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Coordinating Opportunistic Interdisciplinary Projects Across Single-Discipline Capstone Courses*

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There is increasing interest in developing interdisciplinary capstone courses in which students from different majors enroll to work together on complex, real-world projects. Creation of new interdisciplinary capstone courses may not be feasible for some departments or institutions, however, due to administrative or funding complexities. As an alternative, the inclusion of interdisciplinary *projects* engaging students enrolled in separate single-discipline capstone courses may offer the opportunity to undertake interesting projects, or engage with certain sponsors, that would not be possible without the contributions of students from diverse disciplines. Having such projects undertaken by interdisciplinary teams of students who remain in their single-discipline capstone courses does not reduce, and may amplify, the challenges found in full-fledged interdisciplinary capstone courses (e.g., misaligned schedules, differing requirements, and unfamiliar working cultures). This paper provides findings from the pilot year of a series of opportunistic interdisciplinary capstone projects associated with NASA's Psyche Asteroid Mission involving students from computer science, computer systems engineering, engineering management, industrial design, and graphic design. The findings highlight the importance of close communication and flexibility between faculty and identify a novel and potentially-replicable approach of including project management capstone students on interdisciplinary teams. The paper also describes changes that were implemented for the national expansion of the program with the 2018–2019 academic year and provides early lessons learned associated with those changes, outlining a plan for iterative improvement.

Keywords: interdisciplinary; STEM; disciplinary culture; teamwork; program evaluation

1. Introduction

In January 2017, NASA selected the Psyche asteroid mission, led by Arizona State University (ASU), as one of two missions in NASA's Discovery Program (https://psyche.asu.edu). The Psyche spacecraft is scheduled to launch in mid-2022 and arrive at the mostly-metal asteroid, known as *(16) Psyche*, in early 2026. Funding for the mission includes development of four efforts to engage undergraduate students, one of which is the creation of capstone projects across a range of disciplines that contribute to topics relevant to the Psyche mission, from science and engineering to communications and accounting. Several capstone projects were piloted during the 2017–2018 academic year at ASU, an institution which offers over 80 capstone or capstone-style courses annually. Additional capstone project opportunities are being piloted nationally in 2018–2019, with plans for continued expansion throughout the lifetime of the mission.

To facilitate broad adoption, the effort is focused on the design and development of standalone capstone projects (rather than entire courses) that may be undertaken by faculty and students in any capstone course (or across capstone courses in multiple disciplines) with relevant interests and abilities. Given the large variation across institutions in the types of capstone courses offered, the ways in which they are administered, and their principles, objectives, and requirements [1–5], the Psyche-related projects are designed to allow modification and adaptation to local contexts by the participating faculty and departments. Additionally, since the projects are associated with the Psyche mission, which itself requires the skills of a wide range of disciplines working together, many of the projects conceived to date are naturally interdisciplinary.

Developing projects that require multiple disciplines, but that can be incorporated into existing,

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single-discipline courses at and across a wide range of institutions has the potential to amplify the challenges of interdisciplinary capstone courses that have been documented in the literature [6–11]. The current projects at ASU and beyond provide the opportunity to implement existing best practices from the research literature and, where necessary, to develop structures, frameworks, and assessments to guide faculty in implementing interdisciplinary capstone projects across single-discipline capstone courses in the future. This paper describes the pilot year effort, including evaluation results, and early lessons learned from the second year of the program, which included expansion to six other universities (with some teams containing members from more than one university).

2. Implementation

2.1 Pilot projects

The initial pilot projects during the 2017–2018 academic year involved faculty and students from six disciplines at Arizona State University (computer science, computer systems engineering, engineering management, graphic design, industrial design, and public relations) working on four types of projects. Two of the Psyche-related projects involved interdisciplinary teams of students from distinct capstones courses: (1) A competition to create the first Psyche mobile app and (2) the design and manufacture of an imaging system to image iron meteorite samples for analysis. A third project, the development of an image analysis algorithm for bulk chemical analysis of iron meteorite samples to create a reference database for use when data are acquired at Psyche, involved only computer science students on the actual teams, but those teams needed to interact regularly with the interdisciplinary imager teams. Table 1 shows the composition of the nine capstone teams working on these projects in terms of academic major and gender. (The remaining project was development of a public relations strategy by a single team but, in its initial iteration, this one-semester project did not include participants from other disciplines and is not discussed here.)

Note that the two teams working to develop the algorithm for use with images produced by the imaging systems were made up of solely computer science students (though they interacted with the interdisciplinary teams developing the imaging systems) and did not have an engineering management student to provide project management, which is a missing element with implications discussed below.

2.2 Challenges and solutions

Those who have created interdisciplinary capstone courses or projects know that much of the challenge lies in the fact that interdisciplinary projects "attempt to unite two or more orientations that may (or may not) share any substantial overlap in terms of substantive and theoretical concerns" [4, p. 10]. As expected, we encountered many of the issues documented in the research literature, including those related to project administration, student schedules, workspaces, deliverables, disciplinary cultures and expectations, and assessment. Although it would be ideal to design a completely new course from the ground up to preclude these issues [12], it is not feasible in our situation, so we have adopted/adapted existing solutions and explored new ones.

2.2.1 Project and team assignment

As Howe, et al., (2016) and others have found, each capstone course participating in our projects during the pilot year was set up and administered differently (see Table 2) [5, 13]. Particularly challenging at the beginning of the year was that students who would be the sole member from their discipline on a team (such as graphic design or engineering management) could select a project or be assigned

Table 1. Academic major and gender composition of Psyche-related capstone teams (n = 62)

	Comp. Sci.		Comp. Sys. Eng.		Eng. Management		Graphic Design		Indust. Design	
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Mobile App 1	3	4	–	–	–	1	1	–	–	–
Mobile App 2	2	3	–	–	1	–	–	1	–	–
Mobile App 3	4	1	–	–	–	1	–	2	–	–
Mobile App 4	6	–	–	–	1	–	–	1	–	–
Mobile App 5	3	2	–	–	–	1	–	1	–	–
Iron Meteorite Imaging 1	–	–	3	2	1*	–	–	–	–	1
Iron Meteorite Imaging 2	–	–	3	2	1*	–	–	–	1	–
Meteorite Image Analysis 1	5	–	–	–	–	–	–	–	–	–
Meteorite Image Analysis 2	5	–	–	–	–	–	–	–	–	–
TOTAL	**28**	**10**	**6**	**4**	**3**	**3**	**1**	**5**	**1**	**1**

* One project manager shared by two teams.

almost immediately at the start of the semester. For teams consisting of multiple students from the same course, however, it took a few weeks before all the assignments were settled based on students' elections. This put some of the early-assigned students behind in their capstone deliverables, which had to be coordinated with their faculty. Additionally, students in the large computer science course were spread across six sections. Using student project preferences as the sole assignment criteria resulted in some of the computer science teams being comprised of students from different sections administered by different teaching assistants (which had implications for student schedules, as discussed below). For Year 2, we sought a way to implement team and project selection/assignment processes that were more constrained and streamlined to address both issues. While we were able to have computer science teams assigned within the same sections in Year 2, we were unable to change the timing of team assignments. This was particularly challenging when assigning engineering management students from ASU (which began the semester in mid-August) to teams of students from other universities who started their academic year one or more weeks later. At present, a solution is not evident. Forming functional teams across courses and institutions relies on the efforts and flexibility of the participating faculty and students, so this is a barrier to scalability.

2.2.2 Student schedules, workspaces, and deliverables

It can be difficult for students within the same major to find times they are all able to meet [6], but this is exacerbated when teams are composed of students from significantly different majors, such as the Psyche mobile app teams with students from computer science (from different sections), graphic design, and engineering management or, as in Year 2, when students are from different time zones (due to being at different universities or being online students). To facilitate this, students self-organize their meeting times (resulting in some teams meeting in the evenings or on weekends) and any sponsor meetings always include a call-in option for those who are online students or who are off-campus for jobs or other reasons.

In the pilot year, a special challenge for interdisciplinary teams comprised of students from completely different (non-engineering) departments was finding workspace, especially for teams building something physical. Particularly on large campuses like ASU, student access to secured buildings and workspaces may be limited to majors, so after-hours work sessions with non-major teammates can be difficult. For example, our two imaging rig teams were lent valuable equipment that needed to be secured. Their shared capstone space did not have sufficient storage, nor did it allow entry by non-majors, so in the spring semester they were lent space in a lab offered up by a sympathetic faculty member. Clearly, this is not a sustainable solution, particularly as we expand the projects to other institutions, and a one-size solution to this challenge is not evident at present. At ASU for Year 2 we are occupying refurbished space with rooms for Psyche capstone student meetings and storage and are engaged in a campus-wide discussion of how to better provide space for interdisciplinary student projects (both curricular and extra-curricular). However, interdisciplinary projects at the other universities partnering with us in Year 2 have had to rely on the generosity and resourcefulness of their faculty and departments. We continue to pursue solutions to this issue.

As documented in reports of other interdisciplinary capstones, students participating in Psyche-related capstone projects are still expected to meet their specific course's deliverables, which can be challenging since, as Abdel-Mohti, et al. (2016) found, "students who participated in this [interdisciplinary] project put in more effort than those who were involved in a discipline-specific project" (p. 1) [6]. A unique element of our projects that partially mitigates this challenge, however, is the inclusion of a project management capstone student on most teams, who aligns and facilitates the competing deliverables schedules for their teams. Feedback from the pilot year suggests that adding project

Table 2. Administration of participating capstone courses

	Course Size	Project Assignment	Mode	Project Origin	Funding available
Computer Science	300	Student-selected (but teams formed by instructor)	In-person	Sponsor-driven	No*
Computer Systems Engineering	50	Student-selected	In-person	Sponsor-driven	No*
Engineering Management	100	Instructor-assigned	In-person & online	Both	No*
Graphic Design	50	Student-selected	In-person	Student-driven	No*
Industrial Design	16	Student-selected	In-person	Student-driven	No*

* Unless from sponsor.

managers to teams of students who had never been actively managed before added to the real-world fidelity of the projects: the content-focused team members learned how to work to a project schedule and be responsive to a manager and the project management students had their first realistic experiences managing different kinds of contributors. As one project manager shared, "It has given me the best idea of what managing an interdisciplinary team is like and I've used the knowledge that I've gained in college to do so." Another project manager admitted, "It's harder than I thought it would be."

From the sponsor perspective, the project management students (including two online students in the pilot year) were critical to being able to scale the program, facilitating the flow of information and feedback and keeping projects on track without daily monitoring by the sponsor. Given the numerous positive outcomes in terms of student practice, sponsor experience, and project progress, we intended to have one project manager assigned to every Psyche-related capstone team in Year 2, though due to the capacity of the engineering management capstone we were only able to assign project managers to 16 of our 29 projects. Year 2 includes ASU engineering management capstone students providing project management to Psyche project teams at three of the six new university partners as well. Assessment of the efficacy of assigning ASU students to other universities' teams is ongoing.

2.2.3 Disciplinary cultures and expectations

Of course, interdisciplinary projects do not always run smoothly—on the course- or team-level. As Hutter et al., (2018) points out, "Courses taught across disciplinary units have an added challenge of disciplinary differences that need to be understood and negotiated for the successful administration of the course" [9, p. 263]. By senior year, many students have been steeped in the culture, norms, and work habits of their discipline, and may have had few opportunities to work on projects with students outside their major. This blending of disciplines is one of the ways that interdisciplinary capstones may better prepare students for the workplace but is also a potential source of strife. As Cooper, et al. (2015) attests, "When students are developed fully within a single discipline program that also offers their capstone, the structure promotes the student, instructor, and advisor expectations. . . . However, as students are assigned outside of their engineering discipline to support other capstones, the potential for misunderstanding of how their unique disciplinary skills support the capstone outcomes increases" [7. p. 700].

In some ways, having a project manager on teams in both the pilot year and Year 2 has helped ease those issues by, for example, assuring that the graphic artists delivered their products when needed by the developers or that the developers provided timely feedback to the artists. However, without a true workplace hierarchy, this role occasionally puts the project management students into the awkward position of having to scold or cajole their peers without being empowered to reward or sanction individual participants. As recommended in the literature and reflected in the program evaluation below, there is a need to better define team duties, responsibilities, and norms and help the students explore the host of interesting similarities and differences inherent in diverse disciplines' cultures and expectations [14, 15].

3. Assessment and evaluation

3.1 Assessment

Since the opportunistic interdisciplinary projects represent only a few of the projects in each single-discipline capstone course, in the first semester of the pilot year each course implemented its own assessment processes per its usual syllabus, with different team members being evaluated against different criteria. This challenge is not reserved to projects that mix students from widely different majors, such as engineering and art, but is encountered even by capstones bringing students together from different engineering programs, with one suggested solution to develop a "common design assessment language" [8, see also 16]. In the case of opportunistic interdisciplinary projects, however, it is not feasible to implement wholesale change across each single-discipline course. As a hybrid solution, in the spring semester of the pilot year, we combined the existing mid-term assessment processes used in the engineering management and computer science courses as a gauge of team dynamics and progress. Issues identified were addressed with the individual teams. Thus far in Year 2 we have continued this, along with more detailed feedback from the project managers, and used it for all teams, working with the students, faculty, and teaching assistants to rectify issues that surfaced. We have noted similar issues to those outlined by Ginige (2018), such as "artificially high" peer assessments and the possibly-outsized effect of negative written comments [17]; we plan to work to develop a more robust assessment procedure in future years. Given that course-related measures provide only student- and team-level assessment we also conduct a separate program evaluation.

3.2 Program evaluation

For the program-level evaluation in the pilot year, we used an adapted version of empowerment evaluation [18] spread across the full academic year, in which students participated in "(a) developing a mission, vision, or unifying purpose [for the program]; (b) taking stock or determining where the program stands, including strengths and weaknesses; and (c) planning for the future by establishing goals and [determining] strategies to accomplish program goals and objectives" [19, p. 23]. Used successfully with other NASA student programs with distributed participants [20], this process takes place iteratively as the program progresses, allowing program coordinators to make mid-course corrections, continuously improve, and adapt as the context and needs of participants change over the lifetime of the program (in this case at least through 2027 or later, if the mission is extended). As described in the results below, the majority of students' responses in the evaluation did not focus specifically on interdisciplinarity, though responses about more general topics suggest that working in teams with multiple disciplines can have an impact particularly on communication, collaboration, and practical aspects such as scheduling meetings and managing course deliverables.

3.2.1 Program purpose

To help identify a shared purpose of the program, participants were asked, "In your opinion, what do you think are the goals of a capstone course?" Although our program cannot necessarily change the mission or vision of the constituent capstone courses themselves, soliciting participants' opinions on the goals of capstone provides information for what we should emphasize within our administration of the Psyche projects. Year 1 participants' responses (n = 61) were analyzed using open coding, from which seven themes emerged (in some cases, multiple themes were embedded in a single student's response). The responses of almost two-thirds of participants (61.3%) were characterized as identifying the goal of capstone *courses* as providing a real-world experience, including deadlines and demands (though, as shown in subsequent phases of the evaluation below, some students did not feel that they understood the real-world application of their particular *project*). As one student wrote, "The goal of a capstone course is to provide real-life project experience to the students as well as using that opportunity to teach them about the complications of a real-time project. It demonstrates what it would be like to work in a team project for a company" (male computer systems engineering student). Almost half of participants (46.8%) mentioned teamwork in their response. "In my opinion, I feel that the goals of the capstone course are to gain experience with a team and within my field" (female graphic design student). More than a third of participants (38.7%) discussed career preparation or practicing professionalism as a goal of capstone, including "To help us in our careers by teaching us to be professionally better, in terms of speaking, writing, teamwork and time management" (female computer systems engineering student). The other goals mentioned were to use skills that had been learned in the major (21.0%), produce quality work (19.4%), solve problems (16.1%), and learn new things (11.3%). It should be noted that there is overlap in these categories. For example, teamwork, if implemented well, can be part of the real-world fidelity of a capstone project. Responses from the students closely correspond with the purposes outlined in the literature [e.g., 1–3].

3.2.2 Taking stock

On the same survey, the students were also asked to list the five most important activities or aspects of capstone. This yielded 310 responses that were then coded by theme into 54 items ranging from having access to tools and resources to interacting with sponsors to task management. In a subsequent survey, the students were invited to review this shorter list and then vote on the five aspects they felt were most important—even if it was an aspect that was not in their original list. They were allowed to cast more than one vote for a single aspect if they felt it was especially important. From this, nine aspects received a vote from at least 15% of the respondents. Using this set of aspects, a second survey was provided for the final phase of *taking stock* in which students were asked to rate to each of those nine aspects on their status, using a scale from 1 (poor) to 10 (excellent). The results from both phases are shown in Table 3. Note that the aspects the students felt were most important are not unique to interdisciplinary capstone teams, though some of the improvements suggested in the next step of the evaluation highlight the challenges of interdisciplinary teams.

The next phase of the evaluation, *planning for the future*, requires substantial and time-consuming reflection and written contribution by the participants. To constrain the demands of the activity, and to focus on the areas that needed the most improvement, we selected the four aspects with the lowest ratings for the participants to provide substantive feedback: Having meaningful real-world impact; communication with others; cooperation with others; and gaining real-world industry experience.

Table 3. Results from the taking stock phase of the program evaluation

	Rating	N_{Votes}	Percentage[1]
Working on a real project/practical experience	8.4	16	28.60%
Applying knowledge and skills from your major	8.2	27	44.60%
Creating and breaking down a complex project	8	14	25.00%
Design	7.8	10	17.90%
Problem-solving	7.7	11	19.60%
Cooperation with others	7.6	15	26.80%
Gaining real-world/industry experience	7.6	12	21.40%
Having meaningful real-world impact	7.4	9	16.10%
Communication with others	7.4	19	33.90%

[1] The percentage of respondents who selected this aspect as one of the five most important aspects during the *taking stock* phase.

3.2.3 Planning for the future

In planning for the future, students were invited to suggest specific goals related to improving each aspect, to recommend strategies to accomplish those goals, and to identify sources of evidence that the goals were met (what we should look for, measure, or assess to know we have reached the goal).

3.2.3.1 Having meaningful, real-world impact

The main goal students shared for improving the aspect of *having meaningful, real-world impact* was that the projects be more explicit about their potential impact—both external impact and impact for the students themselves. Among other comments, students suggested that there be "better clarification of the scope/impact of projects in initial project descriptions," that projects "have a common impact that is relatable to participants" and "reinforce the intended purpose and audience," and that we "should show students working on the project how important this project is." As strategies for reaching the goal of making impacts explicit, they suggested including *real-world impact* as a section in capstone project summaries, continuing to emphasize the impacts to students throughout the length of projects, setting more specific success criteria that would help indicate impact, and providing more opportunities to work with the end-user or experts. Per their recommendations, evidence or documentation the goal was met would come from positive student feedback (via surveys) as well as student work being suitable for integration into a released product or other output.

3.2.3.2 Communication with others

For the aspect of *communication with others*, the primary goal reported was to have increased interaction between the project sponsor and the students in the teams, as well as within and among the teams. Students reported that "students need to be held more accountable," that we should "lower the risk of unprofessional communication between team members," and that "everyone in a team [should be] on the same page at all times." The suggested strategies were to enforce weekly or bi-weekly meetings, solicit feedback about how things are going throughout the semester (not just at the end), host social events, and use communications technologies like Slack, group chats, Google Hangout, etc. Evidence or documentation for meeting the goal would include positive student feedback (via surveys), the frequency and quality of team communications (via the recommended technologies), and the number of teams that adhered to the required frequency of meetings. Interestingly, the only two comments related to interdisciplinary teams were not related to communication between disciplines but rather suggestions that the separate capstone classes be more coordinated by the faculty.

3.2.3.3 Cooperation with others

The most common theme in the suggested goals for *cooperation with others* related to team culture and, as expected, some touched on cooperation across disciplines. Students felt we should aim for "more group cohesion and norms," "everyone on the team interacting well with every other member of the team," "being open to others' opinions," and getting "members to engage one another in different fields." Strategies for reaching the goal of facilitating improved team culture and cooperation centered on setting expectations, including making sure team members understood their roles and adhered to team norms. Recommended evidence or documentation of meeting the goal included positive project progress and a complete final deliverable, reduction in the number of complaints and conflicts reported in student feedback (via surveys or direct communications), and teams having frequent meetings with each other and the project sponsor.

3.2.3.4 Gaining real-world/industry experience

The two main goals related to gaining real-world/industry experience were to have increased interaction with the project sponsor and other profes-

sionals and to practice professionalism, including working to expectations, requirements, and deadlines. Echoing some of the other aspects above, specific strategies included setting up more frequent meetings with experts or other professionals, having presentations about industry standards and best practices, providing "meaningful" and "real-world" projects, having required meetings with the project sponsor for accountability, and making explicit connections for the students about what they are learning and how it relates to the working world. For evidence and documentation, students recommended using feedback from participants (via surveys) on how applicable they felt their project/participation/experience was to the "real world," how prepared they felt to go into the workforce, and what/how much they had learned from the experience. Other recommended evidence included feedback from professionals, assessing the final output against expectations (such as "how well the solutions apply to the problem"), and required deadlines.

From the goals, strategies, and sources of evidence suggested by the students in the four categories above, it appears that the interdisciplinary nature of the capstone projects was not the most salient element to them, though we have kept the unique challenges of interdisciplinary capstones in mind while implementing their recommendations.

3.2.4 Implementing recommendations

During the pilot year, our evaluation concluded at the end of the academic year, so we were not able to make changes that would affect the pilot year participants themselves. At the start of Year 2, we were able to implement many of their recommendations to attempt to address the goals identified by the evaluation and improve the experience for the new participants.

To emphasize the *real-world impacts* of the projects, we included language in the capstone project proposals that specified how the projects would directly contribute to the Psyche mission. We found out subsequently, however, that in most participating capstone courses the students did not receive the full project proposal submitted by the project sponsor. To address this, next year we will craft a version of our project proposals that is a student-centered project brief to be discussed with students at our first meeting, highlighting the impact of the project (and the importance of the participation of multiple disciplines to the success of the project). This year we also established specific success criteria for the projects and have connected the teams to technical mentors or other outside experts at least once a month who reinforce the importance of the project and make connections between students' experiences and the working world (and which also addresses one of the suggestions related to *gaining real-world/industry experience*). To provide all students with the same introduction to the Psyche mission and the role that capstone projects play, we delivered a standardized on-boarding presentation at our first meeting with each team that emphasized their roles and responsibilities as Student Collaboration members of the Psyche as specified in the official Psyche Team Guidelines that govern the full Psyche mission team.

In our pilot year, we let the teams choose how frequently they wanted to meet with us, which resulted (unsurprisingly in retrospect) in the effective teams being the most regularly engaged and the struggling teams failing to reach out until the last minute. In Year 2, to address one goal related to improved *communication with others*, we instituted a minimum requirement of bi-weekly meetings between each team and the project sponsors (also addressing one of the recommended strategies for improving *cooperation with others* and *gaining real-world/industry experience*). While students are welcome to use their preferred platform for intra-team communication (group chats, Discord servers, texting, etc.), we also required all student team members to join the Psyche capstone Slack workspace, with special channels for each team along with shared channels for capstone-wide communications. Admission to the channels was extended to the capstone faculty and technical mentors on an opt-in basis. We currently monitor 42 Psyche capstone Slack channels and have found this to be a very efficient way of communicating with teams and team members on a regular basis (with an ongoing record of communication) and identifying issues early. In one case, we were able to detect a problem within a team and address it quickly due to the messages we observed in Slack in real-time. Students were also invited to join *Remind*, a group text-messaging tool, to receive occasional timely message updates. Although not a recommendation from the students, we created a shared Google Drive folder accessible by all participants that included the on-boarding presentation, Psyche Mission team and communications guidelines, tutorials for setting up Slack, Remind, and GitHub, and staff contact information. To provide more opportunities for inter-team connections and increased access to professionals (also relevant to *gaining real-world/industry experience*), in the first semester we hosted two social events and three WebEx presentations by NASA and university experts. To solicit more frequent feedback from the students, we surveyed all capstone students at the mid-term and end of the semester, including asking the teams directly about their project management team mem-

bers (and asking the project management students about the members of their team). We shared the results with the capstone faculty and, in aggregate, with the teams themselves. The mid-term feedback was particularly helpful in working with a few teams to get back on track in terms of team dynamics, roles and responsibilities, and project progress.

While we attempted to improve cooperation with others through the on-boarding presentation and we continue to monitor and try to improve group dynamics through our bi-weekly sponsor meetings and by offering more frequent surveys, much more needs to be done in this regard, particularly as it relates to the interdisciplinary teams and teams that include online students or other students working at a distance. In line with recommendations from the literature [e.g., 21], we are currently developing a free, 1-credit equivalent online course, *The Inclusive Mindset: Tools for Building Positive Team Culture*, with a subject matter expert who works with global interdisciplinary teams. This course will be available before the start of Year 3 and will be required for all students participating in Psyche capstone projects. We may also attempt to integrate other professional trainings [e.g., 22]. Additionally, although we did talk with teams at the beginning of Year 2 about the roles of the project management students and the roles of students from different disciplines on teams, it is clear that this needs to be more extensive and formalized [23]. Furthermore, through bi-weekly team meetings and separate monthly meetings with the project managers we have observed that not all project management students are equally prepared for or adept at working with their teams and some of them need a better understanding of their roles and responsibilities as a project manager. In preparation for Year 3 we will work with faculty from each of the disciplines represented in the projects to develop presentations that clearly outline the roles, contributions, responsibilities, and expectations for students from each discipline, so they understand their own roles and contributions and those of others. While in the first semester of Year 2 we have been monitoring the progress of the teams towards their deliverables through a standardized set of questions we ask and record at each meeting (relevant also to the strategies recommended for *gaining real-world/industry experience*), for better documentation of team member participation in the spring semester we will stress reporting of contributions by individuals and sub-teams, possibly incorporating a measure of frequency of participation in particular capstone activities [24], as a way of emphasizing accountability and cooperation [e.g., 17].

To explore the efficacy of the changes we made in Year 2, we began our empowerment evaluation much earlier, soliciting information on the purpose of capstone at mid-term of the first semester and conducting the *taking stock* phase a few weeks before the end of the semester and into the spring semester. Analysis is currently underway, and the *planning for the future* phase will be completed before the end of the spring semester, which will inform changes for Year 3 of the program. We anticipate that there may be differences in student feedback compared to last year due to the national expansion to other universities and inclusion of a larger number of online-only ASU students. We expect to continue adapting to the changing context and scale of the program as it expands throughout the lifetime of the mission.

4. Conclusions

As other researchers have concluded, at the faculty and departmental level, communication, flexibility, and openness to continuous improvement is critical to the success of interdisciplinary capstones. This is particularly the case for opportunistic interdisciplinary projects, as they do not afford a wholesale course redesign. While students' responses in the program evaluation do not center on having multiple disciplines in a project as the most salient quality of the capstone experience, their responses suggest it can have an impact particularly on communication, collaboration, and practical aspects such as scheduling meetings and managing course deliverables. To investigate this further, in the future we will include questions about working in interdisciplinary capstone projects specifically. We will also explore ways to help students experience and understand the potential affordances and benefits of working in interdisciplinary teams. We are using lessons learned from the pilot effort (including our novel approach of assigning engineering management students as project managers), the research of many others engaged in this area, and the ongoing evaluation of the program to make process improvements during our first phase of national expansion. We invite other capstone faculty interested in implementing opportunistic interdisciplinary capstone projects or incorporating Psyche-related projects into their courses in the future to collaborate with us on this iterative development process.

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