Student Teamwork Experience in a Hands-on Robotics Course

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ABSTRACT

Effective teamwork is powerful and beneficial, especially in multidisciplinary robotics projects and courses. In an undergraduate robotics project-based course, students typically come from diverse backgrounds and work together in teams to achieve a common design goal on robotic platforms. In this complete work, we study the changes in students' mastery experience through various stages of a hands-on robotics course, with the goal of understanding and facilitating the students' learning and collaborative experience.

We address the following two specific research questions:
RQ1: As the robotic project complexity advances, how do students' knowledge, confidence, and teamwork dynamics progress?
RQ2: How are students' mastery experiences and team satisfaction related to their reported confidence in robotics projects?

This paper looks at a third-year hands-on undergraduate robotic course at a large Midwestern University with a heavy team collaboration component. This course develops full-stack autonomous navigation and mapping for mobile robots and includes both hardware and software design. The goal of the course is to introduce students to multiple sensor systems and real-world mobile robot platforms and to promote teamwork while giving the students confidence and knowledge in building, implementing, and testing their robot functions.

In this work, we leverage Tandem, an educational tool designed to support student teams. We analyze the students' teamwork effectiveness, confidence, and team performance through both Tandem survey data and quantitative project evaluation in the robotics course. We explore the relationship between the students' confidence in a robotic project and their project performance (e.g., whether confidence rises before or after a project milestone, and the correlation between project performance and team satisfaction). We also study the changes in the students' teamwork experience as the robotic project complexity grows, with the hope that this work may provide some insights on improving student team experience as we design and plan future multidisciplinary robotics projects and courses.

INTRODUCTION

Teams are common in multidisciplinary robotics projects and courses [1]. Teamwork ("an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives") is evaluated as one of the required student outcomes in ABET (The Accreditation Board for

Engineering and Technology) for engineering program accreditation [2]. Teamwork has been shown to make students more effective learners [3] and help improve students' academic performance, persistence, participation, retention, and motivation towards STEM areas [4]. Team-based learning has also been shown to contribute to the development of more effective collaboration and communication skills among engineering students [5, 6, 7].

In a typical multidisciplinary team-project-based course, students come from a diverse range of backgrounds and technical expertise, and work together to accomplish various learning goals. The tasks can range from hardware assembly, software development, and real robotic implementation and debugging. Various strategies have been used to measure and understand the students' teamwork experience in such multidisciplinary engineering education settings. For example, [1] used survey questions and five-point Likert scales to ask students about their empathy, team development, and specific collaborative actions. Their study focused more on understanding remote-based teamwork learning. [4] and [5] focused on connecting teamwork behaviors with individual academic performance through peer-evaluation and self-reflections from students. [8] provided suggestions on improving teamwork through intervention strategies for student groups, such as creating a "team contract", mentors, and self-evaluations. [9] designed a series of behavior-theory-based plans, such as accountability and project management plans, to enhance and evaluate student teamwork experience through engagement, student team roles, goal clarity, and managing conflicts.

In this study, through data from an upper-level (third-year) undergraduate hands-on robotics course at a large Midwestern public research University, we investigate the students' teamwork experience in terms of effectiveness of working together, how well they are sharing ideas and workloads, and their team confidence. We study the relationship between these factors of teamwork experience by answering questions such as: What causes a team to "work well" ? What would cause a team to have high team confidence? How does sharing ideas and sharing workloads correlate? Would logistics impact teamwork? We also assess the students' mastery of the course subject content and investigate the relationship between the students' knowledge with their teamwork experience and confidence. In the following, we present our research questions and describe our data collection methods, results, analyses, and discussions.

RESEARCH QUESTION AND METHOD

This work studies student teamwork in a hands-on robotics course setting. We are interested in understanding how well the students master course materials while working in teams, as well as their teamwork experience, including their team satisfaction, teamwork dynamics, and confidence. We are also interested in exploring possible factors that contribute to the teamwork experience.

We address the following two specific research questions:

RQ1: As the robotic project complexity advances, how do students' knowledge, confidence, and teamwork dynamics progress?

RQ2: How are students' mastery experiences and team satisfaction related to their reported confidence in robotics projects?

The first research question addressed was how do students' knowledge, confidence, and teamwork dynamics progress, as the robotic course project complexity advances. As the semester progresses, we wish to study the overall trend of the students' teamwork experience and dynamics, how teamwork satisfaction and confidence differ (if any), and the relationship between confidence and the students' knowledge of the course and team dynamics.

The second research question addresses the relationship between the students' mastery experiences and team satisfaction related to their reported confidence in robotics projects. Even though the course content is highly technical, one of the educational goals is to encourage and promote student confidence in hands-on robotics team-based projects. We investigate whether there is correlation between confidence and both team-based performance and individual-based assessments, and what factors may contribute to teamwork confidence and satisfaction.

Additionally, we investigate and report relationships between the student teams' performance (as measured by class score), the students' individual knowledge (as evaluated by individual assignments), and their teamwork dynamics and confidence.

Course Structure and Content

In this work, we look at the student and teamwork results in a third-year hands-on robotic course at a large Midwestern public research University with a heavy team collaboration component. This course is undergraduate-level, with primarily junior-standing students participating. The content of the course covers full-stack autonomous navigation and mapping for mobile robots, where the students build, develop, and implement both hardware and software parts on the robot to achieve autonomous navigation functionalities. The course lasts approximately 15 weeks (one entire semester).

By the end of the semester, the learning goals are that the students understand the fundamentals of autonomous robot navigation (such as mapping, localization, path planning, odometry, control parameter tuning), as well as gaining confidence and knowledge in building, implementing, and testing their robot functions while working in a team setting. The students' individual knowledge

in the robotic course content is assessed through a midterm exam, a final exam, and review quizzes, and their team performance is assessed through three major project reports and robot performances.

Team-based Evaluation

In this course, the students' grades (as a measure of academic performance, as evaluated by the instructional team) include two parts. For team-based scores, we include three major project scores. The projects details are as follows:

Project 1: Building the robot, and tuning control parameters for driving the robot in square trajectories. Students submit and are graded based on a project report that includes fundamental understanding (e.g., explain the concepts of control parameters), tables of parameters, and robot driving videos (hands-on demo, with quantitative accuracy measurement - higher accuracy/lower error corresponds to higher grades).

Project 2: Mapping a maze environment using LiDAR (Light Detection and Ranging) sensor data as mounted on the robot, localizing where the robot is inside the maze environment. Students submit and are graded based on a project report that includes fundamental understanding (e.g., explain the concepts of simultaneous localization and mapping), tables of parameters (e.g., spread of particle filters), and robot driving videos and mapping and localization accuracy (hands-on demo, with quantitative accuracy measurement - higher accuracy/lower error corresponds to higher grades).

Project 3: Implement autonomous navigation and path planning functions (e.g., A-star search algorithm) on the wheeled robot. Students submit and are graded based on a project report that includes fundamental understanding (e.g., explain the concepts of search algorithms and frontier exploration), tables of parameters and exploration strategies, and robot driving videos (hands-on demo).

The three major teamwork-based projects occupy 60% of the total course grade.

Individual-based Evaluation

Even though this course is primarily designed to be teamwork- and project-based, we would like to evaluate each individual student's mastery of the class concepts. For individual-based scores, we include a midterm exam score, a final exam score, and lecture review quizzes, where technical questions were posted for students to answer. These components were completed by individual students. We specify in class instructions that for these three tasks, no "teamwork" was allowed, and we assess their individual exam and quiz performance as an evaluation of the

mastery of the course knowledge and concepts. These individual exam and quiz scores sum up to 25% of the total course grade. The remaining tasks in this course (15%) consist of components such as general participation, intro assignments, a small camera calibration task etc., where every student was able to achieve full grade, and thus this portion was excluded from the following analyses.

Data Collection

The data for this study and paper was collected in the 2024 Fall semester offering of this third-year hands-on undergraduate robotic course. Tandem, an online educational tool designed to support student teams, is used to collect student surveys as the course progresses. Tandem provides quantitative data as students self-assess their teamwork skills, dynamics, confidence, whether the students feel their teams are working well/not working well, etc. Tandem also collects student feedback about possible factors that are linked to teamwork experience, such as logistics.

The data comprises a total of seventeen student teams (K = 17 teams) with three students on each team (total class size N = 51 students). Teams in this class are assigned by instructors, with considerations of Tandem recommendations based on their beginning-of-semester survey results. The team assignment was intended to balance between people the students already know, logistics factors such as whether the students live near each other, and when possible, encouraging multiple women or under-represented minority students in one team.

Team Assessment/Support Tool

In this work, we leverage Tandem, an educational tool designed to support student teams. Through Tandem's online platform, students in this course are given a beginning-of-semester survey, a mid-term survey, and an end-of-semester survey to provide periodical review and self-assessment about their strengths and areas of growth, their expectations and experience of the course, etc. The students are also given weekly opportunities ("team checks") to provide assessment and feedback on their teamwork experience, particularly in the three major projects, paired with instructor-evaluated course content mastery experience (how much the students mastered the course content and materials) as recorded in the students' gradebooks. Use of this de-identified data was deemed exempt by the Institutional Review Board [HUM00207597]. We also express our gratitude to the course instructors, staff, and students.

RESULTS

We present quantitative and qualitative results and statistical analyses on the student teamwork experience. We seek to study and understand the relationship between different factors that

contribute to teamwork experience and effectiveness, as well as their relationship and progression with the course projects.

Average Course Teamwork Experience Score

In Tandem checks, students evaluate five aspects of their teamwork experience, including whether the students assess their team is "working well", their "team confidence", how well they are "sharing ideas", whether "logistics" is working well or having trouble, and whether they share "equal workloads" in team projects. The students self-assess and individually rate each category on a 9-point scale ranging from "Working Well" to "Having Problems", with higher value the better (indicating it is working well, 9 being the max score). In these weekly checks, the students only give a rating on their own team and do not perform inter-team assessment.

Figure 1 shows the course average teamwork response score as obtained. As shown, all teams indicated they thought the teamwork experience worked quite well, with an overall average score of 7.22(1.46) out of 9 for "working well", 6.80(1.39) for "team confidence", 6.87(1.96) for "sharing ideas", 6.75(1.62) for "logistics", and 6.64(1.79) for "equal workloads". The number in the parentheses indicates standard deviation across all team checks. Scores in all categories remain relatively stable throughout the semester, with a small dip at mid semester that may coincide with project 2.

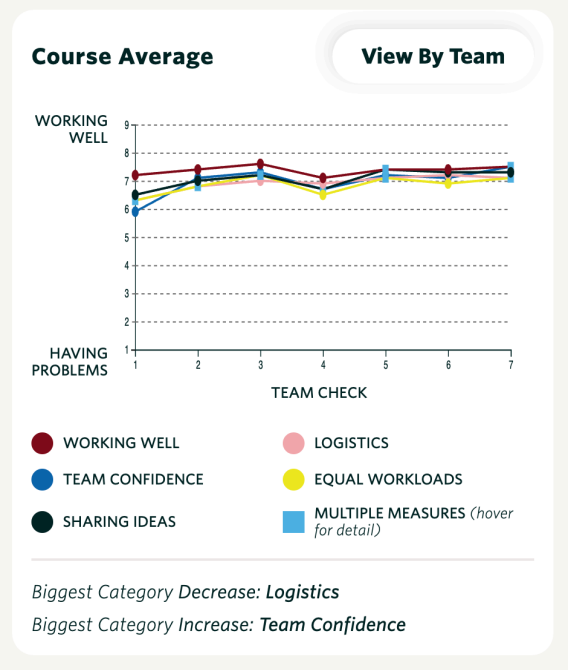

Figure 1: Tandem teamwork response score averaged across all teams throughout the semester (obtained from a total of T=7 teamchecks, N=51 students, M=17 teams). Best viewed in color.

For this course offering, the “team confidence” category showed the biggest response score improvement as the semester went on. This is in accordance with the text-based feedback and self-reflections provided by the student surveys. In the beginning of the term, some students shared sentiments such as “I worry a lot about how people perceive me…. I need to improve my confidence in my own ideas and voice them out” and “My main problem in teamwork is that I won't share my thoughts during a team meeting…I am hoping that…I will have more confidence to share my thoughts.”. By the end of the semester, we received more comments such as “I'm proud of our algorithms…. I was very proud of us for picking ourselves up after the first project and getting our workflow in order. It definitely increased our confidence for the rest of the projects.”“I feel proud of how our team developed…” and “How effective we worked as a team”.

Correlation Between Teamwork Experience Categories

To study the relationships among the five categories of the team experience, we performed correlation analyses using three statistical measures and reported their results. First, we calculated Pearson’s correlation and reported the Pearson product-moment correlation coefficient R as well as the p-value associated with the chosen alternative. The Pearson product-moment correlation coefficient R ranges from -1 to +1, with values close to 1 indicating a very strong positive correlation between two variables. Lower p-value (typically less than 0.05) suggests that the observed correlation is statistically significant. Second, we calculated Kendall rank correlation coefficient, which is another non-parametric test that measures the strength of dependence between two variables. Positive value (close to 1) also indicates strong positive association. Third, we calculated Spearman rank correlation, which measures whether there are statistically significant relationships between variables, where, similarly, higher positive values indicate strong positive correlation. All three correlation analyses were performed based on the Tandem team check data, concatenated across seven team checks.

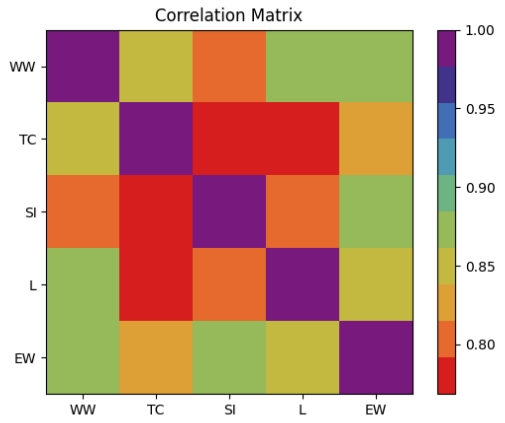

Figure 2: Tandem teamwork response score correlation matrix. WW: Working Well. TC: Team Confidence. SI: Sharing Ideas. L: Logistics. EW: Equal Workloads. Best viewed in color.

Table 1: Pearson's correlation matrix results for teamwork response score (R and p-score).

	WW	**TC**	**SI**	**L**	**EW**
WW	1.00 (p=0.00)	0.84 (p< .001)	0.81(p< .001)	0.88(p< .001)	0.88(p< .001)
TC	0.84(p< .001)	1.00 (p=0.00)	0.77(p< .001)	0.78(p< .001)	0.82(p< .001)
SI	0.81(p< .001)	0.77(p< .001)	1.00 (p=0.00)	0.80(p< .001)	0.88(p< .001)
L	0.88(p< .001)	0.78(p< .001)	0.80(p< .001)	1.00 (p=0.00)	0.86(p< .001)
EW	0.88(p< .001)	0.82(p< .001)	0.88(p< .001)	0.86(p< .001)	1.00 (p=0.00)

Table 2: Kendall rank correlation coefficient results for teamwork response score (tau).

	WW	**TC**	**SI**	**L**	**EW**
WW	1.00 (p=0.00)	0.70 (p< .001)	0.76(p< .001)	0.78(p< .001)	0.79(p< .001)
TC	0.70(p< .001)	1.00 (p=0.00)	0.64(p< .001)	0.67(p< .001)	0.70(p< .001)
SI	0.76(p< .001)	0.64(p< .001)	1.00 (p=0.00)	0.76(p< .001)	0.80(p< .001)
L	0.78(p< .001)	0.67(p< .001)	0.76(p< .001)	1.00 (p=0.00)	0.79(p< .001)
EW	0.79(p< .001)	0.70(p< .001)	0.80(p< .001)	0.79(p< .001)	1.00 (p=0.00)

Table 3: Spearman’s correlation matrix results for teamwork response score (R and p-score).

	WW	**TC**	**SI**	**L**	**EW**
WW	1.00 (p=0.00)	0.84 (p< .001)	0.89(p< .001)	0.91(p< .001)	0.92(p< .001)
TC	0.84(p< .001)	1.00 (p=0.00)	0.79(p< .001)	0.81(p< .001)	0.84(p< .001)
SI	0.89(p< .001)	0.79(p< .001)	1.00 (p=0.00)	0.88(p< .001)	0.91(p< .001)
L	0.91(p< .001)	0.81(p< .001)	0.88(p< .001)	1.00 (p=0.00)	0.91(p< .001)
EW	0.92(p< .001)	0.84(p< .001)	0.91(p< .001)	0.91(p< .001)	1.00 (p=0.00)

Figure 2 shows a visual illustration of Pearson's correlation matrix results across these five teamwork experience categories. This chart is generated from the 5x5 correlation matrix, where each cell represents the correlation coefficient between two categories. As shown, all categories have a strong positive correlation between each other (WW vs. TC, WW vs. SI, and so on).

Tables 1-3 presents the Pearson's, Kendall, and Spearman's correlation matrix results. All three tables indicate that the statistical correlation relationship is significant based on the low p-value, and the correlation coefficient values indicate strong positive correlation amongst all five categories.

As shown in Tables 1-3, "Working Well" is strongly correlated with all the other four categories (team confidence, sharing ideas, logistics, and equal workload). "Team Confidence" has the strongest association with two factors, "working well" and "equal workload". This is informative and indicates that sharing an equal workload in teamwork plays an important role on the effective performance of the team (working well) as well as the team's confidence. "Sharing ideas" correlates strongly with "equal workload", which makes sense, as both from the quantitative data and the day-to-day instructional observations, teams who are more open and effective in sharing ideas usually are the teams that balance workload well, resulting in a more successful teamwork dynamic.

Interestingly, "sharing ideas" and "team confidence", although still quite highly correlated, have the lowest coefficient values, likely because the "sharing ideas" category emphasizes the individual's confidence, knowledge and openness whereas "team confidence" evaluates their overall confidence as a team. The quality of the "ideas" being shared may also be a plausible factor - it is possible to imagine a scenario where all the participants are more than willing to share ideas, but perhaps some of the ideas are irrelevant or difficult to implement, thus leading to a slightly lower confidence level.

"Logistics" is highly correlated with the team "working well" and "equal workload", which is informative, as it suggested that logistics could be one of the important factors that can help encourage equal workload, if the team assignment facilitates ease in terms of logistics. If the students do not have to worry about logistics such as time or location to meet, they are more likely to share equal workload, and promote a more effective teamwork environment.

"Equal Workload" seems to be highly correlated with all other categories, and most notably, the "working well" category. This is in accordance with observations from [9] where "Equitable contribution" was also listed as one of the topmost reasons for group work in STEM education. This indicates that to promote effective teamwork, the instructors and the students should be particularly mindful of ensuring all team members share equal workload and ideas, potentially facilitated by a mindful logistics design.

Teamwork Experience and Performance

In this section, we investigate how the students' teamwork experience correlates to their academic performance in this course (as evaluated by the grading of this course). Table 4 shows the Pearson's correlation coefficient results (R and p-value) for teamwork response score correlated with the overall course grade, the group assignment grade (three major teamwork-based project scores), and the individual assignment grade (midterm, final exam, and lecture review quizzes).

We first observe that overall p value increased in Table 4 compared with Table 1, indicating a "weaker" correlation relationship (based on the standards that usually $p<0.05$ is deemed statistically significant). For overall course grade and group-project grades, the "working well" category and "team confidence" still has a weakly significant (p-value in the range of 0.06-0.08) correlation, indicating that for such a hands-on course with a major teamwork-based component (60% of grade), how well a student team works and their team confidence play a positive role in their academic performance in terms of class grades and group project grades.

In terms of the students' individual mastery of the class materials as evaluated through midterm and final exams and lecture review quizzes, we did not see a significant correlation with teamwork experience (Table 4, last row, higher p values). The correlation coefficient values are also lower than group-based project scores.

Among all five categories in teamwork experience, the "sharing ideas" has the highest correlation coefficient value with individual scores, which could indicate that if a student has a better mastery of the course knowledge, they share ideas better and more effectively in teamwork projects. Conversely, the relationship could be the opposite: if they share ideas more, it enhances their individual understanding and learning of the materials. The relationship here is an important one for us to investigate further.

Logistics category has the lowest correlation with individual performance, which is understandable as logistics would play a more significant role in teamwork planning and experience, but less so for more individual-focused learning and activities.

The "equal workload" category shows a low correlation similar to the "logistics" category, as the individual exams and quizzes make the "equal workload" category essentially irrelevant. Note that based on the relatively higher p values in this set of results, we may only determine a weak evidence of these relationships, and for future work it would be worth investigating again with possibly larger samples to better estimate the relationship.

Table 4: Pearson's correlation coefficient results (R and p-value) for teamwork response score correlated with the overall course grade, the group assignment grade, and the individual assignment grade.

	WW	**TC**	**SI**	**L**	**EW**
Course Grade	0.44 (p=0.08)	0.46 (p=0.06)	0.39(p=0.12)	0.38(p=0.13)	0.39(p=0.12)
Group Assignment Grade	0.45(p=0.07)	0.46 (p=0.06)	0.38(p=0.13)	0.39(p=0.12)	0.40(p=0.11)
Individual Assignment Grade	0.28(p=0.28)	0.30(p=0.24)	0.33 (p=0.20)	0.22(p=0.39)	0.25(p=0.33)

Teamwork Experience Examples

Tandem records teamwork status in one of the following three categories based on the student peer evaluations, “needs support”, “approaching trouble”, or “working well”. The “needs support” marker indicates the reported team check scores of at least one individual is less than 4.0 (out of 9) consistently (for 1+ week), meaning likely at least one of the students on the team feel less satisfied with their teamwork experience. The “approaching trouble” marks the reported score of at least one individual is less than 6.0 (out of 9) for 2+ weeks, or the team average is larger than 4.0 but less than 6.0. This gives a reminder to the instructor teams to check in on the teams in need. The “working well” teams generally have a higher reported team score (above 6.0) across all categories, indicating the team is working well together.

In the following, we present three specific examples, one in each of the categories, as an example of an individual team response. Both the team average reported teamwork scores and the spread (ranging from “More Agreement” to “More disagreement” on a 9-point scale) are presented. A Universally Unique Identifier (UUID) is assigned to de-identify the teams.

Teamwork Experience: “Needs Support” Example

Figure 3 and Figure 4 show an example of a team that “needs support”. Figure 3 shows the team average response score for all five teamwork experience categories. We observed for this team, their mean “working well” score ranged between 4.0-6.0 out of 9 throughout the semester. The “sharing ideas” and “equal workload” scores generally decreased as the semester went on, and

the “logistics” averaged around 5.0, which is a relatively low score. This is in accordance with the instructors’ observations of the team’s actual performance in class, where the team members were indeed having trouble figuring out meeting times and schedules. Certain member(s) skipped lab sessions due to one reason or another, which could contribute to the decreased score in sharing ideas and equal workload.

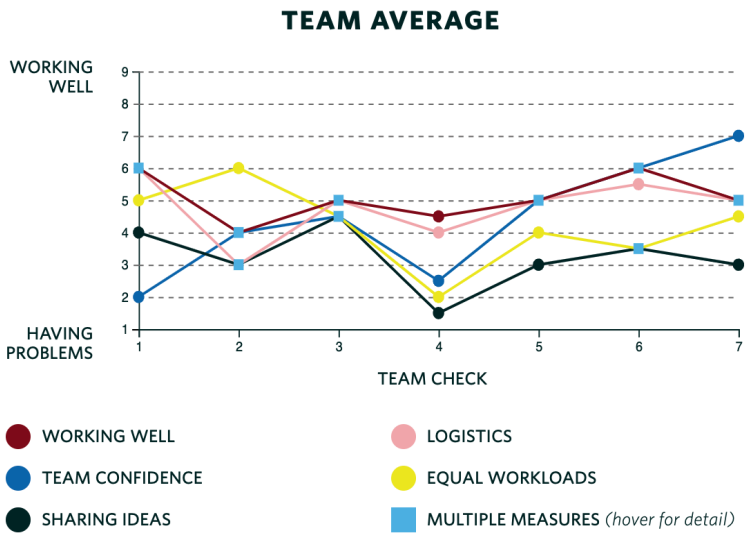

Figure 3: Tandem teamwork response (team average) for Team ‘8fad’: “needs support”. Best viewed in color.

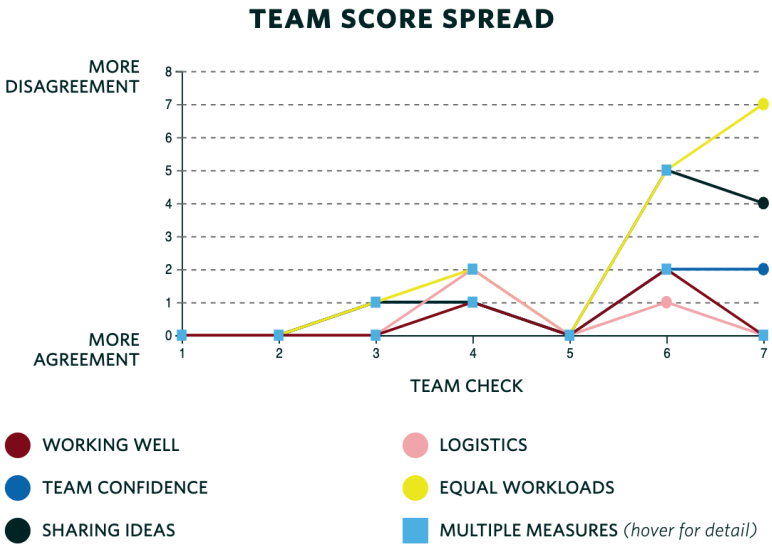

Figure 4: Tandem teamwork response (team score spread) for Team ‘8fad’: “needs support”. Best viewed in color.

Interestingly, we observed that even for this group, the team confidence went up from an initial low 2.0 to a final 7.0 out of 9, which is a significant improvement. In class, the team did show improved performance in some of the later projects and they were able to accomplish all major tasks with decent performance (group score average 18.93 out of 20 points, averaged across three major group projects). The team also came in person and discussed with the instructional team and spent more hours in office hours as semester progressed.

Based on Figure 4, we also observed a wider spread of the reported scores, particularly in the "equal workload" category. The wider spread indicated more disagreement amongst teams, and, in this case, seemed to be associated with a more negative teamwork experience. In the text-based survey responses, at least one team member gave a relatively low score and provided reasons, such as certain team members kept missing meetings or were not participating equally, while some other team members are more "generous" with the scoring, thus causing the wide spread. In the end-of-the-semester surveys, team members from the same group also reported concerning keywords such as task distribution, extra work, work quality, 'absent', etc., which further validated the team average score results reported in Figure 3.

Teamwork Experience: "Approaching Trouble" Example

Figure 5 and Figure 6 show an example of a team that is "approaching trouble". Our first observation is that the overall team average response score is generally higher than the previous group in Figure 3.

One interesting observation for this group in class, is that one team member is very capable and almost always took the initiative to implement new algorithmic functions, to ask instructors questions, etc. As such, especially in the beginning of the semester, the team as a whole reported lower scores on "equal workload" and has a wider disagreement across categories. The team member who took on more work expressed concern via text-based survey responses over "no plan", difficulty in finding meeting times, and "communication"; while other teammates expressed "hard project" as a factor.

As the semester progressed and as the team continued to work together (teams remain the same throughout the semester), we observed an improvement in team confidence level (from an initial 4.0 to 6.5) as well as in "sharing ideas" (from a low 2.5 to 6.0).

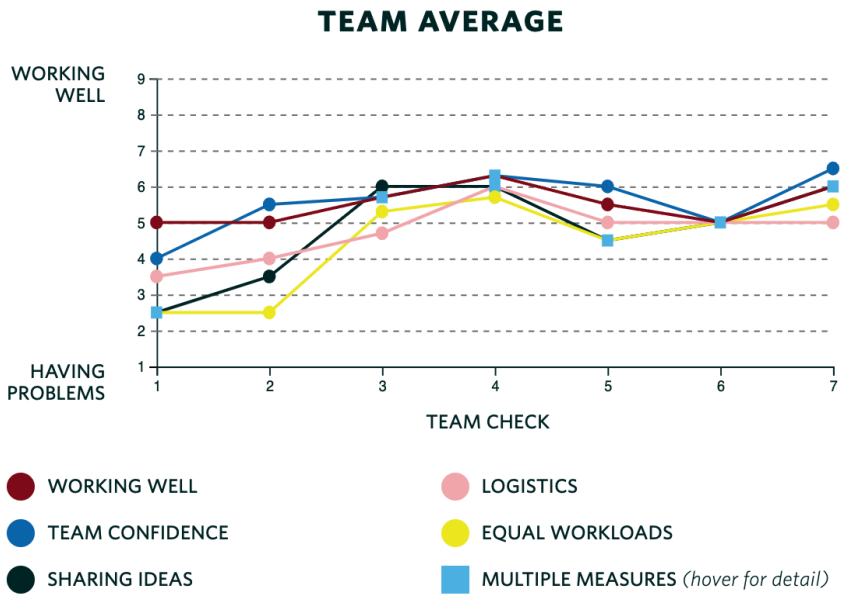

Figure 5: Tandem teamwork response (team average) for Team '9afc': "approaching trouble". Best viewed in color.

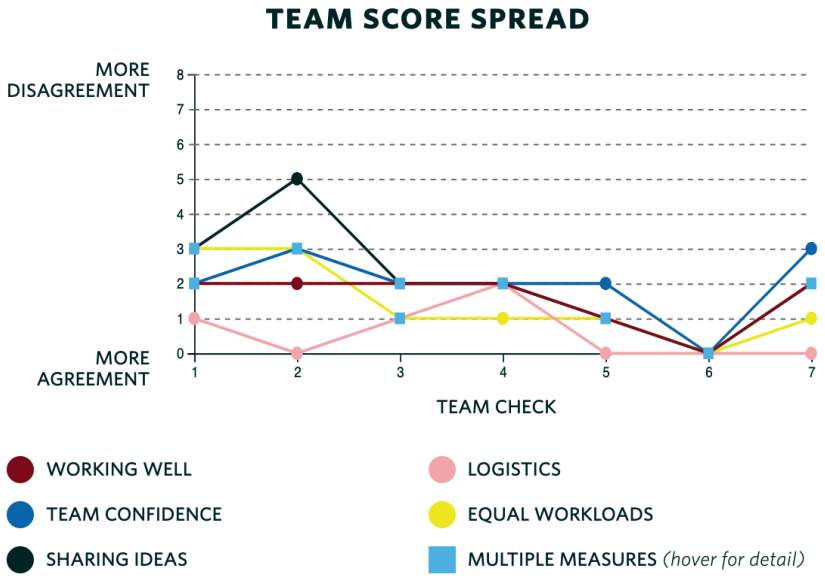

Figure 6: Tandem teamwork response (team score spread) for Team '9afc': "approaching trouble". Best viewed in color.

As shown in Figure 6, in terms of the team spread, we observed the team responses moved closer to "more agreement" as the projects progressed. This indicates the team is obtaining valuable practice in teamwork and getting better at sharing ideas and working together, with involvement from more team members and more agreement amongst team members. In terms of project-based performance, their score in the third group project is 7.5% higher than their first group project score, indicating a positive development in their teamwork effectiveness.

Teamwork Experience: "Working Well" Example

Figure 7 and Figure 8 show an example of a team that is "working well". The overall teamwork response scores are much higher than both previous groups, with scores generally averaging between 8.0 to 9.0 on a 9-point scale, and the team score spread is leaning more towards "more agreement".

In terms of class performance, this group worked very well based on instructional team observations, and all team members regularly came to class, labs, and office hours and they were among the first to accomplish some of the tasks in group project 2 and 3. They also are engaged and discuss together often both inside and outside the class.

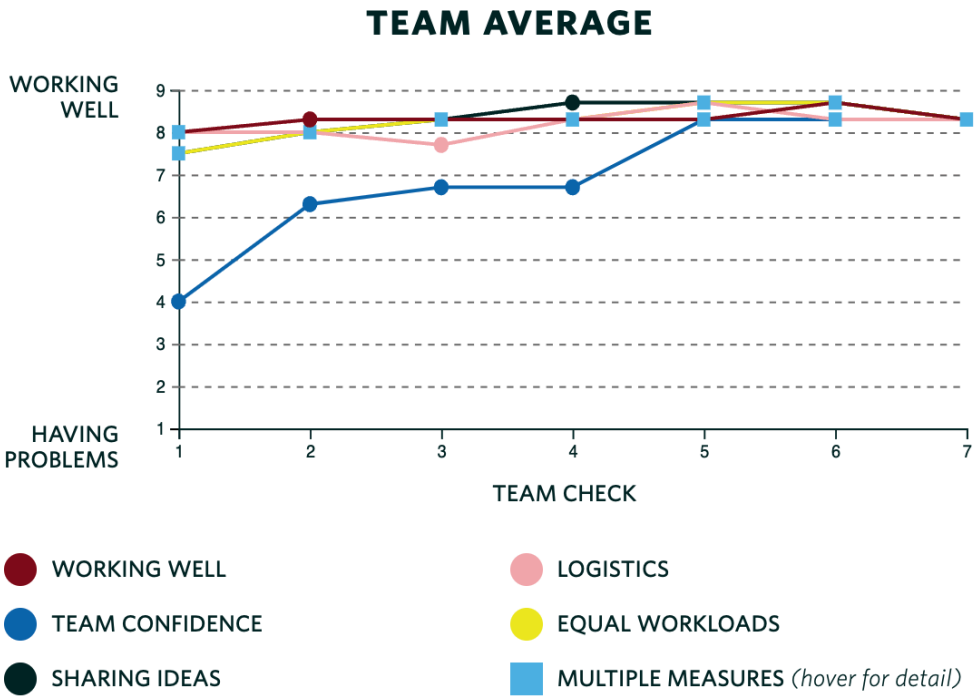

Figure 7: Tandem teamwork response (team average) for Team '82d5': "working well". Best viewed in color.

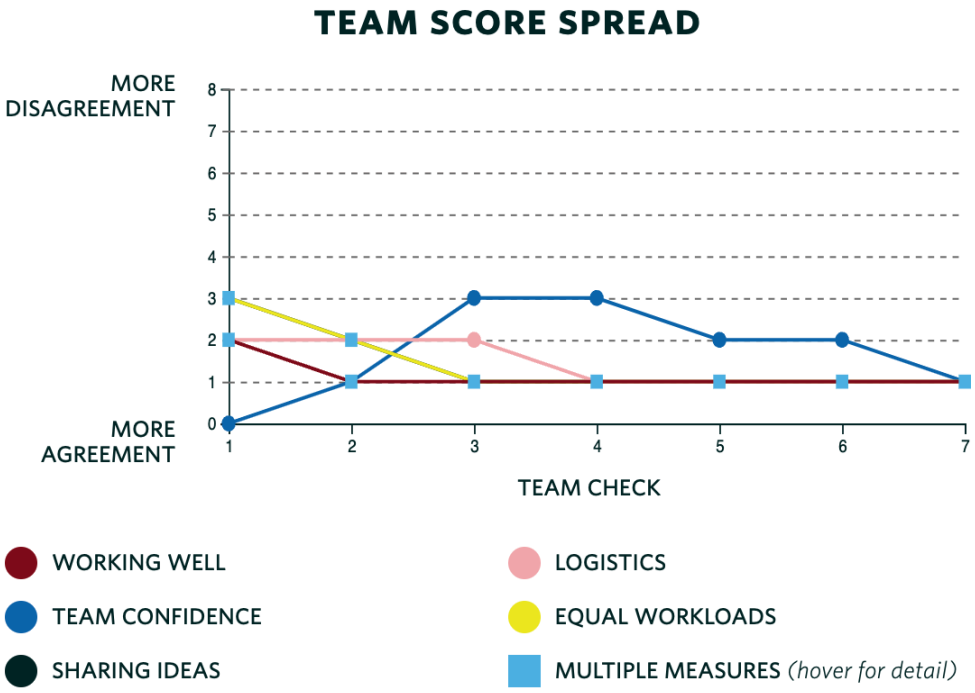

Figure 8: Tandem teamwork response (team score spread) for Team '82d5': "working well". Best viewed in color.

One interesting observation is that we also see a significant rise in team confidence scores in this group. Based on the text-based survey response, at the beginning of the semester, before groups were formed, the team members in this group expressed concerns such as:

- "I am a very good team player…Hopefully my team works well to capitalize this skill."
- "The one I don't feel confident about is when people don't do the work they should. We can use this experience to set solid deadlines and talk about expectations."
- "I sometimes struggle with confrontation of teammates that do not want to contribute or don't after being asked to. I have gotten better as I have had a few experiences with this, so if necessary I will be better about making sure everyone contributes together."

This may contribute to the initial low team confidence as the team members just started to learn the other persons on the team and to work together in a new course, and, thus, still have some reservations about how well the team may work.

As the projects progress, we observed an increase in their team confidence as well as group project scores (5% increase from Project 1 to Project 2, and 2.5% increase in Project 3, grade-wise). In the mid-term evaluation feedback, the team members noted their experience as:

- "Maybe start a bit earlier, but we made it work"

- "I feel proud that our first project was actually able to drive in a square"

- "It's nice to see the other's thoughts on where we are, and it's nice to know we all think we are the same amount of confused".

From both the quantitative scores as well as the comments, we observe a heightened sense of "team pride", and camaraderie (the sense that all team members were "in this together"). By the end-of-the-term feedback, the comments and responses include:

- "After the first project we all did pretty well with timing after learning from the first one... Tuning took longer than expected and it made us realize we need to stay ahead in order to have time to debug near the end."

- "I'm proud... Unlike the first project, we were able to finish these pretty early and were even first to finish slam [simultaneous localization and mapping], so I was very proud of us for picking ourselves up after the first project and get our workflow in order. It definitely increased our confidence for the rest of the projects."

As instructors, we observed their improvement in coding workflows and overall project quality, and as stated by the student team members themselves, the students also reported a sense of "definite increase" in their confidence, which we are very pleased to see.

DISCUSSION and CONCLUSION

In this work, we analyzed the students' teamwork effectiveness, confidence, and team performance through both Tandem survey data and quantitative project evaluation in a hands-on, primarily project-based, undergraduate robotics course.

To address Research Question 1, we studied the changes in the students' teamwork experience as the robotic project complexity grows, and we observed that for the class, most students rated their teamwork experience as "working well", with a significant increase in team confidence over the course of the project. "Logistics" seems to have a bigger decrease, which suggests that for a course with a heavy teamwork component, from an instructional team point of view, it may be beneficial to design strategies to facilitate student teamwork logistics, such as being mindful of the space and time that students can meet and work together. Based on survey responses, we also observed students do feel more confidence and pride after a project milestone, and teams

who worked well and had higher team confidence generally receive a higher group project grade and course grade overall.

To address Research Question 2, given data from this course, we did not observe a significant relationship between teamwork experience and the students' individual academic performance. However, we did note that there is a correlation between teamwork experience and group-based project scores, particularly in "working well" and "team confidence" categories. We also note that a student's individual performance may impact how well they are "sharing ideas", and thus indirectly may impact teamwork. There is strong positive correlation among all five categories of teamwork experience, indicating that for a team to work well together, "sharing ideas", "logistics", and especially "equal workload" is quintessential, and if a team works well together, it boosts team confidence, and vice versa. "Equal workload" also promotes team confidence, which suggests that for a group-project-based course, it may benefit if the instructors and the students are aware and mindful of workload distribution and design assignments and pedagogical strategies that intentionally encourage and promote equal workload.

Importantly, this data is limited to a single offering of a specific course in a specific context. Our interpretations of patterns need to be with that recognition. The first author's knowledge of the context (as course instructor) allows for careful triangulation of information, but we need additional data for some quantitative analyses and we need to be cognizant of how the students' teamwork experiences are affected by our context.

Through Tandem, we also obtained some valuable feedback on the course itself, including suggestions about improving lecture materials and code comments, and more staff testing and debugging help. We plan to incorporate these comments and further improve the course in the future offerings. Both the text-based feedback as well as the team response scores provided suggestions on how to better design this course. We also hope the observations from this study can help provide some insights on factors that contribute to an effective teamwork experience in designing and planning future multidisciplinary robotics projects and courses.

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