A Focus on Functional-Based Teams in the Development of Prototypes of Innovative Technology: Observations from a QEP Grant Implementation at Tennessee Tech

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Abstract

The purpose of this contribution is to provide preliminary findings about the role of student teams within a redesign that was implemented in a junior-level Fluid Mechanics course in the Department of Chemical Engineering at Tennessee Technological University (Tennessee Tech). As a major component of the redesign for the Fluid Mechanics course, students were trained in the elements of a functional-based team approach[1] in order to identify teammates for the duration of the project, develop an Agreement of Cooperation, and assess their teammate's performance within the project via their initial agreement. Preliminary findings from this course - which focused on students' collaborative learning skills and featured the prototype of innovative technology developed by these teams[2] - indicate that students develop skills that prepare them for teamwork in upper level courses as well as industry and other collaborative opportunities post-graduation.

Keywords

Renaissance Foundry, Teamwork, Collaboration, Innovation-Driven Learning, Functional Teams

Introduction

The purpose of this contribution is to provide preliminary findings about the role of student teams within a redesign that was implemented in a junior-level Fluid Mechanics course in the Department of Chemical Engineering at Tennessee Technological University (Tennessee Tech). This course is the second of a three-part undergraduate-level course sequence in a curricular redesign that implements the Renaissance Foundry Model (herein, the Foundry), an innovation-driven pedagogical platform.[2] The Foundry provides an iterative learning framework through which student teams identify a student learning challenge and progress through the two paradigms of the Foundry—knowledge acquisition and knowledge transfer—to develop a prototype of innovative technology that addresses the identified challenge (for additional details, see the Foundry website: https://sites.tntech.edu/foundrymodel/foundry-model/.)[2] Through funding by the Quality Enhancement Plan (QEP) program at Tennessee Tech, the redesign aimed to enrich student learning via immersion experiences[3] which included, but were not limited to, industry speakers and student trips to related industry facilities.[4]

For the Fluid Mechanics course, specifically, student teams were asked to identify a challenge (problem) relevant to applications of fluid mechanics that would address a societal need. As a major component of the redesign, students were trained in the elements of a functional-based team approach[1] in order to identify teammates for the duration of the project, develop an Agreement of Cooperation (AoR), and assess their teammate's performance within the project via their initial agreement. Preliminary findings from this course - which focused on students' collaborative learning skills and featured the prototype of innovative technology[2] - indicate that generally students develop skills that prepare them for teamwork in upper level courses as well as industry and other collaborative opportunities post-graduation.

Background

Core Skills Needed for Effective Teamwork

Motivated by literature on collaborative learning, the Foundry makes ample use of teams in order to provide a meaningful learning environment suitable for mimicking real-world conditions for the engineer-in-training. Small teams of students (three or four members) are formed using a functional-based approach developed by Sauer and Arce[1] to assist students in gaining an appreciation of the different roles and skills needed to accomplish a complex task using teamwork. One key characteristic in focusing on the use of teams within a Foundry environment is providing students with opportunities to appreciate different points of view, learn how to leverage the use of different and complementary ideas, and develop social-centered protocols to be effective in communication within a team. Jorgensen et al. argued that,

> effectively, to navigate the Foundry elements, students must not only comprehend the purposes and importance of all the pieces of the pedagogical platform, but also understand and invest in the development of teambuilding skills that facilitate the exchange of ideas within the learning process.[13] (p. 2)

Furthermore, the Foundry utilizes two key paradigms to navigate the transition between a challenge and the prototype of innovative technology, and student teams are constantly exposed to varying conditions where they need to adapt to be able to move efficiently towards the development of the prototype.

Team-Based Learning

A pivotal component of active and inquiry learning is the social interaction that students engage in as part of the processes associated with these types of learning environments (such as the Foundry).[14, 15] According to Felder and Brent,

> Persuading students that group work is in their interest is only the first step in making this instructional approach work effectively. The instructor must also structure group exercises to promote positive interdependence among team members, assure individual accountability for all work done, facilitate development of teamwork skills, and provide for periodic self-assessment of group functioning.[14] (p. 5)

Thus, as students begin to play a more central role in their learning processes, they become facilitators of learning themselves, pushing the inquiry process forward and exploring key topics of the content in more depth.[15,16]

Therefore, it is critically important for students to have a strong skillset focused on the following aspects: 1) Team formation, 2) Team managerial protocols, and 3) Team-centered assessment or accountability. Although the literature indicates that several approaches have been used to form teams (e.g., use of societal interests, academic achievement, personality compatibility, etc.,[2,10,17]), Sauer and Arce[1] argued that in order to have a balanced and unbiased team, a functional-based approach is an effective way of accomplishing this aspect. Sauer and Arce[1] offer a parallelism between sports teams and academic teams (see also Arce, 2000[8]) wherein their view is that the team members are intimately coupled to the functions needed to complete a task. After team formation, many teams seem to struggle to find successful managerial protocols that help them to efficiently perform. Sauer and Arce[1] recommend an "Agreement of Cooperation" or Responsibilities (AoR) developed by the team and signed by all the members as a useful tool to help with this aspect. The agreement is rooted in a societal contract theory[18] and works similarly to professional contracts usually in place in industry and/or business organizations. Finally, there is no completion of the guidance for successful teams if an accountability tool is not in place. In the current study, a rubric guided by the AoR was developed and implemented by student teams.

Context

Background and Rationale

In previous courses guided by the Foundry, it was preliminarily observed that teams with members who were cognizant of necessary roles, as well as balanced teams with regards to different team-functions, resulted in overall better team performance. Therefore, the immersion of students in their own functional-based team and the promotion of their learning of specific roles in teamwork resulted in efficient and effective implementation of the Foundry to achieve the development of a prototype of innovative technology.[4,13] Such intentional training and immersion are needed based on the observation that such items are typically overlooked in a busy fifteen-week implementation of engineering curriculum or simply assumed that students innately possess such skills. Further, preliminary observations in these courses indicate that before such training, students identified these skills as being already possessed and honed to the point of needing no further training. Our observation is that although students have a prior knowledge concerning some of the typical functions within a team, the understanding of the roles is limited or shows several misconceptions.

During a two-hour laboratory section, such training items were addressed within the Foundry platform as course activities.[4] These activities were developed and utilized to expose students to the importance of the concepts behind developing and performing as a functional team. One important aspect was identification of typical functions needed in a team to achieve a team goal. Furthermore, the training also focused on the identification of roles necessary for success within the context of the challenge and appropriate selection of team members for the roles identified. A useful set of tools to achieve the distributed selection and identification of specific member functions was a functional resume, the creation and implementation of a strong AoR, and an appropriate rubric for evaluation within the responsibilities outlined by the AoR.

The Implementation

Recognition of Appropriate Roles within a Functional Team

Within the fifteen-week structure of one semester, two weeks within the lab sessions of a Chemical Engineering Fluid Mechanics course were devoted to knowledge acquisition regarding the elements of a functional-based team.[2] Within this training, small arbitrary teams of three students were asked to identify roles that they considered most appropriate for generating a prototype of innovative technology in the context of a then-unidentified challenge within Fluid Mechanics.[2] Eventually, student teams would identify a challenge with consideration of the context of the Fluid Mechanics course to develop a prototype of innovative technology that might have some level of societal impact.[2] However, during this phase of the training, the focus was on the functions or roles that a team member should demonstrate or possess in order to highly contribute to the success of the team. Once the aforementioned arbitrary teams had developed the titles and description of the roles they thought to be most imperative to the eventual challenge (i.e., development of a prototype of innovative technology with some consideration of Fluid Mechanics), students were asked to transfer their knowledge acquired individually, as well as through these arbitrary teams, to develop a class agreed-upon list of roles pertinent to the development of a prototype of innovative technology that utilizes fluid mechanics concepts.[2] The purpose of this process was to instigate student ownership of the different functions needed to successfully achieve a team goal.

Development of Functional Resumes

After the completion of the aforementioned activity, students were trained within the lab sessions of the course during the subsequent two weeks on how to prepare a functional resume to be selected for a specific role within a student team for the development of the prototypes of innovative technology.[2] Again, an activity was developed within the Foundry to illustrate to students the power of the systematic implementation of the platform during the process of innovation. Within this activity, students were asked to develop a resume for the timely participation in the university-wide career fair. Knowledge acquisition in the training of development of a functional resume centered on discussion of the elements of a resume and how to optimize the resume in the context of a specific desired position. Using knowledge acquired, students were tasked to create a resume specific to their desired position within the functional team, *i.e.*, with respect to a specific role identified in the training above (knowledge transfer).[2] Resources for this activity included a graduate mentor/role model that is a graduate student within the department and has in-depth understanding not only of the Foundry but also in the business application of resume building and functional teams.[20] Ultimately, after revision, the resumes were blinded, and instructor-identified student captains were selected to review the resumes and determine their teams based solely on the information provided within the blinded resumes. The resulting teams represented individuals that were identified to provide specific and relevant expertise within their role on a functional team of three students to collectively create a prototype of innovative technology with societal impact that included concepts of fluid mechanics.

Team Contracts/Rubrics for Evaluation

Once the captains selected their teams, each team was asked to create an AoR over the next two weeks which would ultimately serve as a contract for how individual students would behave or function in their respective teams. In a specific training section, students were guided through a series of activities which highlighted four elements that are present in strong social contracts[21]: 1) depth and detail, 2) accountability, 3) evaluation, and 4) enforceability.[23] By focusing on these elements, these activities helped students to better identify the gaps that would be present in the implementation of a team-based strategy if not addressed within a contract. Knowledge acquisition in these activities was encompassed with a brief introduction about the components of each of these elements. Knowledge transfer was then encompassed by the activities paired with these introductions that helped students comprehend how these elements manifest in simulated team-based interactions. By the end of the scaffolded progression, students were able to not only create a contract that integrated these four elements into the structure but also create a draft evaluation rubric that mirrored these elements.[23]

Final Presentation (Prototype of Innovative Technology)
After undergoing the rigorous training described above, students were tasked with implementing the Foundry via activities in which they were fully immersed in the identification of a challenge (*i.e.*, a real-world, societally relevant concept requiring fluid mechanics topics towards addressing that challenge) and progressing through knowledge acquisition and knowledge transfer towards the development of their prototype of innovative technology to address their identified challenge.[2] Each week, the facilitator of learning was available to students for discussions regarding their direction and how to redirect, if necessary, through activities within the elements of the Foundry model. At the end of the fifteen-week semester, students were to present the results towards their prototypes of innovative technology via a poster presentation to which judges external to the course were invited to assess student teams via a rubric including the following assessment items: 1) Challenge identification, 2) Novelty of the identified challenge, 3) Relation to course fundamentals, 4) Educational implications, 5) Business and marketing plans, and 6) Appropriateness of prototype in addressing the challenge.

Data Collection and Methods

Survey Data

Once student posters were assessed and the semester had ended, a total of thirteen judges were surveyed regarding their observations of team interactions, professionalism, and cohesion. This data provided internal feedback regarding the performance of student teams in order to obtain insight into the effectiveness of the pedagogical techniques described. In addition, this data offers an opportunity to calibrate the aforementioned activities in order to enhance elements identified as potential concerns or areas of improvement. This survey was designed to be in an electronic format within the Qualtrics program and was delivered via email to the judges after their participation in the final presentation of prototypes of innovative technology.[2] Further, this survey commenced with a notice regarding consent for the use of these responses for the purpose of research, a component that was included in the items that obtained Institutional Research Board approval as part of a larger QEP study related to this course.[4]

Descriptive Statistics

The data collected from the judges included questions with items pertaining to the interactions and professionalism displayed by teams during the final presentation. In total, there were six questions (revealed through figures 2 and 3) that are associated with team interactions and professionalism. The responses were in a five-point unipolar scale range (from *always* to *never*).[22] Furthermore, the survey included three open-ended questions regarding the cohesion of the teams as displayed during the final presentations. In total, nine out of thirteen judges responded to this survey.

Preliminary Findings

Overall, the responses to the scale-related items concerning team interactions were positive and indicated that the majority of teams displayed elements related to positive interdependence as associated with the pedagogical items integrated within the course (Figure 1). The responses to the scale-related items concerning professionalism were also overall positive and indicated that the majority of teams displayed elements related to the preparedness components as associated with the pedagogical items integrated within the course (Figure 2).

Finally, the open-ended questions related to team dynamics also indicate a positive assessment of team cohesion as displayed in the final presentation for this class. A few of the responses regarding this item, for example, indicate that the teams, "did a good job of presenting their projects in a cohesive and organized way". Additional comments included but were not limited to: i) The communication among team members and uniqueness of ideas indicated that they worked in an inclusive environment and valued the input of each team member. Many of the projects reflected a need in a specific culture/environment and this seemed to show some level of empathy and awareness of global issues; ii) This course is remarkable in incorporating the horizontal aspects of the T-Shaped engineering model. This came as a surprise to me as, usually, there is no time during the semester to dedicate much attention to this topic; and iii) This course is an excellent model for other departments in the sense that students worked as a team on a one-dimensional topic (i.e. fluid mechanics) that will allow an effective build-up of skills for the time these students need to take the upper level Process Design courses.

Figure 1. Judges' Responses to Likert-Type Questions Regarding Observed Team Interactions

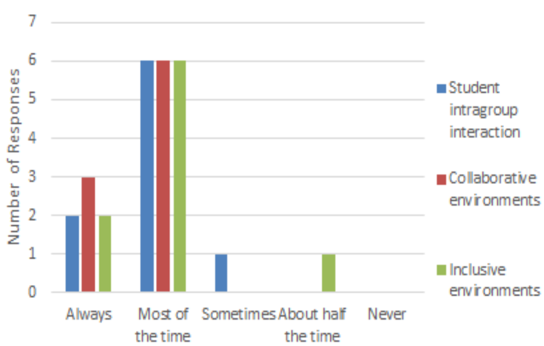
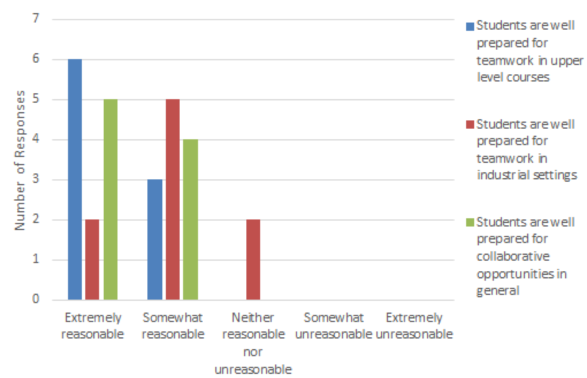


Figure 2. Judges' Responses to Likert-Type Questions Regarding Student Professionalism



Implications/Conclusions

Overall the preliminary findings from this study were positive and suggest that the training completed with regards to operating within a functional team were beneficial for developing effective communication and other intragroup dynamics. Additionally, according to the findings, such communication and intragroup collaboration was noted by the comments from external judges including how these dynamics influenced problem identification, idea generation, and team problem-solving skills. Further, feedback from the facilitator of learning of the follow up courses that students take during the semesters following this Fluid Mechanics course also indicates a very promising trend related to the formation of teams and functions of the students in the different teams. Finally, a line of research worth pursuing regards the efficiency and satisfaction of teams.

References

1. Sharon Sauer, Pedro E. Arce. Team member selection: A functional-based approach. *American Society of Engineering Education (ASEE)*. 2004.

2. Arce PE, Sanders JR, Arce-Trigatti A, et al. The renaissance foundry: A powerful learning and thinking system to develop the 21st century engineer. *Critical Conversations in Higher Education*. 2015;1(2):176-202. https://www.asee.org/documents/conferences/annual/2016/Zone2_Best_Paper.pdf.

3. Arce PE, Schreiber L. High performance learning environments, hi-PeLE. *Journal of Chemical Engineering Education*. 2004:286-291.

4. Jorgensen S, Arce-Trigatti A, Sanders JR, Arce PE. Promoting innovative learning strategies: A collaborative curricular re-design at the undergraduate level. *Proceedings of the American Society of Engineering Education (ASEE) Southeast Section*. 2019.

5. National Academy of Engineering. *The engineer of 2020: Visions of engineering in the new century.* National Academies Press; 2004.

6. National Academy of Engineering, (NAE). *The grand challenges in engineering.* National Academies Press; 2010.

7. Grasso D, Burkins M. Beyond technology: The holistic advantage. In: *Holistic engineering education.* 1st ed. New York, NY: Springer New York; 2010:1-10. 10.1007/978-1-4419-1393-7_1.

8. Arce PE. High performance learning environment, hi-PeLE™, as a best practice in engineering education to develop the creative and innovative engineer of the 21st century. 2009.

9. Sawyer K. *Group genius: The creative power of collaboration.* New York, New York: Basic Books; 2007.

10. Felder R, Brent R. *Teaching and learning STEM: A practical guide.* John Wiley & Sons; 2016.

11. Körner M, Wirtz MA, Bengel J, Göritz AS. Relationship of organizational culture, teamwork and job satisfaction in interprofessional teams. *BMC health services research*. 2015;15(1):243. https://www.ncbi.nlm.nih.gov/pubmed/26099228. doi: 10.1186/s12913-015-0888-y.

12. Volkov A, Volkov M. Teamwork benefits in tertiary education. *Education + Training*. 2015;57(3):262-278. https://www.emerald.com/insight/content/doi/10.1108/ET-02-2013-0025/full/html. doi: 10.1108/ET-02-2013-0025.

13. Jorgensen S, Arce-Trigatti A, Mathende A, et al. An activity to illustrate teamwork: An introduction to the renaissance foundry model through mindful abstraction. *Proceedings of the American Society of Engineering Education (ASEE) Southeast Section*. 2019.

14. Felder RM, Brent R. Navigating the bumpy road to student-centered instruction. *College Teaching*. 1996;44(2):43-47. http://www.tandfonline.com/doi/abs/10.1080/87567555.1996.9933425. doi: 10.1080/87567555.1996.9933425.

15. Felder R, Brent R. Active learning: An introduction. *ASQ Higher Education Brief*. 2015:1-5.

16. Felder RM, Brent R. Learning by doing. *Chemical Engineering Education*. 2003;37(4):282-283.

17. Smith K, Imbrie PK. *Teamwork and project management.* New York, New York: McGraw Hill; 2007.

18. Jeffery A. Thompson, David W. Hart. Psychological contracts: A nano-level perspective on social contract theory. *Journal of Business Ethics*. 2006;68(3):229-241. https://www.jstor.org/stable/25123912. doi: 10.1007/s10551-006-9012-x.

19. Sauer S, Arce PE. Assessment in the high-performance learning environment. *Proceedings of the American Society of Engineering Education (ASEE)*. 2011.

20. Adams B, Arce-Trigatti A, Sanders R, Arce PE. A practitioner research project featuring the application of the foundry to an undergraduate gel lab experiment. [Paper presentation]. *International Society for the Scholarship of Teaching and Learning (ISSoTL) Conference 2019 – Atlanta, GA*. 2019.

21. Thompson JA, Hart DW. Psychological contracts: A nano-level perspective on social contract theory. *Journal of Business Ethics*. 2006;68(3):229-241.

22. Richardson SB, Leonard KF. *Designing quality survey questions.* Thousand Oaks, California: SAGE Publications, Inc.; 2019.

23. Arce-Trigatti, A. (2018). *Social Contracts*. [Workshop]. Presented in Fluid Mechanics, Chemical Engineering 3121, undergraduate level course, Spring 2019. Tennessee Technological University.

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