International Journal of Teaching and Learning in Higher Education 2023, Volume 35, Number 1, 92-100
http://www.isetl.org/ijtlhe/ ISSN 1812-9129

Student Group Work in Widely Interdisciplinary Teams

Emanuel Istrate & Shawn M. Soobramanie
University of Toronto, Victoria College

Group work is often used in university courses. This article examines group work in a widely interdisciplinary holography course that combines both art and science, for students from the arts, humanities, social sciences, and sciences. In these interdisciplinary teams, how much specialization of labor (dividing work according to students' pre-existing abilities or personal interests) is acceptable? We present student survey responses regarding their attitudes toward interdisciplinary group work, and their practices in dividing the work, to determine how much specialization of labor is taking place within the interdisciplinary teams. The surveys indicate a mix of approaches among groups concerning the division of labor based on prior skills. In the presence of specialization of labor, students learned from their partners and displayed a positive attitude toward working with someone from a different discipline. We believe that the intriguing nature of the holography projects helped many students avoid dividing the work according to their prior skills, and helped them see the value of working in a widely interdisciplinary team.

The purpose of this work is to examine interdisciplinary student collaborations on group projects, where teams span the humanities, social sciences, and sciences, and must complete projects that involve both art and science. Such teamwork across disciplines is an area that is not fully explored; the literature on student teamwork focuses mainly on courses that fall within a single discipline. Here, we study student attitudes toward collaborating with someone from an unrelated discipline and the way students divide the work among team members.

Literature Review

Project-Based Learning (PBL) is a form of learning anchored in constructivist thinking, where students build a deeper understanding of material by completing a project (Krajcik & Shin, 2014). Its main pedagogical features have been reviewed by Helle et al. (2006) and include (a) *problem orientation*: learning activities are driven by a problem; (b) *delivering a concrete artifact*: students must deliver a concrete end product; (c) *learner control of the learning process*: students control the pace and the sequence of their work; (d) *contextualized learning*: authentic or simulated working environments help students situate the learning; (e) *multiple forms of representation*: students integrate knowledge in different forms and from multiple sources; and (f) *development of favorable motivational orientations*: projects are chosen to be relevant to students' interests, leading students to ask their own questions.

A related pedagogical method is Problem-Based Learning (Lu et al., 2014), where students are asked to solve complex, ill-structured problems, without having to create an artifact or other deliverable. Both Project-Based Learning and Problem-Based Learning often arrange students into groups or teams. Therefore, these approaches are related to Team-Based Learning, Collaborative Learning, and Cooperative Learning, which all aim to help students enhance their learning by working together. Team-Based Learning (Considine et al., 2021; Michaelsen & Sweet, 2008) is a very structured method, where the teacher actively guides student activities. Cooperative and Collaborative Learning are usually less rigorously structured. In Cooperative Learning all students perform similar tasks while supporting each other (Davidson & Major, 2014; Johnson & Johnson, 1999b). Collaborative Learning allows students to work on separate tasks, which all contribute to a common goal, and encourages students to take a larger role in organizing the collaboration (Davidson & Major, 2014; Hmelo-Silver & Chinn, 2015). While many Collaborative Learning methods are implemented mainly during class time, others combine in-class with out-of-class activities (Love et al., 2014).

The literature published on small group work lists several advantages compared to the traditional practice of students working alone and learning directly from their instructors. For example, Considine et al. (2021) note that Team-Based Learning "has been shown to enhance student engagement and facilitate deep learning" and that it "also improves student learning outcomes and develops communication and teamwork skills, problem-solving and critical thinking skills, and professional behaviours." Hmelo-Silver & Chinn (2015) note that effective Collaborative Learning leads to student engagement, mutual respect, and positive independence, among other results.

Group learning activities have been implemented successfully in a variety of disciplines, such as biology (Gaudet et al., 2010), accounting (Cottell, 2010), and many others. Cooperative learning and other small group work have also been implemented at the pre-university level (Bertucci et al., 2010; Johnson & Johnson, 1999a; Slavin, 1988), and similar advantages have been observed.

Much of the work on small group learning is based on social interdependence theory as reviewed by

Johnson and Johnson (2009), which require that group work activities be designed carefully, taking into account several aspects. For example, Cooperative Learning approaches insist on the following five conditions for success (Smith, 1996): positive interdependence, face-to-face promotive interaction, individual accountability, development of teamwork skills, and group processing.

Team composition is an important consideration for optimal small-group learning. Michaelsen and Sweet (2008) insist on team heterogeneity and on properly distributing member resources to prevent the natural tendency of students to team up with those who have similar characteristics. Allowing students to self-select into groups has been studied in numerous disciplines, such as business (Bacon et al., 1999) and others. Harlow, Harrison, and Meyertholen (2016) looked at the effects of assigning students to teams based on ability.

An issue with small group work is that team members often choose the tasks that they are already most comfortable with. Some authors (Bacon, 2005; McCorkle et al., 1999) find this "specialization of labor" objectionable because students should practice the tasks that give them the most difficulty. Other authors, however, encourage students to choose the tasks for which "they are well suited" (Dommeyer, 2012). This specialization of labor has not been raised in recent publications, presumably because authors are more concerned with structuring group work in ways that lead to good teamworking (Channon et al., 2017) and a fair distribution of the efforts (Dommeyer, 2012; Knox et al., 2019).

Most studies on collaborative learning and group work have examined teams of students where all team members are expected to bring similar knowledge or skills. For example, in an upper-year science course, all team members are expected to have a solid knowledge of the scientific discipline. Even though students in a course might come from various, related programs of study, the expectation is that they will have experienced approximately equal learning outcomes, and will acquire similar levels of new skills and knowledge.

Collaboration in these "symmetric" cases has been widely studied, as summarized previously. Some studies have looked at multidisciplinary projects between related disciplines, such as a collaboration between a business administration and an accounting program with teams composed of students from both courses (Kruck & Teer, 2009), or a collaboration between students in courses on supply chain management, production planning, and product design (Long & Carlo, 2013). Several publications describe collaborations for interprofessional training in the health sciences. For example, a palliative care interdisciplinary program forms teams with medicine, pharmacy, nursing, social work, and spiritual care students (Thiel et al., 2020); a health systems science program for medicine students brings together medicine, nursing, and physician assistant students to enhance their understanding of the system in which they will work (Musick et al., 2021).

Several studies have looked at the collaborations between students from disciplines that are less closely related. Project-Based Learning courses have been described involving civil engineering and architecture students (Keenahan & McCrum, 2021); graphic design, communication, information technology, and psychology students (Lim et al., 2018); and hotel/restaurant administration, computer science, and graphic design students (Vogler et al., 2018). These studies note benefits in student learning, while also highlighting the need to facilitate communications between the various disciplines. Beddoes (2020) presents work with interdisciplinary design project teams, emphasizing the need to develop "interdisciplinary teamwork artifacts and practices," which help minimize undesired team dynamics and misunderstandings.

Choi and Pak (2006) have reviewed the terminology used to describe collaborations among disciplines. They explain that *multidisciplinarity* represents "a juxtaposition of disciplines that is additive, not integrative;" *interdisciplinarity* "is a synthesis of two or more disciplines, establishing a new level of discourse and integration of knowledge;" while *transdisciplinarity* "provides holistic schemes that subordinate disciplines, looking at the dynamics of whole systems." Using these definitions, our work falls within interdisciplinarity, because it integrates knowledge from multiple disciplines, but does not subordinate the disciplines under a holistic scheme.

Goals of this Study

Our goal with this study is to investigate effective teamwork in widely interdisciplinary settings, where students from across the humanities, social sciences, and sciences collaborate on course projects. We use the term *widely interdisciplinary* to emphasize that the interdisciplinarity goes beyond closely related subjects, such as a collaboration between business administration and marketing programs (Kruck & Teer, 2009).

We revisit the issue of specialization of labor (Bacon, 2005; McCorkle et al., 1999), in the context of interdisciplinary Project-Based Learning (PBL) activities. Preventing this division of work based on students' prior abilities or personal interests is a consideration when designing collaborative learning experiences so students maximize their learning. It is not clear, however, that this must also be the case in widely interdisciplinary collaborations, or if specialization of labor should be more acceptable in interdisciplinary settings. To provide a complete answer to this question, one would need to study it from a variety of perspectives, including the overall goals of the educational institution and its programs of study, and the effect this work has on students' critical thinking within and outside their own discipline, etc. Collecting all of this information is a worthwhile long-term goal. In this article, we take the first step, which is to report on students' attitudes and approaches toward working with someone from a different discipline. This will help us determine what type of learning happens in such group work, and what benefits students derive from participating in widely interdisciplinary courses.

We performed a qualitative study, with the bulk of the data based on student surveys using open-ended questions, asking students to comment on their experience in the group, and on the methods used to divide the work. A content analysis of student response data was used to identify to what extent students engaged in the specialization of labor in their asymmetric teams, and how effective they found their interdisciplinary teamwork to be.

The next section describes the interdisciplinary course that was used for this study. It is followed by a section discussing some general aspects related to widely interdisciplinary courses.

The Setting: A Course on Holography at the University of Toronto

The study presented here looks at the course *Holography for 3D Visualization,* offered at the University of Toronto (Istrate & Miller, 2009). This course gives an introduction to holography, a method to produce three-dimensional images with the help of a laser, by recording both the amplitude and phase of light from a subject (Gabor, 1948). The course teaches the scientific principles of the holographic process, and the artistic principles of using holography as a medium for the production of art. As a breadth course, it attracts students from all disciplines in the humanities, social sciences, and sciences, along with architecture and engineering students. Beside lectures in the usual classroom setting, the course makes use of Project-Based Learning pedagogy (Krajcik & Shin, 2014) through two projects where students work in a studio to make holograms using a laser and the necessary optical equipment and chemical processing baths. One of the two projects additionally involves the production of 3D graphic scenes in software. Students work in teams using elements of Collaborative Learning (Hmelo-Silver & Chinn, 2015).

Because this is an interdisciplinary course, students are required to complete their projects in interdisciplinary teams. Teams are formed of two students, coming from different disciplines. Ideally, we would like the teams to be formed of a Fine Arts student working with a Physics student so they combine the skills most necessary to produce art through holography. This, however, is rarely possible, because many course participants study neither Fine Arts nor Physics. Therefore, we only require that they team up with someone from a different discipline. For example, a team might have an Architecture student working with a Computer Science student, or a Political Science student working with a Life Science student. This can still be considered to be a *widely interdisciplinary* collaboration, because we discourage teams from closely related disciplines, such as two different sciences. This way the two members of the team will bring different perspectives to the projects. We do not use larger teams because the process of creating 3D graphics content on computers is not easily divided among more students.

To facilitate the process of finding a partner, students submit a personal profile to the course discussion board, where they write about their academic background, interests in the arts and the sciences, and themes they would like to explore in the holography projects. They then form teams based on the content of these profiles. There is no formal contract between project partners, but they are instructed to discuss a number of points before forming a team, such as work style, time availability, accountability to each other, etc. Course staff approves the team formation, and ensures that students come from different disciplines.

The learning outcomes of the course can be divided as follows: On the science side, students learn the optical physics of holography and aspects of human visual perception. On the art side, they learn about past artists' work in holography and fundamental work in visualization. In the two projects of the course, students produce holograms. They gain experience proposing, executing, and defending a work of art while simultaneously developing skills in manipulating the optical components for recording holograms. In addition to these direct learning outcomes, students are exposed to teamwork and learn to collaborate with someone from a very different academic background.

The instruction for this course, covering both optical Physics and Fine Arts is delivered by a team of two instructors. The main course instructor has a background in optical science and holography. A second instructor with experience in holography as an artistic medium, as well as 3D visualization, is contributing to the art topics of the course and the project evaluations.

It should be noted that the treatment of art and science in this course is not completely symmetric. The lectures and other demonstrations focus more on science concepts. For this component of the course, students complete tests and assignments individually. The projects are done collaboratively and place more emphasis on artistic thinking. Therefore, students spend more time thinking about scientific concepts individually and about art concepts as part of their team.

This does not reflect a difference in emphasis in the course or an assumption that one part is more important than the other, but is due to the nature of the projects. The course marking scheme is split evenly between art and science, with each component accounting for about half the course grade.

Despite this uneven division of science and art activities, the interdisciplinary nature of the class composition and the tasks leads to interdependence among the group members as required for group work (Smith, 1996).

Interdisciplinary Collaborations and the Specialization of Labor

In this section, we discuss some aspects that appear more generally in widely interdisciplinary courses. In a course that attracts students from across disciplines and requires them to work closely with each other, we expect two types of learning to take place. First, we have the conventional learning of course material that is covered in course lectures. Through Collaborative Learning taking place in the projects, a second type of learning is also taking place: students learning from each other. This second type of learning is less uniform and less predictable, as it depends on the exact composition of each team and relations between its members. It can be, however, more authentic than learning from an instructor, and should be considered an important outcome of an interdisciplinary course. In addition to the knowledge gained from their partner, students also practice the skills needed to work with someone from a vastly different background. A Project-Based Learning approach for interdisciplinary topics allows instructors to take an advisory role (Helle et al., 2006), helping students construct knowledge based on the expertise of their partner.

Because everyone's learning experience in the project team is different, test and assignment questions must ensure that they are fair to all students in the class. Direct fact-based questions cannot be asked, since not all teams might have discussed exactly the same facts. Instructors can instead use reflective exercises as a basis for evaluating the learning. Students can be asked to reflect on the experience of working in an interdisciplinary group. With the necessary prompts, students can write about the contributions they made to their partner's learning, as well as what they have learned from the partner and the teamwork. For the holography course described here, the reflection prompt was as follows:

"[Describe] the concept(s) your project aims to convey; the process through which your team arrived at this concept; how the concept evolved and how it got implemented in the hologram; what you think was successful about this project. Be sure to specify what the contributions of each team member were. What made your collaboration successful, what could be improved in your collaboration, and how would you do that?"

Topics for interdisciplinary collaborations need to be engaging for students from a wide variety of backgrounds. In a science-art collaboration, the topic needs to combine sufficient depth to explore its scientific and technological aspects, while also providing the necessary flexibility and freedom for artistic expression. This requires a certain amount of novelty; it helps if neither side is fully explored and established. Painting, for instance, allows artistic expression based on the complex chemical processes that produce colors in paint, but would be a poor subject for an interdisciplinary course: Paint chemistry was developed a long time ago, and there are few unanswered questions where a chemist can contribute. Computer graphics is a much better topic for today since there are many ways in which a computer scientist can support an artist working in this relatively new field.

As elaborated in the introduction, a question that arises in organizing interdisciplinary collaborations among students is that of the specialization of labor. For courses within a single discipline, specialization of labor can be considered to be a drawback, because students avoid the tasks where they need more practice. For interdisciplinary courses, one needs to decide what amount of specialization of labor is acceptable and must ensure that students do indeed learn from their peers who come from different disciplines.

Method

The data presented here was collected from students in the holography course described previously during the Spring terms of 2017 and 2018, using a protocol approved by the Research Ethics Board at the University of Toronto. Students were invited to complete a survey before starting the group work, and another survey after the group work. This data was complemented by interviews with one student in each of the 2 years, done after the course had finished. The data and quotes presented here come from the surveys. The interviews were semi-structured and used only to clarify how the students perceive the collaboration. They used similar questions as the surveys.

The surveys were administered on paper during class time. They were voluntary, and no incentives, such as bonus points, were used. To minimize undue influence, the surveys were administered by research staff not connected to the course, and no course staff was present in the room during that time. The first survey was administered in week 3 of the 12-week course, while the second survey came in week 11 of the course. All students in the course were invited to participate. A total of 58 students were enrolled in the course during those two terms. Out of this number, 31 students completed both surveys of this study. This number is not sufficient to give statistical significance to quantitative data. Hence, the discussion that follows uses qualitative student answers, which underwent a content analysis.

Results

The previous sections introduced widely interdisciplinary group work, the holography course where this has been implemented, and the methods of our study. In this section, we seek to provide information regarding student learning and the specialization of labor in these interdisciplinary projects. Example student responses are included. As elaborated in the Method section, the results presented here are from surveys before and after the group work.

For most students, this was the first opportunity to collaborate on a course project with someone from an unrelated discipline. The initial survey shows that when starting their projects, most teams did not plan to apply specialization of labor. By the time of this first survey, students had selected their partners, which means they knew already about their academic background, and had a rough idea of their interests, but had not interacted with them significantly. The student responses show that most teams were approaching the project as a joint exploration. Their most common desire at that time was for their partner to keep an open mind: “I’d like my partner to be open-minded, take responsibility (i.e, share the work load) and have some knowledge of physical science” (social science student, whose partner was in the humanities). “Responsibilities and open-minded would be the most important traits to work as partners” (science student, whose partner was in the humanities). This suggests that students were somewhat afraid that someone from a different discipline would not accept their ideas or contributions. Another desire that students had at the beginning of the work, was for their partner to be punctual, which presumably was due to negative experiences in past courses.

Many students were counting on the complementary skills brought by their partners: “A strong understanding of the science component, and an open mind for collaboration for art component” (humanities student, whose partner was in the sciences). “Precision, logical thinking, mathematical background, punctuality” (humanities student whose partner was in the sciences). The quotes in the previous two paragraphs are in response to the question: “For you, what would be the set of skills an ideal project partner should bring to your team?”

The survey also had a more direct question about the division of tasks, to which most students indicated a desire to share in all aspects of the work: “I like planning/creative elements but I want to learn the science. I think it would be great for us to both be involved” (humanities student, whose partner was in science). “I would prefer both of us to be involved as [sic] many steps in the process as possible” (social science student whose partner was in the sciences). “I’d want us to participate equally in all aspects; if a specific skill is needed for our idea, whoever knows it already will do it, but in general I like to be cooperative” (humanities student, whose partner was in the sciences). A few students, however, did not yet know how they would divide the work: “I don’t know yet” (social science student, whose partner was in the sciences). Also, a few students did plan to make use of their complementary skills: “I would like to do the alignment and whole laser process, and would prefer that my partner had a bigger part in the art direction” (humanities student, whose partner was in social science). This shows that specialization of labor was not something most students were planning to do, although there were exceptions. Students were planning to share in all aspects of the work. This is probably related to the novelty of the material—holography. The quotes in this paragraph are in response to the question: “What parts of the process of creating holographic art would you like to do yourself, and what parts would you prefer to leave to your partner?”

The survey at the end of the group work, which corresponds to the end of the course, provides information on how the division of work was done within the teams, how the collaboration in the interdisciplinary setting compares to students’ past collaborations within a single discipline, and what the students’ experience was during this work. Open mindedness was not brought up again, which indicates that their fears in this respect were not justified.

The vast majority of students stated that working on projects in interdisciplinary teams is preferable to individual work. To the question “Would you have preferred to do this project without a partner?” some of the answers are: “No, I feel that a partner, especially in art classes, helps to give second opinions/critiques that are crucial to the end result” (science student whose partner was in the humanities). “… I rarely enjoy group work but this was an exception” (humanities student whose partner was in the humanities). “No, due to the knowledge the other partner offered, and the knowledge that I gave from working with them” (humanities student whose partner was in the sciences). “I feel indifferent. Usually I work alone have had trouble with past partnerings, but the project was effective” (humanities student whose partner was in computer science).

In the end, some teams divided the work according to their skills: “We worked very collaboratively but also played to each other’s strengths” (humanities student, whose partner was in the sciences). "We splitted [sic] duties based on knowledge & skills" (humanities student, whose partner was in the sciences). Other teams, however, tried to avoid doing that: "We have different strengths and weaknesses but instead of splitting the duties cleanly, we both attempted to expand our individual horizons and dabble with the unknown" (humanities student, whose partner was in the humanities and sciences). "Similar types of work and skills" (science student, whose partner was in the humanities). Therefore, specialization of labor did happen in some of the cases. However, the division was often done based on personal interests, rather than the actual program of study of the participants: "We ended up splitting duties because each of us had a particular subject we wanted to further explore and experiment with. However, we still worked together to produce final projects" (science student, whose partner was in the humanities). "We did similar types of work for the first project. The second was more heavily weighted on my side as my partner wasn't comfortable using the blender software" (humanities student, whose partner was in social science). Other teams divided the work based on their available time: "Mostly did what each person was comfortable with. Also the duties may have changed based on the time and availability of the partner" (humanities student, whose partner was in the sciences). The quotes in this paragraph are in response to the question: "Did both partners do similar types of work, or did you end up splitting duties based on knowledge and skills?"

Even with some specialization of labor, most students acknowledged learning from their partners and appreciated being able to learn the work style of a different discipline: "I learned to accommodate different ideas into my own creative visions" (humanities student, whose partner was in the sciences). "Creativity, writing skills" (science student, whose partner was in humanities). They also appreciated that the interdisciplinary teams lead to a different collaborative experience, compared to collaboration in a single discipline: "Collaboration can be different when you have very diff. ideas" (humanities student whose partner was in the sciences). The quotes in this paragraph are in response to the question: "What did you learn from your partner?"

In terms of the more specific benefits of interdisciplinary collaborations between the arts and the sciences, students indicated that collaborating with someone from a different discipline helped them clarify their ideas about the content of their holography projects: "It was great and eye-opening for sure. Having a different perspective really helps me make the best things I can" (computer science student, whose partner was in life science). "… his skills […] gave me new insight into different ways of viewing structures and their features" (science student whose partner was in humanities). Some students reflected on their own contribution to an interdisciplinary team: "Fantastic, it forced me to meet with someone new, but also feel like I could actually contribute in a useful way due to other diverse knowledge" (humanities student, whose partner was in the sciences). Beyond the content of the holography projects, students appreciated learning to work across the disciplines: "Yea, it was useful. Learning to collaborate with someone diff. minded" (humanities student, whose partner was in the sciences). Students also valued being able to form acquaintances across the disciplines, which is not easily done in a large university, and to understand how others approach things beyond the content of the course: "It was really interesting to also see the different outlooks we have on life in general. I learned a lot from working w/ someone outside my discipline in terms on [sic] out-of-class stress as well" (science student, whose partner was in the humanities).

While the majority of students noted the benefits of their interdisciplinary collaboration, not all students felt that way. Some teams found that their previous knowledge and skills were not applicable: "I don't think being from different disciplines had any impact on our collaboration. We didn't really use any of my partner science skills in the project" (humanities student whose partner was in the sciences). Others felt that the two team members brought similar skills to the project: "Somewhat useful. I don't think either me or my partner were far enough on one side to have that much influence on the project" (humanities student whose partner was in the sciences). "Minimal. Difference in disciplines barely made a difference" (science student whose partner was in the social sciences). Finally, a small number of teams had trouble collaborating for other reasons: "To me, not very. It was nice getting to know a new person in another discipline but not the best working w/ them in my experience" (science student whose partner was in humanities). The quotes in the previous two paragraphs are in response to the question: "Overall how useful was the collaboration with someone from a different discipline?"

These responses confirm that in the majority of cases, students learned from their partners, learned to work with someone from a different discipline, and developed a positive attitude toward such collaborations. As can be seen, however, some did not find the interdisciplinary nature of the teams as valuable. One should note that the students in this elective breadth course were self-selected. The data, therefore, reflects the view of a group of students who chose to participate in these interdisciplinary activities. To what extent these findings will apply to students who would not choose to participate voluntarily in such a course remains to be seen.

The humanities students in the these examples also include a few architecture students. Due to the relatively low number of architecture students, it would be difficult to list them separately, while maintaining their anonymity.

Discussion

The purpose of this study was to look at interdisciplinary group projects, where students from vastly different programs of study work together. One of the main issues considered by our work is the specialization of labor, which is the tendency of students in a group to divide the work according to their pre-existing abilities or personal interests. In traditional group projects within a single discipline, some find this specialization of labor to not be desirable because students avoid practicing the portion of the work where they most need practice (Bacon, 2005; McCorkle et al., 1999). For interdisciplinary group projects, however, the situation is different. It is not immediately obvious if specialization of labor is desirable, and to what extent.

Previous studies of widely interdisciplinary group projects (Keenahan & McCrum, 2021; Lim et al., 2018; Vogler et al., 2018) noted student learning in these settings, but did not address the question of specialization of labor directly. In the present work, using a content analysis of student surveys, we conclude that specialization of labor happened to some extent in the art-science group projects. However, many students have still chosen to perform tasks with which their partner was more familiar. This is most likely due to the intriguing nature of the projects. Even in the presence of specialization of labor, students learned from their partners, who had very different backgrounds. This confirms one of the main assumptions of widely interdisciplinary group projects: that students can learn from their partners even if they divide labor according to their skills. Specialization of labor can therefore be acceptable, at least to some extent. Students displayed positive attitudes toward the group work and the contributions of their partners, which aids in learning.

The example answers shown here were selected to cover the vast majority of responses, although the small number of students makes it difficult to analyze how frequently each type of response was given. Our data cannot be expressed numerically in ways that achieve statistical significance. Nevertheless, we believe that these responses are useful as a first step in understanding how students approach teamwork in such a widely interdisciplinary course. We hope that such interdisciplinary courses will become more popular, which will allow data to be collected from more students in the future. These results were collected from an elective course and may change if the course became mandatory.

A future step would be to determine the optimum level of specialization of labor in such interdisciplinary teams, based on an analysis of the learning goals of the course, as well as the individual goals of the participating students. The literature on non-interdisciplinary (Boud et al., 2013) and interdisciplinary (Beddoes, 2020) group projects emphasizes the need to train and guide students to work effectively in groups. A future study could evaluate various methods to achieve this in the context of holography teams.

Conclusions

To conclude, our work aims to investigate student attitudes toward interdisciplinary group projects in the context of a course covering both the science and the art of holography, looking in particular at the way interdisciplinary teams divide the work. The course description and student responses presented here add another perspective to the growing literature on widely interdisciplinary group work in a university setting.

Human Subject Research and Informed Consent

The data presented in this work was collected using procedures approved by the Research Ethics Board at the University of Toronto. Participants provided informed consent before completing the surveys or participating in the interviews.

References

Bacon, D. R. (2005). The effect of group projects on content-related learning. *Journal of Management Education*, *29*(2), 248–267.

Bacon, D. R., Stewart, K. A., & Silver, W. S. (1999). Lessons from the best and worst student team experiences: How a teacher can make the difference. *Journal of Management Education*, *23*(5), 467–488. https://doi.org/10.1177/105256299902300503

Beddoes, K. (2020). Interdisciplinary teamwork artefacts and practices: A typology for promoting successful teamwork in engineering education. *Australasian Journal of Engineering Education*, *25*(2), 133–141. https://doi.org/10.1080/22054952.2020.1836753

Bertucci, A., Conte, S., Johnson, D. W., & Johnson, R. T. (2010). The impact of size of cooperative group on achievement, social support, and self-esteem. *Journal of General Psychology*, *137*(3), 256–272. https://doi.org/10.1080/00221309.2010.484448

Boud, D., Cohen, R., & Sampson, J. (2013). *Peer learning in higher education: Learning from and with each other*. Routledge.

Channon, S. B., Davis, R. C., Goode, N. T., & May, S. A. (2017). What makes a 'good group?' Exploring the characteristics and performance of undergraduate student groups. *Advances in Health Sciences Education*, *22*(1), 17–41. https://doi.org/10.1007/s10459-016-9680-y

Choi, B. C. K., & Pak, A. W. P. (2006). Multidisciplinarity, intersdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine*, *29*(6), 351–364.

Considine, J., Berry, D., Allen, J., Hewitt, N., Oldland, E., Sprogis, S. K., & Currey, J. (2021). Team-based learning in nursing education: A scoping review. *Journal of Clinical Nursing*, *30*(7–8), 903–917. https://doi.org/10.1111/jocn.15599

Cottell, P. G. (2010). Cooperative learning in accounting. *Cooperative Learning in Higher Education: Across the Disciplines, Across the Academy*, 11–33.

Davidson, N., & Major, C. H. (2014). Boundary crossings: Cooperative learning, collaborative learning, and problem-based learning. *Journal on Excellence in College Teaching*, *25*(3 & 4), 7–55.

Dommeyer, C. J. (2012). A new strategy for dealing with social loafers on the group project: The segment manager method. *Journal of Marketing Education*, *34*(2), 113–127. https://doi.org/10.1177/0273475312450384

Gabor, D. (1948). A new microscopic principle. *Nature*, *161*(4098), 777–778. https://doi.org/10.1038/161777a0

Gaudet, A. D., Ramer, L. M., Nakonechny, J., Cragg, J. J., & Ramer, M. S. (2010). Small-group learning in an upper-level university biology class enhances academic performance and student attitudes toward group work. *PLoS ONE*, *5*(12). https://doi.org/10.1371/journal.pone.0015821

Harlow, J. J. B., Harrison, D. M., & Meyertholen, A. (2016). Effective student teams for collaborative learning in an introductory university physics course. *Physical Review Physics Education Research*, *12*(010138), 1–11. https://doi.org/10.1103/PhysRevPhysEducRes.12.010138

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education: Theory, practice and rubber sling shots. *Higher Education*, *51*(2), 287–314. https://doi.org/10.1007/s10734-004-6386-5

Hmelo-Silver, C. E., & Chinn, C. A. (2015). Collaborative learning. In L. Corno & E. M. Anderman (Eds.), *Handbook of educational psychology* (pp. 349–363). Routledge. https://doi.org/10.4324/9781315688244

Istrate, E., & Miller, R. J. D. (2009). A holography course in Toronto. *Education and Training in Optics and Photonics*, *June 2009*. https://doi.org/10.1117/12.2208076

Johnson, D. W., & Johnson, R. T. (1999a). *Learning together and alone: Cooperative, competitive, and individualistic learning* (5th ed.). Allyn & Bacon.

Johnson, D. W., & Johnson, R. T. (1999b). Making cooperative learning work. *Theory into Practice*, *38*(2), 67–73. https://doi.org/10.1080/00405849909543834

Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher*, *38*(5), 365–379. https://doi.org/10.3102/0013189X09339057

Keenahan, J., & McCrum, D. (2021). Developing interdisciplinary understanding and dialogue between engineering and architectural students: Design and evaluation of a problem-based learning module. *European Journal of Engineering Education*, *46*(4), 575–603. https://doi.org/10.1080/03043797.2020.1826909

Knox, K. J., Gillis, E. A. L., & Dake, G. R. (2019). A positive student experience of collaborative project work in upper-year undergraduate chemistry. *Chemistry Education Research and Practice*, *20*(2), 340–357. https://doi.org/10.1039/c8rp00251g

Krajcik, J. S., & Shin, N. (2014). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 275–297). Cambridge Univerity Press. https://doi.org/10.1017/CBO9781139519526

Kruck, S. E., & Teer, F. P. (2009). Interdisciplinary student teams projects: A case study. *Journal of Information Systems Education*, *20*(3), 325–330.

Lim, L., Andrew, J., Lewis, S., & Gao, J. (2018). Interdisciplinary teamwork in an authentic project-based learning environment. In D. Wache & D. Houston (Eds.), *Research and development in higher education: (Re)valuing higher education,* (pp. 1–13).

Long, S. K., & Carlo, H. J. (2013). Collaborative teaching and learning through multi-institutional integrated group projects. *Decision Sciences Journal of Innovative Education*, *11*(3), 233–241. https://doi.org/10.1111/dsji.12011

Love, A. G., Dietrich, A., Fitzgerald, J., & Gordon, D. (2014). Integrating collaborative learning inside and outside of the classroom. *Journal on Excellence in College Teaching*, *25*(3 & 4), 177–196.

Lu, J., Bridges, S., & Hmelo-Silver, C. E. (2014). Problem-based learning. In R. K. Sawyer (Ed.), *The*

Cambridge handbook of the learning sciences (pp. 298–318).

McCorkle, D. E., Reardon, J., Alexander, J. F., Kling, N. D., Harris, R. C., & Vishwanathan Iyer, R. (1999). Undergraduate marketing students, group projects, and teamwork: The good, the bad, and the ugly? *Journal of Marketing Education*, *21*(2), 106–117. https://doi.org/10.1177/0273475399212004

Michaelsen, L. K., & Sweet, M. (2008). The essential elements of team-based learning. *New Directions for Teaching and Learning*, *116*, 7–27.

Musick, D. W., Vari, R. C., Kraemer, M. S., Trinkle, D. B., Vari, P. M., Smith, J. C., & Learman, L. A. (2021). Building health systems science education from the core domain of interprofessional education at Virginia Tech Carilion School of Medicine. *Medical Science Educator*, *31*, 215–222. https://doi.org/10.1007/s40670-020-01148-z

Slavin, R. E. (1988). Cooperative learning and student achievement. *Educational Leadership*, *46*(2), 31–33.

Smith, K. A. (1996). Cooperative learning: Making "groupwork" work. *New Directions for Teaching and Learning*, *67*, 71–82.

Thiel, M., Harden, K., Brazier, L.-J., Marks, A., & Smith, M. (2020). Improving the interdisciplinary clinical education of a palliative care program through quality improvement initiatives. *Palliative Medicine Reports*, *1*(1), 270–279. https://doi.org/10.1089/pmr.2020.0092

Vogler, J. S., Thompson, P., Davis, D. W., Mayfield, B. E., Finley, P. M., & Yasseri, D. (2018). The hard work of soft skills: Augmenting the project-based learning experience with interdisciplinary teamwork. *Instructional Science*, *46*(3), 457–488. https://doi.org/10.1007/s11251-017-9438-9

EMANUEL ISTRATE, PhD, is an Associate Professor, Teaching Stream at Victoria College, University of Toronto. One of his past positions was Academic Program Coordinator at the Institute for Optical Sciences at the University of Toronto, where he set up courses and training programs for students studying optics, including a popular holography course. His teaching also includes social aspects of the work of scientists, creativity, ethical entrepreneurship, and the techniques that makes science researchers more effective in their work.

SHAWN M. SOOBRAMANIE is an MT graduate from the Ontario Institute for Studies in Education (OISE). He teaches at Heartlake Secondary School in the Peel District School Board as a mathematics teacher. In previous years, he has also worked in different university mentorship programs as well as elementary teaching positions.