Moving Towards Individual Competence From Group Work in Transdisciplinary Education

Dr. Colin M. Gray, Purdue University, West Lafayette

Colin M. Gray is an Assistant Professor at Purdue University in the Department of Computer Graphics Technology and a Fellow in the Educational Research and Development Incubator. He holds a PhD in Instructional Systems Technology from Indiana University Bloomington, a MEd in Educational Technology from University of South Carolina, and a MA in Graphic Design from Savannah College of Art & Design. His research focuses on the role of student experience in informing a critical design pedagogy, and the ways in which the pedagogy and underlying studio environment inform the development of design thinking, particularly in relation to critique and professional identity formation. His work crosses multiple disciplines, including engineering education, instructional design and technology, design theory and education, and human-computer interaction.

Dr. Marisa Exter, Purdue University, West Lafayette (College of Engineering)

Marisa Exter is an Assistant Professor of Learning Design and Technology in the College of Education at Purdue University. Dr. Exter's research aims to provide recommendations to improve or enhance university-level design and technology programs (such as Instructional Design, Computer Science, and Engineering). Some of her previous research has focused on software designers' formal and non-formal educational experiences and use of precedent materials, and experienced instructional designers' beliefs about design character. These studies have highlighted the importance of cross-disciplinary skills and student engagement in large-scale, real-world projects.

Dr. Exter currently leads an effort to evaluate a new multidisciplinary degree program which provides both liberal arts and technical content through competency-based experiential learning.

Mrs. Terri S. Krause, Purdue University, West Lafayette (College of Engineering)

Terri Krause is a second year PhD student in Learning Design & Technology, a Graduate Research Assistant in Purdue Polytechnic Institute, and is serving on the research and evaluation team for the Transdisciplinary Studies in Technology (TST) program. Her interests include adapting learning experiences for cross-cultural instructional and online instructional environments; with a values-based, ethical focus.

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Abstract

Collaboration has been identified as a key 21st century skill, vital for success in multidisciplinary environments that are increasingly common in engineering and technology contexts. While researchers have frequently discussed how students develop competencies that facilitate success in groups, little is known about how individual students build their own sense of competence and autonomy after working primarily in groups. In this paper, we present results from an undergraduate transdisciplinary degree program in which students spent the first two years of their core degree experience working almost exclusively in groups, while also developing an individual set of disciplinary interests and competencies. Researchers built an understanding of students' individual and group development through extended ethnographic engagement, focus groups, and interviews as students worked concurrently on group and individual projects for the first time during the first semester of their junior year. Based on analysis of this transitional semester, we identified strategies that students used to build an individual sense of competence, in both technical and "soft" skills. These strategies allow for a fuller conversation regarding how students adapt competence gained in their group experiences and identify new areas of competence that must be confronted and mastered. These findings indicate the need to further understand the differences in the ways that the sequencing of group and individual work might impact the development of competencies in individual students, and the ways in which a project-based environment can encourage this development in a systematic and sustainable way.

Introduction

Collaboration has been identified as a key 21st century skill that is critical to engaging with "wicked," ill-structured problems[1-4]. In engineering and technology education contexts, programs have been adapted to focus on group work in cornerstone and capstone experiences (e.g., [5]) to address this challenge and build social skills that are necessary to succeed in the workplace. This focus on collaboration and work in multidisciplinary teams has been recognized as part of the ABET accreditation standards for engineering and technology programs[6,7], requiring institutions to further integrate the development of "soft skills," thereby enhancing the integration and activation of disciplinary knowledge.

In programs that have been adapted to incorporate group work experiences, faculty expect students to develop teamwork and interpersonal communication skills[3,5]. These skills are critical for success in group experiences and are enabled through sustained practice, increasing students' ability to work with disciplinary and interdisciplinary team members to produce more innovative outcomes[8-11]. In traditional engineering and technology experiences, a substantial amount of coursework is completed through individual projects and exercises, particularly in the professional formation years (years 2 and 3), although students generally have opportunities to

work in teams in individual courses towards the beginning and end of their program[5], and nearly all are required to do so on the job[4,12,13]. Most research has addressed the incorporation of group work experiences into cornerstone and capstone experiences, where individual work has historically been typical. However, as many institutions are experimenting with alternative models that incorporate group work throughout a degree program, there is little understanding of how—or whether—students are able to develop the skills they need to work on their own. In this study, we address students' views towards collaboration and their construction of individual competence in a novel transdisciplinary learning environment, where group projects are typical and individual work is highly atypical.

Collaboration and Teamwork Skills

Engineering education researchers have long recognized the importance of collaboration and teamwork, reflecting the need for these soft skills in professional practice, and the value of collaboration in producing innovative outcomes. These skills have been found to be important not only within engineering courses, but also in relation to multi- and inter-disciplinary collaborations[14]. However, the widespread augmentation of classroom lecture with project-based teamwork that incorporates these "softer" skills in active, collaborative learning environments has been relatively recent—brought about in part as a result of pressure from industry leaders demonstrating that graduates frequently lacked critical project experience and skills[15]. ABET took decisive action in 2000 in the form of revised accreditation criteria[16] such as Criterion 3, which required engineering graduates to demonstrate core engineering competencies, knowledge, skills, and techniques (3k), as well as to be able to "identify, formulate and solve engineering problems" (3e), while effectively communicating (3g) with multidisciplinary teams (3d). Comprehension and application of these skills were required (3h) within the professional environment, as well as the broader global and societal contexts[17].

An emerging genre of educational experiences focusing primarily on group work presents an interesting challenge. It is of great concern that individual students may rely on group members' expertise and work ethic and avoid developing or exercising the necessary soft and technical skills themselves—sometimes referred to as "social loafing"[18]. While social loafing and the interplay between individual competence and group action has been studied for almost a century, it is unclear how the expressed desire for collaboration, and students' preparation for both collaborative skill and individual disciplinary knowledge, might be effectively fostered. Bucciarelli[19] has previously argued for the inherently social nature of engineering and engineering practice, so it is important to understand how social dimensions of learning environments may contribute to the professional identity formation of students (e.g., [20]).

Project-Based Learning and Ill-Structured Problems

Project-based learning (PBL) is an instructional and pedagogical paradigm based on a social constructivist understanding of learning, wherein a student builds knowledge in a socially-

situated manner, assimilating and accommodating new knowledge within their own mental schema (e.g., [21]). PBL sits within a superset of situative learning approaches that build upon a constructivist view of how learning occurs, all of which foreground aspects of cultural and social context and the individual learner's relationship to these situated interactions.[22] Project-based models of instruction have been shown to be beneficial in addressing ill-structured problems, which are of increasing interest to the engineering community (e.g., [3]). Cross-disciplinary teams and collaboration are also often cited as critical to addressing these ill-structured problems[11]. This suggests a need for adaptable learning environments in engineering education that are well-suited to the complexity of these tasks[16].

Numerous colleges and universities have developed a variety of configurations of PBL as either cornerstone or capstone courses, providing project experiences aimed at developing students' disciplinary and collaborative skillsets[5,16,23]. However, many programs delay extended collaborative opportunities until students' senior capstone, leaving students with the challenge of adapting to the collaborative work environment while also attempting to apply and showcase their own disciplinary skillset in the context of an extensive design project. To add even more complexity, because the very nature of design thinking and action involves an interplay of convergent and divergent inquiry, including generative questioning that often results in instability and ambiguity[24], these experiences can present students, new to collaborative inquiry, with an unsettling sense of uncertainty[25].

It is in this context that engineering students must define and scope the problem space to meet instructional goals and build their disciplinary and social skillsets. For experienced engineers, this creates an opportunity for what Dorst and Cross[26] refer to as the co-evolution of problem and solution, in which the problem space is simultaneously being defined, extended, and shaped through the articulation of possible solutions. This refers to a chaotic period of time in which design judgment is needed to facilitate the rapid framing and solution-generation processes. Schön[27] has previously identified the need for reflection during this problem negotiation phase. Reflection is essential for ensuring that student designers are aware of their actions, and understand how they are to proceed appropriately in the design task. However, for an inexperienced student—or a set of inexperienced students working as a group—the resultant ambiguity can lead to paralysis of inaction with students unable to intelligently reset the problem definition, or turning to technology as a panacea[25,28,29]. If students have learned to embody and employ effective reflection and self-regulation skills only as individual designers or only in groups (as may be indicated by the limited inclusion of collaborative design in some engineering curricula), the transfer of these skills to isolated or collaborative PBL contexts may present substantial challenges. However, beyond the issues of transfer and acquisition of these competencies, there is little scholarship that explores how students may be disincentivized from building appropriate individual competencies in design environments that are largely group-oriented.

Purpose of the Research

In this paper, we will present results from an undergraduate transdisciplinary degree program in which students spent the first two years of their core degree experience working almost exclusively in groups, although they were expected to develop an individual set of disciplinary interests and competencies. The instructional strategy shifted during the first semester of the students' junior year as they were concurrently introduced to several smaller group projects and a major individual project. The group projects built on their previous collaborative experiences, while the individual project served as a year-long "pre-capstone" experience. This study specifically focuses on the following research question: **What challenges do students face when moving from group to individual work?**

Method

To address this research question, our ethnographic involvement relies upon knowledge of multiple semesters of students' engagement in project work in a transdisciplinary learning environment. We build upon the collection and analysis of student behaviors in relation to their group and individual work over time, in conjunction with evaluation of instructor goals and learning practices, to reveal students' growth of autonomy and individual competency in relation to their project work.

Research Context

This study was conducted within the context of a transdisciplinary, technology-focused undergraduate program at a large, research-intensive, Midwestern university. In this competency-based studio program, students engage in a range of self-selected disciplinary perspectives in an inclusive learning environment that is team-taught by instructors with a range of disciplinary backgrounds[30]. Students were required to select individual areas of disciplinary specialization from, at minimum, one technology or engineering domain and one liberal education domain. This program requirement stems from the focus on transdisciplinarity, engaging students in disciplinary learning throughout their undergraduate program, rather than primarily in the junior and senior years, as may be typical in traditional engineering programs. In the first two years of this program, students had engaged almost exclusively in collaborative group projects. Thus, the semester of data collection under study—the first semester of the cohort's junior year—represented a number of significant shifts, both in self-motivation and activation of disciplinary interests, and in a greater felt responsibility for the completion of individual project work.

Data Sources

Continuous research and evaluation of program outcomes and learning experiences are a core part of this transdisciplinary program. As part of these efforts, instructors and students are interviewed or participate in focus groups at least three times each year, and ethnographic

engagement with the learning experience ensures thorough documentation of student work, instructional practices, and instructor-student interactions. Data sources for this study include a full semester of classroom interactions (Fall 2016) captured through extended observation and video, artifacts from the project development process (e.g., whiteboard sketches, reflections, deliverables, and final projects), mid-semester student focus groups, end-of-semester student interviews, and interviews of the course instructors at the middle and conclusion of the semester. During the Fall 2016 semester under study, eight students were enrolled in the course, and the teaching team was comprised of two faculty members and a teaching assistant, each with a unique educational background spanning communications, library science, and engineering. Multiple researchers were engaged in ethnographic observation throughout the semester, using field notes as a primary form of data collection. These researchers met weekly to discuss their findings and focus subsequent ethnographic engagement with the students and instructors.

Data Analysis

We conducted data analysis for this study using two parallel methods, reflecting the complexity and evolution of student behaviors *in situ*, and the reflective and confirmatory perspective made possible through sequenced interviews or focus groups from each student and instructor participant. First, we relied upon continuous *ethnographic engagement* in the classroom environment to prime areas of concern, allowing for greater focus in subsequent observations, including triangulation via artifacts, reflections, and interviews. This method is referred to as *strip analysis*: an informal means of hypothesis generation based on ethnographic engagement that then sensitizes the researcher to subsequent events in the research context, facilitating deep triangulation or refutation of hypotheses[31]. Second, we built upon the strip analyses to construct interview and focus group protocols that were conducted mid-semester and after the conclusion of the semester. Each protocol included targeted questions to further engage students and instructors in the shift from group to individual work, including the challenges implicated in this shift. We then used the constant comparative approach[32] to locate patterns or themes within the student and instructor responses, which were validated across multiple researchers. These intertwined forms of analysis allowed a focus on: 1) The challenges identified by students through focus groups, and interviews, and by instructors through interviews; and, 2) The way these challenges manifest in classroom interactions and production.

Findings

In the following section, we will describe and illustrate the patterns from the constant comparative analysis, using results both from our strip analyses of ethnographic data and student and instructor interviews. Each theme will be set into context wherever possible, using our understanding of the curriculum and program design, documentation of classroom activities and student artifacts, and perspectives of students and instructors, to illustrate the variety of viewpoints and the ways in which these viewpoints were intertwined in the learning experience. All quotations from interviews, focus groups, or observations will be noted via pseudonyms to

show commonalities across the analysis and to protect the identity of our participants. The course instructors as indicated in text and include Kelly, Elaine, and Clark.

We describe the challenges that students noted or seemed to experience during the transitional semester, as they worked concurrently on group projects and began to frame and build their understanding of individual, year-long projects. Themes include both cognitive, design-related challenges, such as scoping and problem framing, and personal capabilities representing students' self-efficacy, such as time management and maturation. In addition, we noted the importance of the students' self-monitoring of their own ability, and the ways in which this emerged in group and individual work.

Scoping and Problem Framing

One of the fundamental challenges in addressing ill-structured problems is the negotiation of an appropriate problem frame, which describes the scope of work and allows the designer to understand the dimensions of the solution space[16,24]. While students had been asked to work on ill-structured problems in previous semesters[33], including receiving specific instruction on problem framing, many were not able to express their disciplinary interests and passions in a way that informed an appropriately scoped problem frame. This lack of capability reflected students' strong desire to focus on building physical prototypes. They felt that the "building" aspect of previous projects had been neglected, particularly in the previous semester when they were encouraged to balance their time more evenly between low-fidelity forms of prototyping and research to understand the problem space. In addition, the students were becoming increasingly aware that in order to scope and frame a problem, they first had to find an appropriate problem to solve. Each of these challenges is detailed below.

Finding the Problem

In conjunction with students' scoping and negotiation of a problem frame for their project, students must also be able to "find" and describe an appropriate problem to solve. This is a known challenge in developing design expertise—part of what Dorst and Cross[26] refer to as "co-evolution of problem and solution." Students reported two main challenges in understanding what problem they might want to solve: 1) addressing the breadth of their disciplinary interests and passions, and formulating an appropriate problem to solve that was aligned with this breadth; and 2) discerning the role of research in encouraging greater awareness of this potential breadth. This co-evolution process was chaotic for some students, including a rapid oscillation between large disciplinary interests and specific types of projects that might resonate with those interests. For instance, Kevin documented his progression through the process of connecting his disciplinary interest in music to specific formulations of the problem that might allow him to "find" a specific problem to solve:

> *If anything, for me, the hardest part was actually trying to find the problem, especially with the field I'm working in is musical instruments where there's not always a lot of*

> *problems. It's just what you think is really, really cool. And so, if anything that's been the most difficult part about the personal passions project, trying to boil everything down to that one problem that we need to solve, at least for the class where, in reality, I think it's more, "What would make this cooler? What would make this more appealing?"*
> *[...]*
> *I got to there because of my discussions with Corey. I was able to get the project problem boiled down with my work in here, but I was able to finally get a project that I could reasonably to do in the amount of time we have from just talking with my mentor.* (Kevin; MidsemesterFocusGroup)

These problems were often highly topical in nature (i.e., water scarcity in South Africa; spacesuits) without clear design outputs that would be required to lead to a problem frame. Some of this lack of clarity around potential outputs (and the alignment of a problem statement to these outputs) was resolved in productive ways through student engagement in research. Students' research skills had been strengthened in previous semesters with nominal growth[34], but in this new semester, students were beginning to see how this additional awareness of complexity may require work prior to making artifacts (which was their area of comfort). Joel illustrates this awareness of the impact of research on the design process, and the need to execute these elements to get to an appropriate problem that could be solved in the following quote—he reveals the shift in mindset that came with utilizing user research to foster a better understanding of the problem he was trying to solve:

> *Last fall, we knew more about research. We knew that we needed to do a lot more. We need to do a lot more testing, so about three weeks of that four weeks was taken up of just straight researching, of just straight doing interviews or something like that, stuff that wasn't even towards the actual making of the project.* (Joel; EndofSemesterInterview)

One instructor saw this student's role in facilitating this process as being "a lot like new dissertation students"—moving a student "to something [they] could actually accomplish instead of this giant thing, which is not a bad thing by any means, but let's find the piece of that you could actually do something with" (Kelly—instructor; EndofSemesterInterview). As this was their first sizable individual project, the students saw this problem "finding" process as one in which they could—for the first time—fully activate their individual areas of disciplinary interest as well as their personal passions in ways that were impossible given the project requirements in previous semesters, due to the highly unique profile of each student in the program.

Scoping Down

Students almost unanimously agreed that scoping a problem to meet the constraints of a year-long project was difficult. Joel noted: "Scoping is one of the hardest things for me. [I] just have so many ideas and don't know how to get them down to a manageable part." The scope definition

often began with an expression of interest or passion, such as that expressed by Nicholas, who was interested in building a dune buggy:

> *And so, I'm sitting there like, "You know what? I want to try and do something with that." So, that turned into, all right, I want to try and build a dune buggy. And, I was working backwards to get to where I am. So I was trying desperately to figure out how I was going to that implemented into this project for something. And, then I was talking with one of the members of the evaluation team and Adrian told me, "Well, what if-" Because I said I want to make it all hand controls. So, Adrian said, "What if he did this for people who are handicapped?" And, that opened up a totally different door. And so, I started going down that way and then I realized essentially that going through this really long way to get there, I realized how much of a passion it is for me to help people that might not be able to do things that they were once able to do or what not.* (Nicholas; MidsemesterFocusGroup)

This example from Nicholas reveals both the nascent ability of students in addressing problem scope for their projects, and the challenge in encouraging students to shift perspectives in relation to their interest area. While Nicholas showed promise in understanding how the scoping process was occurring, Joel also struggled with the capabilities needed to execute on his vision: "last semester [...] I way overshot it. I way over-thought my capabilities and it turned out that I couldn't do that project, the one I wanted to." Joel had wanted to design a skintight spacesuit, but did not immediately grasp the complexity of this challenge, or the requirement to scope the problem not only to align with his abilities, but also the two-semester time constraint for the project. This need to both make an idea manageable and assess a scope of that idea in relation to personal capability revealed deficits in students' problem framing ability. One instructor noted the barrier for some students of being "hyper-solution-focused instead of truly problem scoping focused" (Kelly—instructor), while another instructor felt that the lack of scoping was a result of "project[ing] absolute rationality onto things" (Clark—instructor). This instructor in particular provided commentary on Joel's spacesuit, noting that he felt Joel saw the problem as "just designing a thing" rather than as part of a concerted, systemic effort that involved multiple industry partners. This barrier of rationality resulted in an inability to address scoping in a way that was commensurate with the challenge of the initial idea.

<u>Back to Building 'Stuff'</u>

Due to the solution-focused nature of many of the students, there was a common desire to "build stuff." Joseph clearly saw the studio space as an area in which some sort of physical building activity should be taking place, going as far as suggesting that the students have a "tinker project" that they could work on, revealing his desire to "recognize a little bit more the value of just sitting around and messing with something without caring what the end result is…" (Joseph; EndofSemester). This drive towards concrete, physical items and away from what some students felt were more abstract concepts, such as problem framing and research, revealed an area of

comfort for many of the students, who had disciplinary interests in areas such as mechanical engineering technology and electrical engineering technology. This bias showed through when students discussed their previous semester's experience, where they were encouraged to more deeply dwell on *why* they were solving a given problem, using techniques such as problem framing and user research to legitimate their choices in terms of physical prototyping. This attitude is exemplified in the following exchange during the mid-semester focus group:

> *Corey: It was concrete this semester. Last semester, it was fluffy frou-frou.*
> *Joseph: I think the word is abstract*
> *Corey: Or that.*
> *Joseph: That works also.*
> *Joel: I like the abstract.*
> *Corey: I know.*

The preference towards physical artifacts also reinforced what items may be useful for a portfolio, or something that the students felt they could be proud having produced. Joseph elaborated on this interest in visualizable outcomes, yielding specific physical artifacts:

> *"I think Corey and I are kind of the people who judge our outcomes based on what you can visually see that you've done at the end of it [...]. Previous semester gave us essentially no artifacts that we wanted to keep or were happy even remembering we had, and this semester I feel like I've got a few things that I'm like, 'Oh cool.' I actually learned a few things. I got a cool contraption thing that I can admire for myself.* (Joseph; EndofSemester)

Time and Project Management

In previous semesters, students had been taught a variety of time management techniques, including the development of team charters to divide responsibilities equitably, checkpoints and critiques to provide intermediate feedback, and class discussions that allowed students to formulate a schedule appropriate for their scope of work. However, groups often struggled to meet the timelines that they set for themselves and frequently underestimated the amount of time that would be needed to execute various phases of the project—particularly those with which they had less comfort or familiarity (e.g., user research). These existing gaps in ability to effectively plan a project and manage available time were exacerbated by the move to individual work, leaving students with less ability in this area feeling anxious and overwhelmed. In this section, we identify several challenges that arose in relation to time management, including a tension between viewing project work as concurrent v. linear, the feeling that more time would result in positive outcomes, and the introduction of classroom-driven and personally-driven tools to manage time more effectively.

Recognition of tools and scaffolds that they were being taught (or recalled from previous semesters) led to a realization of the importance of project planning in managing time

appropriately, but students also recognized spaces where they felt these tools were insufficient to meet their specific working style or challenges.

Linear v. Concurrent

The studio experience had not required students to work on multiple projects at the same time within the same course in the prior three semesters, nor had substantial individual projects been assigned within the studio during the same time period. Thus, students were not used to managing time across multiple assignments within the course, even though they were clearly capable of doing so across multiple courses in which they were enrolled. The most common challenge the students faced was a tendency to view their design activity as linear rather than potentially concurrent. In other words, students could only be in one project "mode" at a time, and were unable to effectively map out activities for both their active group project (Projects 1, 2, or 3, depending on the point in the semester) and their ongoing individual project (Project 4) in a given week. Often this process was driven in a reactionary way, with looming deadlines causing a complete shift of focus away from longer term goals:

> *I simply said, I'm working on one [group] project, and I didn't work on [the individual] project four until the week a section was due, or it was just project four that we were working on. Otherwise, I worked on the main project that was due more closely to that point.* (Ben; EndofSemester)

> *Now, for me, I'm still working on that balance of when to work on what, especially since our deadline for Project 3 is much shorter and sooner, especially with the fact that we have a big break in the middle where we're missing two whole work days due to fall break.* (Kevin; MidSemesterFocusGroup)

> *For group projects it's kind of easy to stay on track because we have group meetings [...] For individual projects you have to balance the workload [and] because I am taking five other classes and stuff I have other projects. It's kind of hard to think of something I need to get done. Like in my head it's like oh yeah I need to do that or I need to do this. I need to just, it gets really confusing after some period of time.* (Adrian)

However, some students had more nuance in the ways they viewed multiple deadlines, seeing a barrier in one project as a reason to switch to the other.

> *Well, for me, I'm trying just to avoid what we did with Project 2 [...] if we weren't sure about what we were going to do on that day for Project 2, we would just ignore it and work on Project 4 and get that all caught up.* (Kevin; MidSemesterFocusGroup)

There were also instances where students looked at the entire scope of the semester, and noted that an extension of a deadline for their group project would leave less time for focused work on the individual project. This resulted in tension among the students, since some felt more comfortable with making a request to extend the group deadlines, while other students were ready to shift into their individual work and not have to cope with multiple overlapping projects.

> *Kevin: [...] We have a whole month and a half after Project 3 before Project 4 is due. And, while yes that's going to be a lot of time for us to just work and focus on Project 4, it's felt very choppy in working on Project 4 because you have the week to focus on Project 4 at the beginning of the year. And now, ever since then, we only get to look at it, if we're lucky, once every other day and sometimes not even that. Once a week or less. And, so, if they extended the deadlines on both the Project 2 and Project 3, there would be less pressure to get everything done faster. And so, you spend more time, you'd be able to work on them simultaneously instead of ignoring one to work on the other.*
>
> *Nicholas: I would disagree with that because, yeah it is stressful to have two projects going on at once but, having that shortened deadline for the one, forces you to focus on the one and get it done. There's an inherent amount of responsibility that you're supposed to be working on the other one too. But, if you extend the deadline on Project 2 and Project 3, then you're leaving yourself less time at the end to focus solely on Project 4.* (MidSemesterFocusGroup)

As students grappled with multiple overlapping projects and deadlines, they tended to view time as a commodity which could extend their capability. Although students had been informed that the concurrent projects were intended to encourage the development of better time management behaviors—maximizing metacognitive skills related to their work—students appeared to see more time as the obvious solution to their lack of progress on the individual project.

> *As for this [Spring 2017] semester [...] project four is the only project we have, but for last semester [the projects were] overlapping and [I'd] be like, "Oh yeah, we're having to do two projects at the same time." I feel like it'd be nice to, I know they were trying to give us more time since they give us project four at the beginning of the [Fall] semester but then we wouldn't have time to do it so there's kind of no point in doing that. I'm not sure what could have been done to make things better but I feel like it would have been nice to just give us more time.* (Adrian; EndofSemester)

Tools to Manage Time

Students were given multiple scaffolds to manage their time throughout the semester, both on a course and individual level. This included explicit project-planning instruction, Gantt charts to show the progression and overlap of projects, and more rigorous use of milestones and task lists.

The students clearly showed gains in their use of these scaffolds in comparison to previous semesters, and they were aware of this growth:

> *[...] we drew out everything on the board and said, "So, this is what we're going to do within the project and all that." And, it really helped us to get on track. That first little push helped set the structure for how the project is going to go. We got off on a good start so now we're rolling and doing really well.* (Nicholas; MidSemesterFocusGroup)

> *Now, this time around, they're showing us that we need to manage our project a whole lot better before we even get started. And, that's the whole point with Project 4.* (Max; MidSemesterFocusGroup)

> *Yeah, I'm trying post it notes and I started using a calendar, I started putting everything together. I'm doing much better this semester than last semester [...]. Now I kind of know what to do.* (Adrian; EndofSemester)

One of the main tools that seemed to be effective in stimulating awareness of time management for students was a printed Gantt chart. The instructors created a table-sized Gantt chart early in the semester that was posted in the studio space, allowing students to track their progress through the semester and visualize the overlap between projects. This course-wide chart then stimulated students' interests and ability in doing similar project management work on their own individual and group projects; Nicholas described this approach during the mid-semester focus group as "one of the main things [...] that's helped us." However, one student did not find this tool easy to read and use, and found the information more overwhelming than helpful:

> *Personally I'm not a fan of Gantt charts because they're kind of hard to read. It's just me. There's millions of lines, you have to try to find the time clue or whatever. It's like, it takes me 10 minutes to find the thing I need to look at but it's helpful. I wish there would be a more clear schedule thing in class. I don't think that's possible.* (Adrian; EndofSemester)

Recognition of Personal Expertise and Compensation for Others' Expertise

Students had developed expectations regarding the balance of group work and individual performance during their previous semesters in the program. The history of group work encouraged students' reliance on each other, including an awareness of each student's individual areas of specialty and knowledge, and an implicit understanding of how these skills might be productively combined to meet the goals of the group for a given project. The program encouraged a diversity of skillsets, which were made explicit through each student's selection of at least two areas of disciplinary specialization. Thus, there was some understanding and articulation of each student's personal expertise (often expressed through broad disciplinary areas), as well as a tacit compensation for the gaps in skills and knowledge on the part of other students in the program.

Understanding and testing one's own expertise

Students were at many different points in their metacognitive and regulative development, and the students' ability to reflect upon their own expertise in these areas was also quite mixed. This diversity meant that some students were ready to test their own limits, while others were still comfortable building their core skills in the context of collaborative work. As Kelly (instructor) stated, "*We had a couple of students who were more than ready to be working on their own. They were done with this whole trying to bring other people along or accountability to somebody else who isn't pulling their weight. Those students really embraced this and ran with it.*" (EndofSemester). Students viewed the shift to individual work as a means of embracing their passions, but two students in particular (Joseph; Nicholas) saw this as an opportunity to prove themselves and validate that they had built the skills necessary for their success.

> *I think the expectation has been throughout all of the projects that we've done, taken different roles and doing different things within it. And, I think, the whole purpose of now doing the project on our own is, in a sense, we're testing exactly how well we've done over the time that we've been in the program because now we're going to have to do it all ourselves.* (Nicholas; MidSemesterFocusGroup)

With this excitement in the move to individual work, students were also aware that this was an opportunity to proceed and develop as an individual, unencumbered by team members that were perhaps not as motivated. For Joseph, this feeling began even before work on the individual project commenced, when he worked with another student who he felt was equally ambitious:

> *It was exhilarating to work in a group that really gave back a lot and I didn't have to worry, necessarily on about. It didn't feel like I was being carried. Well, I was being carried this time around with me trying to do most of the work and stuff.* (Joseph; MidSemesterFocusGroup)

Nicholas reflected on the shift from group to individual work, noting that—because of this evolution of collaborative expectations—he saw the need to identify his current skills and abilities so that he could make plans to build additional skills as needed.

> *They have resources available to us but now it's exactly - we have to figure what we can and can't do and how to distinguish whether or not we need help from what we need to learn still or something like that.* (Nicholas; MidSemesterFocusGroup)

Lack of external perspective on one's own expertise

Although students were generally excited about the shift to individual work, reflecting an opportunity to narrow in on their passions, there was also some fear about the lack of an external student perspective on their development. In the program, they had grown to trust and rely upon one another. Because of the focus on group work, students had sometimes used external

recognition of their own expertise as a shortcut for understanding their own role in a project. One student in particular had a challenge in building reflective awareness of his own actions, which resulted in an inability to utilize the skills of his fellow classmates and teammates. In this specific case, his subject matter knowledge of the design context (parkour) actually damaged his ability to think outside of himself and recognize appropriate skills of others.

> *He couldn't conceptually recognize what he was trying to do with the project we had given him. With the concept of measuring things and the parkour situation and it ended up not being good because it was the area that he sort of had the subject expertise. We tried to also kind of give them their projects where we knew they had at least one person in their team who had some experience with [it] whether it [was] hiking or parkour or whatever for that project topic. He let that cloud the rest of his judgement just sort of assuming he was an expert and not really being able to articulate, even though Clark [instructor] spent an entire hour, it was probably more than an hour, some part if not all of a class saying hey, okay it's this person jumping over this chair. What are you trying to measure?* (Kelly—instructor; EndofSemester)

Another instructor expanded on this specific event, showing the impact of these moments of individual indeterminacy on others in the classroom, and the interplay between knowledge of oneself and knowledge of others' abilities. Adrian was a new student during the Fall 2016 semester, therefore, as well as learning to work on transdisciplinary group projects and bring in personal prior knowledge, Adrian had to learn to engage with a group of students who had already been together for some time. For this project, Adrian was partnered with the student discussed above. Clark (instructor) explains how both students struggled to work as a group, revealing their very different visions of the project goals:

> *[I] was sitting there […] watching Adrian's face; because Adrian clicked on it, but the unpacking of the [project idea]—a lot of them seem to struggle, but we can get them there by us working with them or their teammates working with them. The teammates vary in how good they are, but they're improving their skills and helping each other unpack their cognition. Then they leave that conversation. You've seen their mindset grow, but they can't use that new stuff to replace the previous thing, because the previous thing is the rational world view. He went back to, "We're measuring a guy jumping over the wall," as soon as the conversation ended, even though he manifestly had understood what we were talking about.* (Clark—instructor; EndofSemester)

This lack of self-awareness for some students meant that once they were "on their own" and no longer in collaborative teams, they lacked the support from students they had grown accustomed to. Instructors recognized that the students still needed to develop meta-cognitive skills in order to succeed.

> *I think we saw a lot of that in that the students had no higher level monitoring process without teammates to kick them out of loops. They also didn't have a strong grasp of [... what] I consider to be reality of what they had and hadn't done. There is a strong collapsing of, "I was going to do that. I should do that," and especially, "I thought about doing that, and I didn't." We especially saw this in the research [phase].*
> *[...]*
> *There was an intention and a want to change it, but an almost inability to operationalize the gathering of information and the integration of information. [...]. It seemed like it was based on there not being a lot of awareness that they are integrating information already. They didn't realize they were doing it, so the act of doing it seemed foreign. It was just kind of they had this mindset where the way I think about a problem, the frame I have in a problem, if we think about design language, is given. It's static. Every once in a while it's replaced by a new and better one. There's no conception of those as flexible and migratory.* (Clark—instructor; EndofSemester)

One of the students showed his awareness of this lack of external validation as well, noting that it was easier to recognize the strengths and weaknesses of others than recognizing these same things about one's self.

> *As a member of a group, I felt like I was part of a team, and that helped me think about, ok, what are strengths of other people, and how can I utilize them to improve this project. And, I haven't really been able to think about my personal strengths and also, where I fall short. So, in others I was easily able to recognize their strengths and weaknesses, and I knew that I could at least somewhat handle covering for weaknesses that they had. But, now that I'm working alone, I'm not fully aware of where I fall short, and so I can't really figure out what I need to do to cover [...].* (Ben; EndofSemester)

Maturation and Personal Growth

In previous semesters of this program, despite the predominance of group work, the students tended to view themselves as autonomous and self-driven, in keeping with the philosophy of the program—even when evidence about their capabilities or course progress ran counter to this narrative. As the semester progressed, the students seemed to increasingly discuss their need to get better at certain aspects of their work, or hold each other accountable within their *group* projects in explicit ways.

> *[...] one of the really nice things we've done with Project 3 is essentially the first day we agreed that instead of sitting there making excuses for why we haven't done something or just bickering about the fact that somebody didn't do their part, we said, "All right, we're in our first semester of our junior year. We need to be adults about this."* (Nicholas; MidSemesterFocusGroup)

The explicit call to “be adults about this” revealed a larger desire among the students to be willing to push each other towards shared goals, but increasingly, the more dominant and self-motivated students saw the individual project as a way to focus on their own work and not be as responsible for pushing others to be accountable. For instance, as referenced by Kelly (instructor) in the previous section, there were varying levels of readiness for group work among students—those who were ready to work alone and those who still needed more support. Other students echoed a drive towards autonomy, but occasionally with some sense of conflict between their personal goals for success, and the desire to attain course outcomes, and eventually graduate with a degree.

> *In previous semesters, it felt like we had the pressure to succeed mostly on ourselves because we wanted to have a degree to graduate with, and it was more of a mutual pressure, like we were doing it and they were doing it. This was more like a pressure from them [instructors] to say, "Okay, you guys need to get this done. This is what we put down for you."* (Joel; EndofSemester)

> *There's that threat there that doesn't seem to be very prevalent in this program, which results in a lot of times of teamwork [...]and a lot of times, I think, with people's drive to commit towards a project fully starts to diminish. [In Project 4] I saw sort of the remnants of that start to either go away or get finally realized in that they started to actually have to push themselves.* (Joseph; EndofSemester)

Discussion

In the findings, we have addressed the challenges and opportunities that students faced as they moved from group to individual work, and began to think more about their own personal areas of expertise and abilities to plan their own time. These challenges encompass strategies that students used to build an individual sense of competence, in both technical and collaborative skills, leading to an enhanced understanding of how students adapt areas of strength gained in their group experiences to facilitate working on their own, and identify new areas of skills and knowledge that must be confronted and mastered without group members to rely on. While the educational experience we have documented is atypical in engineering and technology education, we believe that these findings may indicate the need to engage in further scholarship on the role of individual and group competence. In particular, we have indicated concerns in relation to the sequencing of group and individual work, and the way this sequencing impacts individual students’ development. We believe further work in this area may allow for greater understanding of the mechanisms by which a project-based environment can encourage individual and group development in a systematic way.

Assuring Individual and Group Competence

Current ABET accreditation standards indicate the need to engage students in deep disciplinary expertise in collaborative, multidisciplinary environments[17]. However, it would be highly

unusual for a performance in industry to take place in isolation, so the transfer of this performance into practice would be incomplete. In addition, due to the transdisciplinary focus of our program, we require students to engage in both a disciplinary dialogue, which is supported by their disciplinary coursework, and a transdisciplinary dialogue, which extends and encompasses disciplinary perspectives at a higher level of unity. The transdisciplinary sense of "unity" may look quite different than individual competence in a traditional disciplinary stance, which may encourage us to look more fully into practice-driven notions of individual and group competence.

We have used this analysis to identify specific areas in our program where individual and group projects might be effectively paired to maximize authenticity and minimize known issues with both individual and group projects. However, the movement between group and individual work documented in this study indicates areas of substantial complexity that are difficult to address given existing guidance from the research literature. This lack of a full accounting for skill either through individual or group performance underscores a gap in the educational literature, and the need to more specifically target methods of assuring individual and group competence in relation to complex, ill-structured design activity. In the program under study, we currently provide assessment on both the individual and group level, but the students' development across the program indicates some potential weaknesses, even with this safeguard. For instance, in activities such as problem framing, known to be critical to the professional practice of design[24,29], the social generation of frames is key to the development of potential solutions. While individual designers can and do create frames in isolation, identifying potential solutions, this cognitive work is notoriously difficult to access, and thus is almost impossible to fully assess[27,29].

Another topic we have largely not discussed in this paper is the need for valid and reliable assessments of this type of project work. On the one hand, group work complicates the accurate measurement of individual ability, because students have a tendency to compensate for any skill deficits; and innovation in design is actually enabled by unevenness of lived experience and skill. On the other hand, measurement of ability on an individual student's performance alone neglects the vital collaborative and team communication skills that may enhance or otherwise alter the performance.

Social and Pedagogical Barriers to Individual Competence

Students had varying levels of self-knowledge, both related to their understanding of their own collaborative capability and their ability to articulate and demonstrate appropriate disciplinary skills, knowledge, and abilities. This underscores the importance of identifying social and pedagogical dimensions of group and individual work, including the potential impact of this knowledge on the construction and activation of disciplinary and collaborative competence. As group work increasingly becomes typical in secondary and higher education, it is vital that educators engage with and evaluate students' knowledge, skills, and abilities in appropriate contexts. In particular, it is equally important to document individual abilities - not just as a

guard against “social loafing”, but also as part of ensuring that students develop in multiple ways rather than remaining in one niche across all group projects while adrift in individual projects. Because working in groups is the norm in the workplace, the solution is not to stop providing group work, but to provide a better understanding of students’ abilities in working with diverse teams. Having students exercise different roles, or having different students serve as subject matter expert on different projects, may be one way to ensure everyone gets to exercise group and project related skills, as well as their own specific disciplinary skills and knowledge. To adequately evaluate each set of competencies—which are inextricably tied together in many learning environments—requires both an awareness of the social and pedagogical barriers and concerted effort to understand the individual and social dimensions of learning and performance.

Limitations of the Study

While the findings from this study raise important questions in relation to encouraging and assessing individual and group project work, we do wish to call attention to the limitations of this work. Because of the experimental nature of the program, and attrition over time due to this status, the remaining students may be atypical in ways that we cannot fully understand or document. The students’ that have stayed in the program may be expected to have deeper social bonds than students in larger cohorts of this program in the future, and may have had learned patterns of social/group compensation that may be greater than the general population of engineering and technology students. These limitations mean that we do not attempt to generalize our findings to the broader engineering education community, nor do we expect that our findings in relation to the group to individual shift would prove to be true in other similar educational contexts.

Conclusion

In this paper, we have identified some key concerns that arise as students move from collaborative work to their own individual, self-directed projects. Students developed strategies over time that allowed them to effectively build their sense of competence in a group setting, where competence was shared across multiple students to perform everyday tasks. However, these group strategies, where expertise was distributed, often did not prepare students to work effectively as individuals. While these particular barriers to individual success are perhaps unique to the transdisciplinary program under study, the sequencing of group and individual work may impact individual students’ development in ways that are currently not well understood.

As collaborative pedagogies continue to become more common across the engineering curriculum, it is vitally important to understand how students build both a shared sense of competence in managing project work and engaging with disciplinary knowledge, as well as instilling a deep sense of individual competence that allows them to be successful in a variety of team and individual work situations. Our findings indicate the need to engage further with

metacognitive skills that surround collaborative efforts, including manipulating certain portions of the learning experience to simulate the concurrence of group and individual work.

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References

1. Alismail, H. A. and P. McGuire (2015). 21st Century Standards and Curriculum: Current Research and Practice. *Journal of Education and Practice, 6*(6), 150-155.
2. Stump, G. S., Hilpert, J. C., Husman, J., Chung, W. -T., & Kim, W. (2011). Collaborative learning in engineering students: Gender and achievement. *Journal of Engineering Education, 100*(3), 475-497.
3. National Academy of Engineering, U. S. (2004). The engineer of 2020: visions of engineering in the new century. Washington, DC: National Academies Press.
4. Tseng, T.-L., Akundi, A., Wu. T., & Lin, Y. (2016). *Evaluating Individual Learning Effectiveness on Project-Based Learning Methodology by Comparing Team-Based and Individually Assigned Projects.* Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana
5. Kellam, N. N., Walther, J., Costantino, T., & Cramond, B. (2013). Integrating the engineering curriculum through the synthesis and design studio. *Advances in Engineering Education, 3*(3), 256-270.
6. Felder, R. M., & Brent, R. (2003). Designing and Teaching Courses to Satisfy the ABET Engineering Criteria. *Journal of Engineering Education, 92*(1), 7-25.
7. Lattuca, L. R., Terenzini, P. T., & Volkwein, J. F. (2006). *Engineering change: A study of the impact of EC2000: Executive summary*. ABET.
8. Hurst, A., Jobidon, E., Prier, A., Khaniyev, T., Rennick, C., … Bedi, S. (2016). Towards a Multidisciplinary Teamwork Training Series for Undergraduate Engineering Students: Development and Assessment of Two First-year Workshops. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana.
9. Mills, J. E., & Treagust, D. F. (2003). Engineering education: Is problem-based or project-based learning the answer. *Australasian Journal of Engineering Education, 3*(2), 2-16.
10. Lans, T., Blok, V., & Wesselink, R. (2014). Learning apart and together: Towards an integrated competence framework for sustainable entrepreneurship in higher education. *Journal of Cleaner Production, 62*, 37-47.
11. Nijstad, B. A. and De Dreu, C. K.W. (2002), Creativity and Group Innovation. *Applied Psychology, 51*, 400–406. doi:10.1111/1464-0597.00984
12. Daniels, M., Carbone, A., Hauer, M., & Moore, D. (2007). Panel - Ill-Structured Problem Solving in Engineering Education. In *Proceedings of the 2007 ASEE/IEEE Frontiers in Education Conference*.
13. Heitmann, G. (1996). Project-oriented study and project-organized curricula: A brief review of intentions and solutions. *European Journal of Engineering Education, 21*(2), 121-131.
14. Borrego, M., & Newswander, L. K. (2008). Characteristics of successful cross-disciplinary engineering education collaborations. *Journal of Engineering Education*, *97*(2), 123-134.

15. National Science Foundation (1998). *Systemic Engineering Education Reform: An Action Agenda, NSF 98-27*. Retrieved from https://www.nsf.gov/pubs/1998/nsf9827/nsf9827.htm
16. Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.
17. ABET (2017). Accreditation Criteria. Retrieved from http://www.abet.org/accreditation/accreditation-criteria/
18. Kravitz, D. A., & Martin, B. (1986). Ringelmann rediscovered: The original article. *Journal of Personality and Social Psychology, 50*(5), 936-941.
19. Bucciarelli, L. L. (1994). *Designing Engineers*. Cambridge, UK: MIT Press.
20. Walther, J., Kellam, N., Sochacka, N., & Radcliffe, D. (2011). Engineering competence? An interpretive investigation of engineering students' professional formation. *Journal of Engineering Education, 100*(4), 703-740.
21. Lave, J. & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press.
22. Johri, A., & Olds, B. M. (2014). *Cambridge handbook of engineering education research.* Cambridge, UK: Cambridge University Press.
23. Dutson, A. J., Todd, R. H., Magleby, S. P., & Sorensen, C. D. (1997). A review of literature on teaching engineering design through project-oriented capstone courses. *Journal of Engineering Education*, *86*(1), 17-28.
24. Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies, 32*(6), 521-532.
25. Lande, M., & Leifer, L. (2010). Difficulties student engineers face designing the future. *International Journal of Engineering Education, 26*(2), 271-277.
26. Dorst, K., & Cross, N. (2001). Creativity in the design process: co-evolution of problem–solution. Design studies, 22(5), 425-437.
27. Schön, D. A. (1983). *The reflective practitioner: How professionals think in action.* New York, NY: Basic Books.
28. Cardella, M. E., & Lande, M. (2007). Responding to Uncertainty and Ambiguity in Engineering Design. In *DTRS7: Design Thinking Research Symposium*.
29. Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, *101*(4), 738-797.
30. Exter, M. E., Dionne, R., & Lukasik, C. (2015). Design of a Learner-Centered Seminar-/Studio-Based Polytechnic Institute. In B. Hokanson, G. Clinton, & M. W. Tracey (Eds.) The Design of Learning Experience (pp. 139-154). Switzerland: Springer. doi:10.1007/978-3-319-16504-2_10
31. Agar, M. (1986). *Speaking of ethnography.* Beverly Hills, CA: Sage Publications.
32. Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory: Strategies for qualitative research* (Observations). Chicago: Aldine Pub.
33. El Debs, L. C., & Dionne, R., & Exter, M., & Shaurette, M. (2015). *Problem Solving in a Multidisciplinary Environment: Observations from a Newly Developed Program*. Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. doi:10.18260/p.24591
34. Gray, C. M., El Debs, L. D.c., Exter, M. E., & Krause, T. S. (2016). *Instructional Strategies for Incorporating Empathy in Transdisciplinary Technology Education*. Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana.