General Strategy for Development of Teamwork Skills

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***Abstract*— Beyond the technical skills of engineering, students of any engineering discipline need to develop teamwork knowledge, skills, and abilities (KSAs) in order to be successful. Various intervention strategies within education systems have been utilized to promote development of teamwork skills and practices in the past. The research team has incorporated the cooperative yet engaging activity based on the commercial board game *Pandemic*, where students work as a team to play against the game rather than against each other. The activity was introduced to three different engineering departments, highlighting its adoptability. While some discrepancies exist, the qualitative and quantitative data suggest the impact on a department is the same.**

Keywords—Gaming in Education, Teamwork, Interdisciplinary

I. INTRODUCTION

For an engineering student, development of professional skills is of equal importance to developing technical skills, as identified by ABET[1]. Learning skills of any nature requires formalization, facilitation, and feedback [2]. The resources for teaching professional skills like teamwork knowledge, skills, and abilities (KSAs) are limited [3], inapplicable to the educator's setting [4-7], or resource-intensive [2, 8-9].

Traditionally, engineering students are exposed to teamwork training by virtue of assigned teams in a team project. Without formalization, facilitation, or feedback, the experience may invoke inhibiting, immature, or ineffective teamwork KSAs [2].

As identified by the "Engineer of 2020" report from the National Academy of Engineering, successful engineers will become effective members of design teams [10]. In other words, the ability to perform well in a team setting and to contribute to a team's efforts is an important skill for any member of an engineering field [1, 10-11].

This report extends a previous study on an intervention strategy for developing good teamwork skills through the use of a commercial board game [12]. In the pilot study, the details of the strategy were refined and the initial impact was explored. The study found the strategy was effective at developing teamwork skills along with invoking valuable reflections within the students.

The next stage in the work is to explore its generic applicability to other disciplines. The paper begins with a summary of how games have been used as an intervention strategy in education and how effective teamwork is defined. In the next section, the specifics of the intervention strategy are summarized. The evaluation approach, results, and discussions subsequently follow.

II. BACKGROUND, FRAMEWORKS, AND DEFINITIONS

A. Games in Education

Juul's defines six characteristics of games versus simulations [13]. Hadley [12] refines these into six required elements into plain language as follows:

1. Well-defined rules of how to play the game
2. A clear way to determine losing or winning
3. Specific distinctions between losing and winning
4. Players have choices in the game
5. Choices can influence the outcome of the game
6. The game elements motivate player choices.

For the context of this field (games in education), distinguishing between simulations and games is important.[14] While these help distinguish a game from a simulation, they do not serve as qualifiers for effective games.

Wilson *et al.* identified specific game features and how they impact learning outcomes (e.g, cognitive, skill, and affective)[15]. Specifically, they outline how increasing difficulty can influence cognition and retention [16-19]. As will be detailed later, an escalation of difficulty is introduced into the activity.

Li and Tsai's review of science-based games identified learning theories invoked by playing games: cognitivism,

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constructivism, socio-cultural perspective, and enactivism [20]. This activity utilizes a constructivist approach to learning teamwork skills. This activity also benefits from positive interdependence. Positive interdependence is found where an individual's success is linked to the success of others on a team. [21]

In 2005, Hays reviewed 274 articles related to games in education and made four recommendations for others pursuing work in gaming in education [22]. First, the value of the game as an educational tool should be weighed against other options. Like any educational tool, they should also be used as supplementary and complementary materials rather than replacing other established practices. Based on similar findings of Hirsch and McKenna [2], Hays found effective approaches included evaluation, debriefing, and feedback mechanisms Finally, he insists the game supports instructional objectives.

Young *et al*. [14] also performed an extensive review (i.e., 300+ articles) and formulated similar conclusions as Hays. [22] Specifically, they equally emphasized how a game should directly support the instructional goals through proper alignment. The first stage of this research was to explore the alignment of learning objectives with features of the game.[12] For example, the students were taught the importance of diversity through the diverse roles played within the game.

The work of Barab's group found transformational play to be a proper medium for alignment [23-30]. They detailed the theory of transformational play [29] by extending Dewey's ideas of transactivity. [31] Transformational play shares many features to games in general but also require the application of conceptual understanding, problems of significance, and alignment of learning and game features.

B. Team Effectiveness

Many teamwork definitions [32-34] and teamwork effectiveness models [34-39] exist. This research builds upon the model from the Association of American Colleges and Universities' (AAC&U) Teamwork Valid Assessment of Learning in Undergraduate Education (VALUE) rubric due to how it incorporates skill development as part of team effectiveness.[40] The rubric team defined teamwork as behaviors exhibited by individual team members in the form of applied effort, intra-team interactions and communication, and contributions to the overall team effort. While the rubric does not explicitly define team effectiveness, Stevens and Campion effectiveness stems from learning and improving important teamwork KSAs [35].

While the VALUE rubric serves as a good base for an effective teamwork model, we have adopted our own model to aid in alignment of our instructional objectives. Specifically, six domains are explicitly presented and emphasized to students:

1. Intellectual Diversity
2. Communication Skills
3. Equal Contribution
4. Group Decision Making
5. Goal/Task Setting/Execution
6. Team Cohesiveness

Intellectual diversity is implicitly found within many models, but it is only assumed with regards to the language used. For example, conflict typically stems from differences in viewpoints or opinions (i.e. diversity in thinking). This KSA involves (a) respecting intellectual diversity, (b) promoting diverse thinking, and (c) embracing the diverse perspective of one's self. The developmental levels of intellectual diversity, along with the other domains, will be discussed under the content analysis section.

Communication and Equal Contribution are similar, but the features of each are defined in different contexts. Communication ability is limited to the *capacity* to listen and share ideas, but Equal Contributions stems from the ability to apply communication appropriately. Both directly feed into Group Decision Making and Goal/Task Setting/Execution.

Group Decision Making involves sharing and receiving ideas from group members. Goal/Task Setting/Execution encompasses the KSAs necessary to make a plan and follow through.

Finally, Team Cohesiveness is directly adapted from the "Fosters a Constructive Team Environment" aspect of the VALUE rubric [40] and a number of communication characteristics from Stevens and Campion's model.[35] In short, a team member treats others respectively, uses a positive and non-judgmental tone in communication (verbally and non-verbally), motivates their team members, and provides assistance and/or encouragement when able.

In order to facilitate alignment between the instructional goals and the game features, this model is presented in a reflective exercise and through a formal lecture. In this work, the effectiveness and adaptability of this approach is explored through implementation in a number of different engineering disciplines. In the next stage of the study, other institutions will be studied to assess the differences associated with institutional execution of the activity.

III. INTERVENTION STRATEGY DETAILS

A. Alignment between Learning Objectives and Game Features

As has been detailed, alignment between game features and learning objectives must be achieved if implementation is to be successful. The learning goals for this activity are always:

1. Listing beneficial and detrimental teamwork practices and KSAs
2. Observing the impact of beneficial and detrimental teamwork practices and KSAs
3. Implementing beneficial teamwork practices and KSAs
4. Reflecting on personal level of teamwork practices and KSAs

5. Identifying the importance of the six items within the efficacy model as teamwork practices and KSAs.

The use of a game as the activity medium lowers the risk and impact of failure to help facilitate the constructivist aspect of this approach. In other words, the students are more likely to incorporate what they learn from failing, because it is not tied with the negative aspects typically associated with failing a graded team project.

As detailed in our first study, the game, Pandemic, contains features well-aligned with the efficacy model [12]. In *Pandemic*, players are assigned different roles within a team tasked with treating and developing cures for four epidemics across the globe. They must talk with each other, make decisions as a group, and get along in order to achieve the objectives of the game. In addition, each player must take an equal number of terms to force social loafers [12] to participate. Finally, a balance between developing cures and treating diseases forces the students to effectively set and execute tasks to achieve both goals simultaneously.

B. Student Participants

The study was performed within the Chemical and Biological Engineering (CBE) department, the Industrial Engineering (IE) department, and the Civil and Environmental Engineering (CEE) department of the South Dakota School of Mines and Technology (SDSM&T). Each of these departments teaches an introductory course into their respective discipline. Along with discipline specific content, the course aims to develop professional skills like communication and teamwork skills. The activity was facilitated by the same person to ensure consistency in its execution.

The number of semesters and participants within a semester varies across these three departments. Overall, data has been collected from Fall 2013 to Spring 2016. In addition, the IE department has collected teamwork assessment data since 2009 for unrelated research purposes. As such, we have added the data from students in that department prior to Fall 2013 to the current baseline.

The IE "baseline" contains 56 students (60.7% male) and the CBE "baseline" contains 24 students (50% male). With regards to students exposed to the teamwork exercise, the CBE department contains 123 participants (64.2% male), the IE department contains 82 participants (65.9% male), and the CEE department contains 70 participants (78.6% male).

C. Activity Detail

Resources and details on the intervention activity can be found at the research team's website in [12]. In short, the rules are briefly discussed with the students before they play the game on an introductory setting. This is done by design to show the students the importance of familiarizing themselves with the rules of a team activity (e.g., the design criteria for a capstone project).

While playing, facilitators ensure rules are followed and clarified upon request, but strategies are never discussed or shared. Rather, a number of strategies are shared to give students an idea of how to move forward without suggesting the best way to move forward.

Afterwards, reflections on the first game are shared and connections are made between the reflections and the formal frameworks found in the literature, including our own. The students then play a second game with these connections in mind. The difficulty level is increased as suggested by [12]. In addition, the players' cards must remain hidden from other players. They are allowed to state what is in their hands, but cannot show their hands. This forces communication between the team members.

Finally, the students are asked to provide a subsequent reflection in the form of a memo. They are instructed to reflect on the impact of their new strategies in the second game, the impact of the hidden cards, and the impact of the six teamwork aspects on general engineering teams.

IV. RESEARCH EVALUATION, RESULTS, AND DISCUSSION

A. Assessment Collection

A mix of quantitative and qualitative data were collected in order to assess the different impacts of the intervention activity in the different departments. The main source of quantitative evidence stems from the assessment instrument developed by Stevens and Campion. [41] The instrument is influenced by their Teamwork KSA model [35] and involves scenario questions with multiple choice answers. There is a singular right answer for each question. The instrument involves 35 questions covering five (5) subdomains, but the questions are not equally distributed between the subdomains. The subdomains are (a) Conflict Resolution, (b) Collaborative Problem Solving, (c) Communication, (d) Goal Setting and Performance Management, and (e) Planning and Task Coordination with four (4), nine (9), twelve (12), five (5), and five (5) questions each, respectively. The "language" of the formal lecture is changed in order to prevent "faking" of results on the instrument.

A number of studies [41-46] have looked into the validity and reliability of the Teamwork KSA. The main conclusions drawn from these studies are, as a whole, the instrument is valid with respect to measuring overall KSAs, but has no validity with respect to the domains or even the subdomains.[46] As such, the KSA can serve as the main source of assessment, but with regards to tracking specific components like communication development, conclusions from the results must be taken lightly.

While not a valid form of assessment, the game itself has a number of quantitative indicators to *suggest* the impact of the activity. Specifically, we look at the win percentage of the first and second games.

Qualitative assessment data were gathered from the reflective exercise and the reflective memos. Specifically, the reflection shared in class were generalized for analysis. Also, a content analysis was performed on the student memos using a formal rubric.

B. Content Analysis

In order to compare the memo reflections of the different departments, a preliminary rubric was developed to perform a content analysis. The categories within the content analysis were guided by the teamwork efficacy model. An emergent coding scheme may be developed in future work as the database of reflective memos grows in size.

First, statements, words, and paragraphs were flagged if they were reflective of one of the efficacy categories. Then, each piece was categorized by their developmental level. In other words, a statement regarding communication skill may reflect a high skill in communicating, but other may be fairly rudimentary. The goal of the developmental levels in the content analysis was to not only quantify the frequency of discussing a specific topic, but also to assess quality of those insights.

Each category has a parallel structure in development. However, there are mentions of the six categories, because the memo assignment requests an explicit reflection on them. As such, these specific reflections lack any level of insight and do not suggest the students actually recognize the value of that teamwork category or have a developed sense of the associated skill. If the statement contains any language separate or unique from the in-class lecture, it was explicitly coded. Otherwise it was noted, but separated from the rest of the content analysis.

At the base level, a student acknowledges a category in some context. This is typically seen as a recognition of the presence, or lack thereof, of a category in the activity or in previous teamwork experiences. At the next level, specific examples are provided demonstrating awareness of the parallelism between the model category and a game feature. A reflection is flagged at level three if they can connect the game feature to how it fits into real life. The paramount level depends upon the category:

- Intellectual Diversity - Demonstrates an understanding of the need to both recognize and utilize diversity in a team setting.
- Communication Skills - Recognizes the value in the ability to not only communicate through sharing and listening but also in guiding group conversation.
- Equal Contribution - Provides evidence of what equal contribution means and recognizes the value of everyone contributing as well as facilitating contributions.
- Group Decision Making - Shows how group decision making differs from group thinking; understands that group decisions may entail choosing an individual's idea rather than compromising among individual ideas for the greatest outcome
- Goal/Task Planning/Setting - Provides understanding of effectively defining specific and challenging goals, planning tasks that lead to efficient and effective execution of goals, and coordinate efforts among the group to meet the goals.
- Team Cohesiveness - Demonstrates the ability to assess individual strengths and weaknesses as well as the ability to address individual behavior to better the team

Some statements may be reflective of more than one category at different levels. These were explicitly flagged as combination reflections. As will be discussed later, the preliminary nature of this rubric still requires a more robust validation process. However, it has helped guide understanding of some of the other results gathered.

C. Results and Discussion

The first indicator for effective intervention stems from comparing teamwork KSA scores of the different groups. Specifically, each department was compared against each other, women were compared against men, and women were compared against men across departments.

Due to the large difference in sample sizes, t-tests were performed to identify statistically significant differences in the KSA scores all with 95% confidence levels.

We hypothesized the impact of the activity would be the same independent of the group it was implemented with. The initial analysis from the Teamwork KSA suggests a different result.

A statistical difference is found between the CBE and the CEE departments total scores of 67.8% and 60.9%, respectively. Although the validity of the individual categories is unfounded, they can still provide insight into valid comparisons like the total scores. Except for goal setting, each category was statistically smaller in the CEE department as compared to the CBE department.

The one possible confounding factor is the level of quality of the CBE students compared to the CEE students at this institution. A majority of the scholarship dollars available to the general university go to CBE students due to their high academic achievement. While academic achievement is independent of teamwork, that achievement is enabled by working with others and setting tasks. This does not suggest CBE students are better than CEE students; rather, the CBE students are better equipped than the CEE students from this sample. This difference will be explored later with respect to both the win percentage and the content analysis.

A statistical difference is also found between IE students and CBE student with total scores of 58.3% and 67.8%. In addition, task setting, collaborative problem solving, and conflict resolution were statistically higher among CBE students.

While the same argument as for CEE students could be made here, the baseline data for the IE department does not suggest the same trend. Specifically, when comparing the baseline data from IE and the baseline data from CBE, there are no statistical differences. As such, one of a few conclusions can be preliminarily inferred.

First, the IE students who took part in the study were not as effective at teamwork as those who were part of the baseline. This can be supported when comparing the two groups, where a statistical difference does exist.

Next, in both CEE and IE, the students may not respond as well to a faculty member they are unfamiliar with. The lead facilitator is a faculty member of the CBE department, so students in that department are more familiar with his style of teaching and his intentions. A level of resistance may be met by the other departments. Also, the students may not take the lecture as seriously in the other departments due to a perceived lack of accountability. In other words, as long as they do what they are told, they will get the grade, but CBE students have a different perspective knowing the facilitator will be their professor one day.

This was supported by informal observations of the instructor of record in the IE department. On multiple occasions, a small minority expressed resistance to the activity and regarded it as a waste of time or frustrating.

Finally, we considered this may only stem from gender issues. Historically, women have outperformed men on this assessment [12]. We found a similar result in the overall score, task planning, conflict resolution, and communication. Specifically, women outperformed men overall with scores of 67.3% and 61.3%, respectively.

When comparing women of the CBE department against the CEE department, no statistical differences were found. However, there were still differences found between female CBE and female IE student in the overall and collaborative problem solving categories. However, if compared to the women in the baseline IE group, both the baseline female CBE students and the participant CBE students were statistically the same. This suggests the female IE students from this study are not performing as well as is normal for female IE students.

As such, the statistical difference for both comparisons stems from the male population of each department, respectively. In both comparisons, CBE males outperformed with respect to the overall score, collaborative problem solving, and conflict resolution.

When comparing IE and CEE, there were no statistical differences, independent of gender. This further suggests the source of the discrepancy comes from the students in the CBE department. For some unknown reason, they have high teamwork skills compared to the other departments studied.

With respect to the in class reflections, no noticeable differences are observed. While the observations are different for each session, they all share common elements and themes. As such, they all share the same level of insight from the experience, in class.

The game winning percentage indicates another difference within the CEE department. In all three departments, there are no differences in the win percentage of the first game. On average, they are all ~50%. The difference stems from the second game win percentage. Both IE and CBE saw significant increases in win percentage to ~71%. However, CEE students reported no significant improvement.

In conjunction with the KSA data, this supports the possibility the CEE students studied did not get much from the exercise. The cause for this is still unknown, (e.g., poor student motivation). However, the IE/CBE comparison helps reinforce our initial hypothesis: the activity is suitable for all engineering departments.

As stated previously, the robustness and validity of our content analysis rubric is at a preliminary stage. However, it has provided possible insight or support for the observations above.

The number and level of observations appears to qualitatively correlate with the KSA results. In other words, groups with higher communication scores had more insightful observations into the value of communication.

Equal contribution and group decision making are associated with collaborative problem solving. Goal/task planning/setting are a direct combination of goal planning and task setting, respectively. Team cohesiveness is a component of conflict resolution. Intellectual diversity has no direct tie to the KSA.

The frequency and level of observations made by the CBE department did not seem to fluctuate from semester to semester. On average, approximately a third of the students commented on a model category. The level of those reflections were, on average, at a level two.

This was similar with the IE department. The major difference was the much higher frequency and level of reflection on intellectual diversity. This difference stems from an augmented approach to this exercise.

In IE, the Hermann Brain Dominance Inventory (HBDI ©) [12] is explicitly covered as a way to introduce and educate the students on intellectual diversity. They specifically applied the language of the HBDI to convey how intellectual diversity applied to the game and engineering as a whole. Due to the cost restrictions, we do not recommend the use of HBDI with this activity in all instances. However, the combination of the two had a significant impact on the level and amount of student insight into the value of intellectual diversity.

The CEE memos further support the conclusion regarding lack of motivation. The research team was hard pressed to find reflections of any level of quality in any category. In other words, the number of reflections was a fraction of those found in CBE or IE, and they were, on average, at a much lower level.

Specifically, a lot of the memos had "mirroring" language littered throughout. This is diction mirroring or mimicking the language used in the lecture. This type of language lacks any level of depth or insight and appears as a means to complete the assignment rather than grow from the experience in a constructivist manner. In other words, the students are writing what they think the research team wants to hear, rather than honestly reflecting on the value of the different components.

In addition, the language of the CEE memos has a very "arrogant" tone. One student was credited with saying, *"The first game that we played together went outrageously smooth. Everyone knew exactly what our character roles had to do in order to make it as efficient as possible. We ended up winning the game without having a single outbreak and having a large amount of event cards left."* This student continued the memo

with this tone. Even with losing the second game, they attributed the failure with bad luck versus poor teamwork. While only one example, a number of memos were similar in tone.

Considering all of the results from the CEE department, the authors believe this group was not representative of the typical student in the engineering curriculum. However, some important insights can be drawn from this exception.

First, without challenge, the constructivist approach is hindered. Due to the ease of winning the first game, the student above felt they were well equipped to be an effective team member in the future and found no need to take the rest of the activity serious and construct upon their current knowledge base. This appeared to have a long term effect on the perception of effective teamwork as measured by KSA scores.

In addition, the accountability of the reflective memo was not enforced by the instructor of record. In other words, a grade was only assigned for doing the memo, not the content found within. There is a possibility that students might not have written the memos based on honest and thoughtful reflections in such a case.

Within all departments, a lack of insight can be found in a number of memos, indicating a lack of consistent accountability across all departments. However, the observed proportion was much higher in the CEE department. We believe the results are artifacts of the classes studied, not the activity itself.

D. Limitations of Study

A number of confounding factors may invalidate our results. Mainly, the lack of volume of data from the departments is not enough to show a significant difference between the departments with respect to the reflections. In addition, the content analysis is still in a very premature phase, so it needs refinement and validation before it can be used as a robust research tool.

The main confounding factor is how all the participants were from the same institution. The comparison between CEE students and CBE students may be very different at a public university or a large research university. As such, the next phase is to extend the study to six other institutions which offer a variety of classroom formats.

V. Conclusions

This study implemented a teamwork intervention strategy in three different engineering departments at a small engineering focused university. By comparing quantitative Teamwork KSA scores, activity statistics, and student observations from reflective memos, the goal was to support how this activity has the same impact.

The results comparing a chemical and biological engineering department against an industrial engineering department suggest there are no differences. However, this was not the case with Civil and Environmental engineering.

The data suggests that the CEE students did not embrace the constructivist approach, and thus, did not develop the teamwork skills at the same level of rigor as the other departments. The reason for this is unknown and probably not indicative of CEE departments as a whole. Rather, this is probably a product of coincidence, but requires further study within CEE departments across different universities.

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