, researchers refer to co-located work environments as those in which team members operate in close proximity to one another: they work the same or similar hours, their offices are in the same area or at least on the same floor of a building, they have common areas for meetings or informal interactions, they have common physical space (including walls, whiteboards, or corkboards) for the artifacts associated with the project (files, diagrams, models, prototypes, etc.), and they cross paths routinely during the day and have ready access to one another [9]. At its most extreme form, co-located work is represented by a project room or war room in which all collaborators work all day in single large shared space, with walls and tables providing multiple spaces to construct and negotiate the project details.

In distributed work environments, in contrast, collaborators do not share physical or temporal space. Team members may be located in different buildings (or different cities or countries), they work different hours, and there are few opportunities to meet informally throughout the day. Research suggests, in fact, that distributed work environments can exist when the distance between team members is as low as 30 meters [9, 10].

With the rise in global virtual collaborations, research on distributed work has risen significantly in recent years. In particular, researchers have been concerned with identifying critical characteristics of co-located work that are absent or significantly diminished in distributed work [9-20]. Olson and Olson, for example, identify ten key characteristics of co-located work that support effective collaboration and that are typically absent in distributed environments [9, p. 149]:

- Rapid feedback.
- Multiple channels (e.g. voice, gesture, tone, body language).
- Personal information (i.e. collaborators know one another).
- Nuanced information (collaborators can subtly indicate shades of meaning via gesture or expression).
- Shared local context.
- Informal 'hall' time before and after meetings.
- Coreference (the ability to establish shared points of reference).
- Individual control (anyone present can change the focus easily).
- Implicit cues (access to information about what's happening around the edges of the project, context).
- Spatiality of reference (physical location of both collaborators and objects such as papers, drawings, models).

Characteristics such as the absence of multiple channels or nuanced information may be less of an issue for interdisciplinary teams on a single campus, where participants can and do meet face to face regularly. Two characteristics, however, have emerged through our case study as potentially relevant to interdisciplinary teams: shared local context, and informal 'hall' time before and after meetings. In addition, although not easily identified in the data analysis, we note here that an absence of personal information in interdisciplinary teams may also contribute to the distributed nature of the work.

Shared local context: Co-located teams typically share a common work context; they have similar schedules, are surrounded by similar activities and local events, and operate under the same set of work constraints and expectations. As Leinonen et al. note, 'in distributed settings, team members do not share a common physical environment that provides cues of others' state of work, and so participants do not have common orientations and reference points' [15, p. 303]. This shared local context is common for within-discipline teams. Outside the project course, collaborators may share course times and instructors, deadlines for other tests and assignments, departmental requirements and constraints, student organization meetings, knowledge of faculty and equipment, and general departmental culture. When students come together across disciplinary boundaries, however, they may find conflicts in class schedules that make meetings outside of the project class time difficult; they may face different sets of departmental requirements that result in differing workloads outside the project; they may have conflicting deadlines for other assignments; and they may face different sets of departmental expectations regarding projects.

Informal 'hall' time: Individuals on co-located teams have opportunities to interact informally before and after meetings, chatting 'offline' about the project and forging a set of social bonds that

facilitate interaction. Although interdisciplinary teams on the same campus may have opportunities for such 'hall time' immediately before and after project or course meetings, they often have fewer such opportunities than students on within-discipline teams. Students from the same discipline often share not only the project course but also an array of other courses as well as common areas such as lounges. These shared spaces enable them to run into each other or catch up informally multiple times (often daily) throughout the week. In departments small enough to offer only one section of each course, in fact, disciplinary team members may see each other several times a day every day and have numerous informal interactions. In contrast, students on interdisciplinary teams, particularly in larger universities where departments are often located in different buildings, may see each other only during the class time or scheduled meetings, and may be constrained by class times that require them to move immediately from a project meeting to another course at set times.

Personal information: In co-located teams, individuals either already know one another or come to know each other quickly because of the extensive time spent together. In traditional disciplinary teams, particularly in small departments, this access to personal information often grows quickly as students share courses, student activities, and study lounges. By the time they are seniors, many engineering students are often very familiar with the strengths, weaknesses, and personality quirks of their classmates and thus have an extensive body of personal information about their collaborators to draw on. As noted above, we have not yet analyzed the case study data in ways that track these gaps and their implications, but we raise the issue here as an additional complication in the nature of interdisciplinary collaborations.

The gaps in shared local context and informal meeting times identified in the literature and emergent in the case studies are important not only for their likely appearance in interdisciplinary teams (as noted in the case study described in Section 3, but also for their impact on two important dimensions of collaboration: 1) relational space, and 2) attention and motivation.

Relational space: Perhaps the most critical factor associated with distributed work is the difficulty of establishing the social network necessary for effective collaboration. Leinonen et al., for example, distinguish between 'a *content* space (consisting of the problem to be solved) and a *relational* space (consisting of the social interaction challenges and opportunities)' [15, p. 302] and explore the interdependence of the cognitive and the social domains, noting that relational space is central to success. Some research does indicate that in highly structured teams with clearly defined work roles and a strong management structure, this relational space may be less significant [21]. Most student design projects, however, are not highly structured and managed by an expert because project management itself is often a key learning goal. In such situations in both classroom and workplace studies researchers have identified the social network among collaborators as critical to team success. Nardi and Whittaker, for example, identify a 'communication zone' created unconsciously by the network of informal interactions among collaborators in face to face settings. This communication zone is the metaphorical space that makes more technical communication about the project possible [16]. Similarly, numerous researchers have identified trust as a critical factor in the success of distributed teams and a key limiter in distributed environments, and much of the work on virtual collaboration focuses on how to help collaborators establish functional levels of trust quickly [11–14, 19, 22–24]. And as Jarvenpaa and Leidner note, factors that support trust include 'shared social norms, repeated interactions, shared experiences . . . and anticipation of future interaction' [12]. Elsewhere McNair, Paretti, and Davitt have summarized key behaviors that support the development of such trust [25]. In interdisciplinary student teams, the absence of personal information, informal interactions, and shared local context thus all mediate against the pre-existence of trust among team members or the rapid development of trust in the early stages of the project.

Attention and motivation: The second set of related factors that is critical to team success but that may be hampered by the distributed characteristics of interdisciplinary teams is attention and motivation. That is, in order for participants to succeed in sharing and synthesizing knowledge (a core goal of interdisciplinary collaboration), they must both attend to the information circulating through the team and be motivated to engage and act on that information [17]. Collaborators must share a commitment to a common goal, which often involves insuring that each of the collaborators values the goal in similar ways. As with social networks, the absence of a shared local context in interdisciplinary teams can create varying levels of both attention and motivation. Both may be heavily influenced by the value of the course within the students' curriculum, the other (disciplinary) courses competing for students' time and energy, and departmental expectations about time devoted to in-major versus out-of-major courses.

As noted, much of the work on both social networks and attention and motivation has occurred in the context of virtual collaboration, where participants lack the ability to engage in regular face-to-face dialogue. We argue here, however, that interdisciplinary student teams also confront challenges in these areas because the physical and social conditions of a campus environment can create distributed work conditions for such teams. The following case study operationalizes these conditions and illustrates their effects

on attention/motivation and relational space in two student teams engaged in a green engineering design course.

3. METHODS: A MULTI-CASE STUDY OF DISTRIBUTED WORK IN GREEN ENGINEERING TEAMS

To examine interdisciplinary collaboration as distributed work and identify both faculty interventions and student learning outcomes needed to sustain such work, we turn to an analysis of two case studies in green engineering. Yin defines three conditions that merit case study research: (1) the nature of the research question is typically explanatory, exploratory, or descriptive, typically asking 'how' or 'why'; (2) the investigator lacks methods to control the site and participants; and (3) the phenomenon being studied is contemporary and the context is real-life [26, p. 1]. The distributed nature of interdisciplinary projects in academia has not yet been explored, and this initial investigation involves analysis of working teams as they move through a year-long course. The multi-case study provides an opportunity to explore their collaboration through the lens of distributed work.

3.1 Research site

Both case studies were conducted at a large mid-Atlantic state university with the approval of the university's Institutional Review Board (Case 1, IRB #06-554; Case 2, IRB #06-594). All names included in this analysis are pseudonyms.

Case 1 examined students in a one-semester technical course on life cycle analysis, part of the university's concentration in green engineering. The course included students from several engineering disciplines (civil and environmental, materials, mechanical, and industrial systems) as well as industrial design. Though primarily a content-focused course, students were grouped into teams for a course project lasting several weeks, which involved conducting a life-cycle analysis of a selected product. Teams were assigned to insure a balance of disciplines on each team. Richter has provided a comprehensive discussion of this case elsewhere [3]. This case provides a key starting point for identifying interdisciplinary teams as sites of distributed work.

Case 2 followed two teams of students through a year-long interdisciplinary design course in green engineering. Team 2A included students from materials, civil and environmental, and biological systems engineering, along with one student from business. The project involved design of a system to provide clean water to communities in underdeveloped regions of the world. Team 2B included students from materials, biological systems, engineering mechanics, and industrial and systems engineering; during the first semester the team also included one student from business. The project involved design of a method to recycle rather than landfill waste material from a local manufacturing company. These cases enable us to more fully identify the multiplicity of factors at play in the distributed work of an interdisciplinary team.

3.2 Data collection and analysis

For both cases, data collection included observations of team interactions in class along with interviews of participants. Data for Case 1 also included several surveys with both quantitative and qualitative questions. Data for Case 2 also included observations of out-of-class interactions, electronic correspondence among team members (email exchanges were copied to the observer), and focus groups.

In this article, we present data from the qualitative team observations and interview data from both cases, along with open-ended survey responses from Case 1 and focus group responses from Case 2. Following accepted practices for analyzing qualitative data, we applied an open-coding approach [27]. Responses were segmented into complete thoughts (phrases or complete sentences); segments were then examined for a central theme, themes were compared, and similar themes were grouped together [28–30]. The relevant dominant themes were then used to recode all data. These themes were then compared against prior research on co-located versus distributed work, and areas of overlap were identified. The work presented here addresses those themes associated with the distributed work environment; as noted earlier, we have reported on themes associated with cognitive and epistemological barriers elsewhere [3, 7].

4. FINDINGS AND DISCUSSION

Each of the two case studies provides ample evidence of the absence of both shared local contexts and informal meeting times, and both interview and observation data point to corresponding challenges in attention and motivation.

4.1 Shared local context

In both cases, the absence of a shared local context emerged as a dominant point of difficulty through two themes: scheduling and departmental expectations. In the analysis of Case 1, the prominence of 'scheduling' emerged as a theme in both survey and interview responses; in fact, it was the dominant challenge students identified with respect to interdisciplinary collaboration. Sample responses under in this theme include:

- 'Having to work around everyone's schedules was a bit tedious.'
- '[H]ard to make a coherent project without constantly being in contact with one another.'
- '[D]ifficult to get others together.'
- 'Interdisciplinary teams are hard to work with as seniors because all different majors' schedules are hard to coordinate.'

These comments, though they might also emerge in lesser ways for within-discipline teams, are more frequent in interdisciplinary teams because of the absence of shared course schedules. For example, seniors in mechanical engineering had their capstone meeting times Tuesdays and Thursdays for an hour and fifteen minutes with beginning meeting times ranging from 9:30 am to 5:00 pm. Industrial engineering seniors had a required recitation on Tuesdays and Thursdays from 3:30 to 4:45 pm. Industrial Design students of all academic levels have 'studio' every Monday, Wednesday, and Friday between 1:00 and 5:00 pm.

Similar scheduling problems emerged in Case 2, where conversations among team members often involved the difficulty of finding time to meet outside class or conflicting test and homework deadlines that consistently disrupted group members' ability to participate in common tasks and limited their attention to the project. The observation data for both teams in this case indicate numerous problems with students coming late and leaving early for meetings due to other schedule constraints, and at one point a team member joked that they need to 'bolt the door so no one leaves.' Students consistently lost track of deadlines (an absence of attention) or missed meetings because they forgot. In the post-course interview, for example, one participant noted that these gaps in attention were particularly significant for one of the team members:

> We have issues of she's very busy so, again, just different expectations of meetings. We all wanted to meet, well, she really didn't want to, and again, I think we had a hard time kind of finding that middle ground so we're meeting, but we're not, you know, not your kind of . . . . I think that sometimes on this level it's hard to do that without being at the meeting, you know?

These conflicts also suggest an absence of relational space and shared commitment to the project that are critical in distributed work environments.

Beyond the issue of scheduling, however, Case 2 also pointed to the absence of a shared local context in terms of departmental requirements and expectations. All of the engineering students involved were using this course as their capstone design project, but each faced a different set of departmental expectations for the course. In one case, for example, the departmental requirement was for only a single semester of capstone design, which produced a strong sense of overwork:

> . . . one of my friends is getting the green engineering minor, and he asked me specifically should I do the project, and I said, honestly I probably wouldn't if I was you just because it's a year-long project, it takes a lot of time, I mean when you could be doing one-semester project getting the same kind of, I don't know, not getting the same experience but getting the same [credit] . . . I wouldn't recommend it to anybody who is just trying to get the credit for it. I would only recommend it to somebody who is really truly interested in it and wants to put a lot of time and energy into it because I know the civil design classes do not take nearly the time and energies this does.

In another case, a student's home department required additional presentations, which became a significant source of conflict:

> We signed up to work together on the presentation and just because he's in [another major] doesn't mean that he can't participate in the senior design and it frustrates me because I felt like, you know, all my slides I've worked on, he pretty much too all of them to [his department] presentation and he's off the hook. So, he gave me a very, uhm, laid back attitude [in our] senior design presentation: I don't want to do it, I don't need to do [it], I do my [department thing].

Here the comments suggest both a lack of shared motivation for the project and a significant gap in trust between team members. Similarly, one student explicitly pointed to the ways her local context diminished her motivation:

> There's so many times like I do not feel like doing a report. Like I do not feel like writing anything for us. Like making slides or giving a presentation. Like, I just felt like I didn't have time for it. . . . . I had 18 credits, I had extracurricular things, I had a job, and I ended up dropping the [volunteer] that I was doing and quitting my job, like I ended up getting rid of a lot of things so that I could survive my other classes.

As these examples suggest, differing local contexts not only created conflicts in scheduling but also set up differing degrees of motivation and attention to the project at hand— differences that students may not have been well-equipped to handle but that are often common on cross-functional workplace teams.

4.2 Informal 'hall' meeting time

The barriers to scheduling meetings, identified above, were compounded, particularly in Case 2, by the absence of informal meetings among participants due to physical separation. Although some students arrived at class and team meetings early and could stay and chat for a few moments afterwards, others could not and the teams saw little to nothing of one another outside these times. In Case 1, the participating disciplines were located in the same general area of campus, but housed in separate buildings; each building is at least 30 yards from its closest neighbor. In Case 2, the distances were much greater; some majors were housed in buildings on the opposite side of campus, a good 10–15 minute walk away. Since in-major courses are typically held within the same building as the department, students from different disciplines typically do not pass each other during the normal school day. As one student from Case 2 explained in the post-course interview:

> Because like if you're in your major you have classes with them and it's easier to like, say, well, hey, we've gotta get this, like have a meeting after class instead of having to like plan it more in depth like you have to plan harder. It's a lot more planning is involved, but if you get into a habit of it, it's not too bad. It's just

> more stressful because you have to go to different buildings across [campus] as you say instead of just staying at your home base and having a meeting while you're doing homework or hanging out.

The absence of informal meetings 'while you're doing homework or hanging out' means that students must be more effective both in their use of electronic communication to stay in touch throughout the week and in their use of meeting time to accomplish key tasks and plan action items. And weaknesses in these areas can lead to conflict among team members, as illustrated in one student's description of her team member (in a different major):

> Okay, Sarah, Sarah thinks that there [is] total miscommunication in the team, and she . . . she kept trying, she said was [it] important to meet in person to the point where there was a meeting every day during the week, Monday, Tuesday, Wednesday, Thursday, Friday and it frustrates me because . . . I have other things to do and this is not my full-time job. This is one of my classes. And there was disagreement with how many times did we have to meet? I felt like we can't depend on everyone to meet every single day because that's where we were before. . . . [And] she thinks no one reads her emails. Where I think it's because she's sending so many emails that no one wants to look at every single one of them.

Here Sarah's sense of the team's need to stay in touch about the project (especially as deadlines grew closer) led to a desire for both more meetings and increased email volume—a desire that frustrated her teammates but that reflects, in large part, the absence of small daily interactions that may have mitigated the problem. Again, conflicts such as this point to an absence of trust among team members (i.e. that each person will in fact complete the assigned tasks) and the lack of a social network that would enable team members to engage with one another with a higher degree of mutual respect.

5. CONCLUSIONS—IMPLICATIONS FOR THE CLASSROOM

Importantly, the conditions of distributed work identified for the interdisciplinary teams in this case study are not unique to academic student teams. They may operate in within-discipline teams, particularly in larger departments where shared information, interactions, and contexts may be lower. They most certainly operate in contemporary workplaces where distributed, virtual, and global teams are increasingly the norm. They are thus critical barriers to successful collaboration that students need to learn to identify and manage. As faculty seek ways to enable students to sustain interdisciplinary collaborations, we need to consider the implications of treating such collaborations as distributed work for both course management and learning outcomes.

5.1 For faculty—creating opportunities for physical and virtual engagement

The relative absence of shared local context, informal meeting time, and personal information can have significant impact for faculty in coordinating and managing interdisciplinary teams. In particular, we suggest that faculty need to focus on creating opportunities for both physical and virtual engagement.

Physical engagement: Faculty working with interdisciplinary teams may need to provide students with more in-class time for face-to-face project work because class time may be one of the few (or only) shared meeting times students can establish. Given the importance of face-to-face meetings for successful collaboration, as identified by prior researchers (above), such time should be considered a critical component of the course. Such time should be structured and mentored in ways that enable students to both forge a strong relational space and plan effective uses of out-of-class time, as noted in the learning outcomes (below).

Virtual engagement: At the same time, faculty need to supplement this face-to-face time with the intentional integration of tools for virtual collaboration. While it may be tempting to assume that today's students, embedded in an array of social networking technologies, will inherently leverage these technologies for collaborative work, prior work by Paretti and McNair suggests that such leveraging cannot be assumed and students may instead separate social from professional uses of that technology [31]. Thus faculty should consider implementing and promoting specific virtual collaboration tools available through university course management systems or as freeware, and either requiring or strongly encouraging use of such tools outside class.

5.2 For students —learning outcomes for distributed work

Because the conditions of interdisciplinary collaboration at the university strongly resemble the kinds of workplace conditions many of our students will encounter, structured management on the part of course faculty is only one dimension of the issue. In order to help students develop a set of transferable collaboration skills, faculty also need to attend to learning outcomes that will enable students to better negotiate the next project that requires distributed collaboration. We suggest the following outcomes as a starting point:

- The ability to identify challenges associated with distributed work environments, including the ways in which differences in contexts, limitations in informal meetings, and the absence of personal knowledge can hinder performance.
- The ability to establish trust and relational space in distributed environments.
- The ability to select and employ appropriate

communication technologies to support distributed work, including using the technologies to create social networks, maintain attention and motivation, and effectively transfer complex technical knowledge.
- The ability to monitor distributed work environments for indicators of effective collaboration.

These outcomes represent important transferable competencies that will help students transfer sustainable skills from interdisciplinary collaborations experienced in academic environments to those encountered in their future workplaces.

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Marie C. Paretti is an assistant professor of Engineering Education at Virginia Tech, where she co-directs the Virginia Tech Engineering Communications Center (VTECC). Her research focuses on communication in engineering design, interdisciplinary communication and collaboration, and design education. She was awarded a CAREER grant from NSF to study expert teaching practices in capstone design courses nationwide, and is co-PI on several NSF grants to explore interdisciplinary collaboration in engineering design.

David M. Richter is a Ph.D. candidate in Engineering Education at Virginia Tech. His current research focuses on interdisciplinary collaboration in engineering design teams, design education, and design cognition.

Lisa D. McNair is an assistant professor of Engineering Education at Virginia Tech and co-Director of the VT Engineering Communication Center (VTECC). She is co-PI on several NSF-funded projects that explore issues of learning, practicing and teaching interdisciplinarity in university and industry settings. Her primary research interests are communication and collaboration in interdisciplinary and distributed settings, institutional structures that encourage transformational learning, and the possibilities of liberal education in engineering programs.