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Applying Complexity Theory and Project-based Learning onto Project Designs of Complex Computing Systems

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I was born in Bogotá, DE, Colombia and received the degree of Electronic Engineer from Javeriana University in 1979. Immediately after I worked for Avianca Airlines in the Communications Division. I then traveled to the USA and obtained my MS and PhD in EE in 1983 and 1989 at Syracuse University. I joined the Electronic Engineering Faculty at Javeriana University from 1990 to 2001. In 2001 I came to University of Puerto Rico where I am a professor at the ECE Department.

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As an education professor working in the Teacher Preparation Program (TPP) since the year 2000, Dr. Bellido has taught the following courses: Human Development, Educational Psychology, Learning Evaluation; Theory and Methodology in the Teaching of History and Social Sciences; and Student Teaching of Mathematics and of Social Studies in Secondary School among others. As a collaborator in the Psychology Department she teaches Introduction courses to School Psychology, Fundamentals of Psychology, and the grad course of Learning and Cognition. As the Institutional Coordinator for the University of Puerto Rico at Mayagüez (UPRM) accreditation under the Council for the Accreditation of Educator Preparation (CAEP), she directs, coordinates and work in various committees that must complete evaluation cycles to assess the quality of the unit, the programs, teacher candidates, and alumni impact of the Teacher Preparation Program. These evaluation cycles require a diverse toolkit of instruments, educational materials, and protocols to collect and analyze usable and useful data for monitoring and improving the TPP. Efficient and effective collection, analysis, and presentation of results to stakeholders are important parts of the work done for the TPP evaluation cycles.

As the UPRM Center for Professional Enrichment coordinator for 12 years, Dr. Bellido was in charge of organizing faculty professional development activities. This placed her in the advantageous position to disseminate vanguard information about education, evaluation theory and practice which can be useful for both teaching and research faculty. As the UPRM Resource Center for Education Research and Services Center (CRUISE) coordinator since 2002, she has directed and evaluated more than twenty educational research, professional development and outreach projects from 2002 to 2020. These educational research and service projects include higher-education ecosystems for retention and graduation of STEM scholars, project-based learning instruction, classroom action research, professional and virtual learning communities, creating online educational materials, professional development and training for pre-service and in-service teachers, professional development for higher education faculty and a major Math and Science Partnership project. CRUISE has also worked with projects serving k-20 students directly. All these projects share common themes of the creating of curricular materials and applying the latest educational research to improve the teaching – learning dynamics giving Dr. Bellido extensive experience using evaluation to improve learning strategies from primary to graduate school.

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Introduction

In capstone courses, students solve real world problems using teamwork, their engineering skillset acquired through their curricular and co-curricular experiences, and management and planning. Faculty try to predict the impact of student technical and non-technical skills in the success and quality of projects but literature on this topic is sparse. The purpose of this case study is to identify which variables among technical and non-technical characteristics of students impact engineering project development and quality in small teams of ten (10) members or fewer. The types of projects considered have the following characteristics: they attempt to solve a real-world, open-ended problem; they require a thorough investigation into the application domain; team members possess previous knowledge on the project; and clients and management consistently offer feedback.

Furthermore, this case study expands on the theoretical work developed on organizational research in engineering education. Areas containing organizational research attempt to improve their project processes and management by focusing on the human factors of their developers [1, 2]. The case study offers an alternative perspective through a holistic, analytical approach of developers' technical and non-technical skills to improve project development and management practices. It also highlights the relationship between variables that affect project completion and the effect variables have in different project development stages, which currently lacks literature on the subject.

Capstone course professors and managers of engineering project development have concerns about project management skills as project complexity increases [1, 3]. They have expressed that they rely on instinct to assess project complexity [2]. One of the reasons is that they lack the tools to accurately assess team performance throughout the constantly changing complexity of project development. Erroneous assessment can lead to a loss of motivation, feeling overwhelmed, the inability to develop or learn new skills, the inability to accomplish outcomes, and the risk of an incomplete project for developers [2, 3].

This case study uses a Grounded Theory methodology combined with Complexity Theory and Project-Based Learning to identify the variables that impact successful project completion in capstone courses. The organization of the rest of this paper is as follows: The objectives and background are presented, followed by methodology. Then results and discussion are presented with conclusion and future work.

Objectives

This case study aims to identify which variables affect successful engineering project completion in small teams of 10 members or less; the relationships between the variables; and how management from industries and engineering design courses can improve team management abilities and successful engineering project completion rates. A final course evaluation of 85 to 100 points is characterized as a successful project.

Complexity

This research utilizes Complexity Theory, which consists of principles that describe the characteristics of complex systems. The principles of Complexity Theory are *self-organization*, *emergence*, *non-linearity*, *feedback loops*, and *adaptability* [4]. Of particular importance, emergence is the appearance of a phenomenon of the whole system during a holistic observation of the element's interactions [4, 5]. The edge of chaos is an example of emergence, a phenomenon where the system shifts between stability and instability to maintain equilibrium [6].

A complex system is open to exchanging energy with its environment and is composed of interacting elements with hierarchy [1, 5]. This case study considers a subcategory of Complex Systems called Complex Computing Systems, which contain machine elements [1, 5]. Furthermore, this paper perceives small teams or a group of small teams as a Complex Computing System due to their structure, behavior, and interactions with machine elements.

Williams presents Baccarini's definition of complexity in complex systems as affected by differentiation and interdependence. Differentiation is the number of different elements a system has, while interdependence is the number of interactions with others [7]. Williams also presents Turner and Cochrane's definition of complexity from a continuous change and uncertainty perspective where something is complex because of its unpredictable nature [7].

Ranganathan and Campbell present different complexity types used to evaluate a distributed computing system from a technical perspective. They mention cyclomatic complexity, size complexity, unpredictability, chaotic complexity, and algorithmic complexity [8]. Of particular importance for this paper, cyclomatic complexity refers to a system's interconnected parts and layers, determined with a system architecture diagram. These different complexity types are closely related to Baccarini's and William and Turners' definitions of complexity by structure, process, and comprehension [7].

Case Study

The Computer Engineering Capstone course observed in this case study implements ABET's requirements in its structure and uses open-ended, real-world problems [9, 10]. It is a one-semester-long course where students design and develop a project focusing on software, hardware, communication, or a combination for a particular client. All other core courses of the program are prerequisites for this course. The projects only reach the prototype stage, and the course divides the project into three phases: design, development, and integration. Each phase has an oral examination at the end. The course also requires the students to write a proposal, progress, and final report with their respective oral presentations. During the first two oral examinations, the course faculty question students about their project schedule and task progress before separating and questioning them about their design choices and their module implementations. Student teams must then demonstrate their fully functional and tested prototype for the third oral examination.

Capstone project teams and their projects demonstrate the principles of Complexity Theory. Student teams have the autonomy to choose their team members, project, client, organize themselves, and choose their work methodology, which shows *self-organization*. Student interactions display *emergence* and *non-linearity* when they accomplish work that is not the sum of their abilities. Constant interaction between students, clients, and faculty members to improve the project is the basis for *feedback loops,* where these interactions help modify the project and guide it accordingly. Finally, the teams demonstrate *adaptability* at the end of the different phases in the course, where feedback from professors and clients helps them change their actions for the next phases.

Furthermore, this course is team-taught employing Project-Based Learning (PBL). Project-Based Learning is a pedagogy that has received attention in the past thirty years due to practical educational benefits [11]. Some PBL fundamental elements map to principles of Complexity Theory. These are: student autonomy, constructive investigation, centrality to curriculum, driving questions, and real-world problems [11].

Self-determination and incremental implicit theories

Two other theories are of interest to this research: Self-Determination Theory and Incremental Implicit Theory [12, 13]. Self-Determination Theory describes a spectrum of work motivation with three categories: ammotivation, controlled motivation, and autonomous motivation, depending on the sense of autonomy. Similarly, Incremental Implicit Theory dives into the mindset of people and how they react to challenges [13]. The theory describes two states: fixed mindset and growth mindset. A fixed mindset characterizes an aversion to challenges due to fear of poor performance, while people with a growth mindset partake in challenges to improve themselves [13].

Various factors affect motivation throughout a project's life cycle, directly affecting how developers work [12, 14, 15]. Some of these factors are the types of goals people have towards working. Valle et al. describe two types of universal goals: performance goals based on recognition and learning goals based on mastery of a subject [15]. Valle et al. conclude that those with learning goals or multiple goals have a higher chance of succeeding in their tasks [15]. Compared to Gagné and Deci's Self-Determination Theory, performance and learning goals fit within the theory's motivation spectrum. Performance goals exhibit controlled motivation characteristics because people are motivated due to external factors. Learning goals exhibit autonomous motivation characteristics because people are motivated by an internal value of the work [12]. Likewise, the benefits of multiple goals are closely related to Integrated Regulation, a subcategory of controlled motivation that shares characteristics of both control and autonomous motivation [12].

Another factor that affects the motivation of individuals is the complexity of the work and the relatedness they feel with the work they participate in [16]. An example of task complexity affecting motivation is the research by Vos et al., where they divide elementary school students into two groups: those who will construct a game and those who will play an already constructed game [16]. The research results concluded that the students who constructed a game felt more motivated than the students who only had to play due to the higher complexity of the task [16].

Mindset

Mindset is another variable of interest. In their study of middle and high school students, Dweck and Yeager formalized a mindset theory called Incremental Implicit Theory [13]. This theory states that intelligence is a malleable quality improved through effort and practice. Furthermore, in their research, they concluded that people have two types of mindsets: fixed and growth. They argue that a growth mindset is preferable for improved performance, and, to develop growth mindsets, educators and parents have to praise a student's effort more than their outcomes [13, 17]. Similarly, in her paper, Boyd argues that professors need to change their mindset to help change the students [17].

In the book "How Learning Works: 7 Research-Based Principles for Smart Teaching," Ambrose et al. present a similar idea about students' mindsets [18]. The authors argue that students have formed an identity throughout their lives that they use as a filter for all incoming information [18]. This filter affects how they interpret information and adapt to both feedback and failure [18]. Additionally, the authors argue that the environment plays a role in students' mindset [18].

Teamwork

Teamwork also affects project complexity. Huang and Chen demonstrate how teamwork affects project complexity by exploring the dynamics of team processes [19]. They identify that team members' availability and the rate at which they learn and apply new techniques and skills to the project's context can decrease or increase the chances for project success. Asproni furthers this by identifying that teamwork involves both technical and personal competencies to succeed [20]. Furthermore, Asproni states that face-to-face communication and a high standard of work ethic can have far-reaching positive effects on teamwork and overall project success [20].

One of the most fundamental teamwork problems is the free rider problem [14, 21, 22]. Free riding is the phenomenon where a member or group within a team will consistently do less work than the rest [14, 21, 22]. Pfaff and Huddleston research which variables affect student attitudes towards teamwork and conclude that the absence of a free rider has positive effects on teamwork [21]. Additionally, they also argue that using peer evaluations is a good deterrent for free riders and may increase student focus and motivation [21]. Brooks and Ammons report similar findings in their study of free riding and peer evaluations. Furthermore, the opposite of free riding, such as a student trying to monopolize all the work and excluding the rest of the team, can negatively affect teamwork [23]. Kapp references this problem in his paper while discussing methods to improve teamwork in collaborative project-based courses [23]. He concludes that team building and team performance interventions are needed throughout the course to improve teamwork [23].

Maintaining an appropriate level of teamwork, high motivation, and an appropriate mindset among team members are elements that constitute project management [19, 24]. In Huang and Chen's research, most of the complexity and teamwork quality variation comes from tasks that belong to the project management theme [19]. Project management also plays an impactful role in team members' motivation by assigning tasks to team members based on the complexity of the tasks and team members' skills. It is also management's responsibility to create an environment where the group can change from any level of a fixed mindset to a growth mindset [18].

Project Management

Project management is responsible for establishing the schedule and communicating the project's goals to everyone involved [19]. Huang and Chen exemplify this in their research and discuss the consequences of not making a well-established schedule and clearly stated goals [19]. They argue that overall project complexity increases proportionally to the uncertainty of team members' thoughts on the project's [7, 19]. Additionally, Schmidt and Adams present project management's involvement with motivation, where their results conclude that motivation tends to decrease as a project progresses [7]. Therefore, project management must notice this and react accordingly to help maintain motivation as high as possible [7]. Considering these researches, the variables of interest to this study are cyclomatic complexity, motivation, mindset, teamwork, and project management.

Research Methodology

Grounded Theory is a research methodology founded by Glaser and Strauss in 1967 to produce theoretical accounts on observations and data [25, 26]. The methodology belongs in qualitative research and requires that researchers avoid having previous knowledge on the research topic. The methodology’s process has four main steps: note writing, coding, category identification, and literature comparison. Additionally, the methodology contains theoretical sampling, which allows the ability to direct the focus of the study, and theoretical saturation, a stopping condition where new data no longer offers significant benefits to the theory [25, 26].

This case study uses Grounded Theory to gather and analyze data from the students of a Computer Engineering senior-level capstone course from a Hispanic Serving Institution. After obtaining consent from students each semester, observations taken spanned four semesters. The informal procedure consisted of recording the everyday, work-related conversations the subjects had in the laboratory and how they interacted using Grounded Theory's note writing procedure. The formal procedures were weekly faculty meetings where the course faculty would discuss the characteristics of each team observed. Subjects received peer assessment and feedback Google forms through the course's assignment website throughout the semester. These forms were voluntary, and they would commonly have a response rate of one-third of the group. Finally, the course faculty held an end of the semester meeting to discuss the lessons learned. This document contained information on what instruction and process techniques were impactful on the subjects' performance, what qualities the subjects exhibited that became obstacles to project completion, and suggestions to improve the course based on the observations.

Open coding helped group observations by similar topics [25, 26]. This process identified groupings that had common concepts. The process continued by grouping related concepts into categories that would form the theory using Grounded Theory's axial coding procedure [25, 26]. Finally, new data helped to edit the theory by removing categories that did not fit. The editing process was a two-step process. First, the editing process began at the end of each semester by organizing concepts and categories. Then literature reviews became the basis for editing the theory before the start of the following semester.

Additionally, information recorded in this case study details aspects of the course related to the subjects' performance and the project's complexity. These aspects were the evaluations of subjects obtained at each phase's end and the complexity coefficient of the design of their projects. The oral examination and final evaluations were the primary measures to determine successful project completion.

Data Analysis

Data analysis for the observations involved identifying, analyzing, and coding related terms. These terms consisted of keywords or ideas repeated in various observations and described the subjects or faculty's themes. The analysis of concepts led to identifying shared ideas, such as causes, effects, or descriptions, that would later become categories. This analysis also helped identify any concept or category that did not appear to fit the case study. This process repeated throughout the semesters until the theory reached theoretical saturation.

Literature analysis helped refine the concepts and categories. The concepts and categories identified in the previous semester directed the study to review papers on those subjects. After the literature review, the identification of new concepts; modification of existing concepts and categories; and theoretical sampling refined the core of the study. At the end of this process, the remaining categories formed the basis for an explanatory theory of the observations.

Historical data analysis began by first extracting the data from the course faculty's archive evaluations and saving them in an Excel file. Excel function formulas helped identify the means, variances, and standard deviations from each phase from every semester. Welch’s T-Test for unequal variances helped determine if a significant difference between semesters existed on their course phase evaluation with a 5% confidence interval. Finally, box plots further visualized this difference between semesters.

Additionally, progress reports contained the necessary diagrams to use the cyclomatic complexity formula. The cyclomatic complexity formula is as follows [8]:

$$CC = E - N + P \quad (1)$$

The terms in the cyclomatic complexity (CC) equation represent nodes (N), edges (E), and components (P). A graph containing the averages of the complexity coefficients of each semester helped visualize any trends in the data.

Results

A total of 225 observations from informal and formal interviews of the teams helped identify concepts and categories. The observations produced various notes that had similar concepts as their central theme. These concepts are free-riding problems, projects that were too simple or too complex, subjects that did not want to participate, among others. Teamwork, motivation, mindset, complexity, and project management proficiency became the focus categories for this research after grouping concepts by their relatedness.

Multiple characteristics within observations required the observations’ placement under multiple categories. Teamwork had the highest number of observations at 73. Project management proficiency was the second highest with 51 observations. Mindset had 48 observations and was challenging to evaluate due to confusion with motivation since both categories share behavioral characteristics. Motivation had 42 observations. Finally, complexity had the lowest number of observations at 18; this constitutes only 8% of the total observations.

The results showed that average scores in all 3 phases of the course and the final score have decreased in recent years. The results of Welch's T-Test demonstrate that Spring 2019's average has been significantly lower than all other previous semesters. The box plots also demonstrate that the median results for each phase and final score of Spring 2019 are outside the box range of some previous semesters. This suggests that there might be a significant difference between them, but this result needs more investigation to understand how significant the difference may be. Additionally, the boxes leading to Spring 2019 have been decreasing consistently with respect to their previous semesters, with a significant difference in Figure 4 between Spring 2019 and Fall 2018. Figures 1, 2, and 3 demonstrate similar decreases but differing variations.

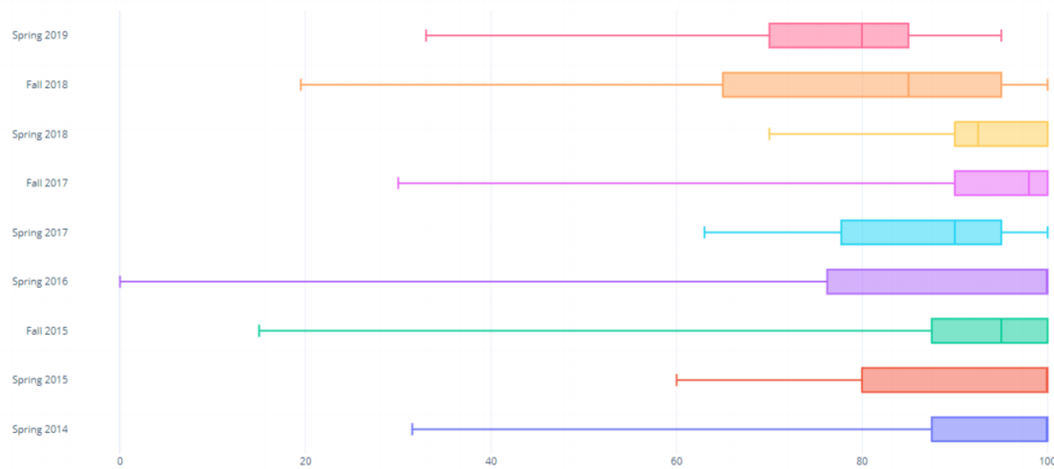

Figure 1: Oral Exam 1 Box Plot demonstrating a slight decrease in average grades for the first oral exam in recent semesters

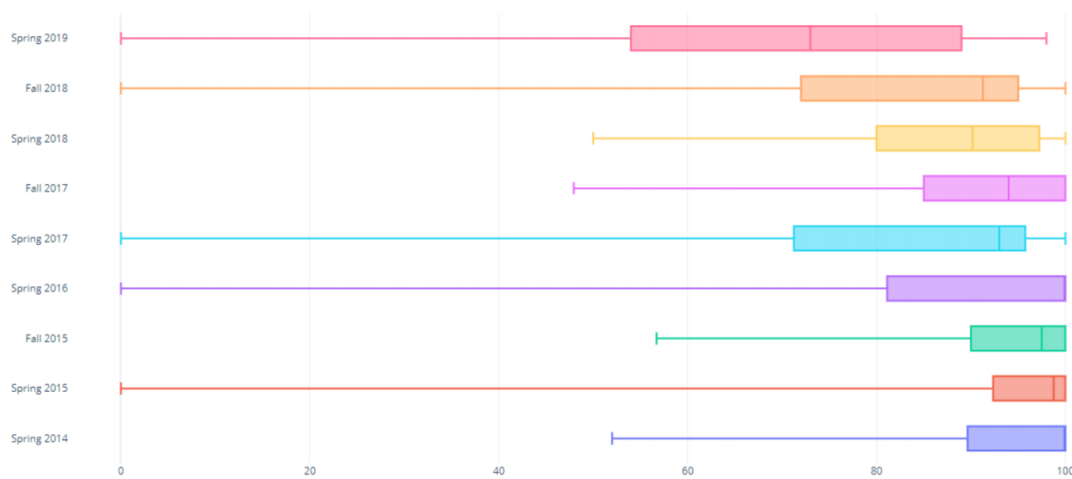

Figure 2: Oral Exam 2 Box Plot demonstrating a more significant distribution and decrease in the average grades for the second oral exam in recent semesters

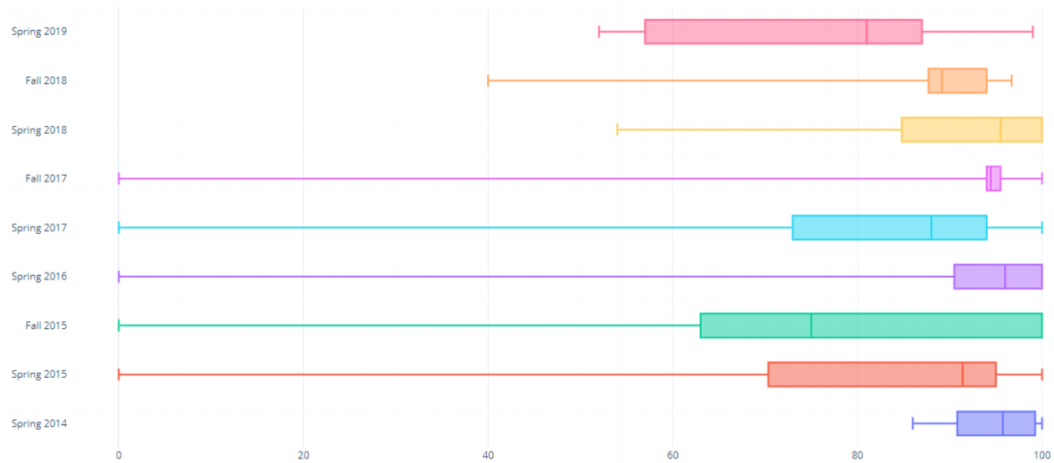

Figure 3: Oral Exam 3 Box Plot demonstrating a minimal decrease but higher distribution in the average grades for the third oral exam in recent semesters

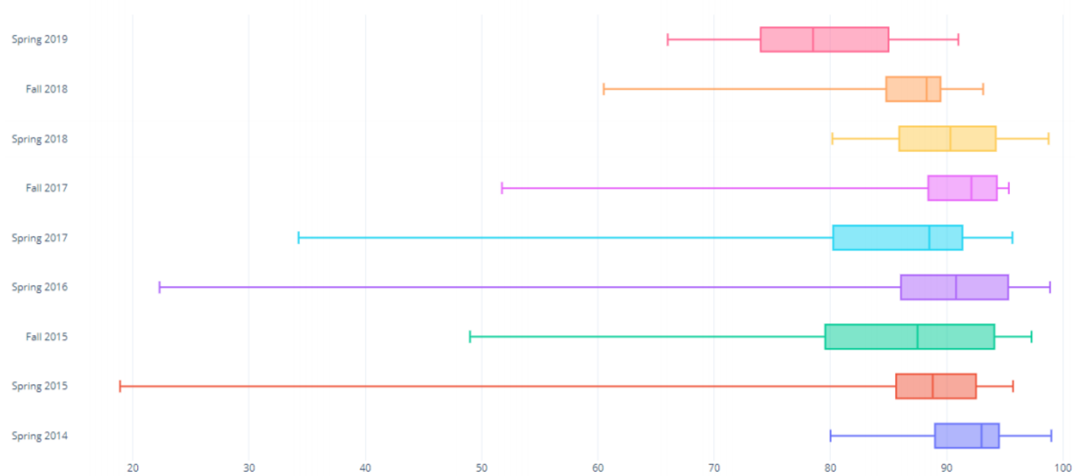

Figure 4: Final Evaluation Box Plot demonstrating a significant decrease in average grades for the final grade in Spring 2019 compared to all semesters

Additionally, projects’ complexity coefficients are measured using the cyclomatic complexity formula. System architecture diagrams are used to calculate a project's complexity coefficient due to their complete representation of the project’s elements and their interactions.

The projects' complexity coefficients ranged from 6 to 9, with few outliers. Furthermore, there are two types of system architecture diagrams used to analyze complexity coefficients: diagrams with components and without components. These components can represent physical or virtual boundaries within the system, such as having parts of the system running in different physical servers or abstract boundaries such as internal modular implementations. The cyclomatic complexity formula uses graphs composed of nodes, edges, and components to determine the complexity of a system. The definition of graphs comes from the theory of graph theory within mathematics. Nodes (N) are shown as circles on the graph representing the different modules that constitute the system. In contrast, edges (E) are represented as arrow lines and denote the communication paths for data transmission between nodes.

The following two figures show two different projects: one without physical boundaries between elements and another with physical boundaries. Figure 5 shows an abstracted graph created from a system architecture diagram of a team that successfully completed their project and does not use components. The nodes (N) and edges (E) represent the elements within the system and how they communicate with each other. Figure 6 shows the other system architecture diagram type where the intermittent square lines denote the components (P). Figure 7 demonstrates a line plot with the different complexity coefficient averages among the four semesters.

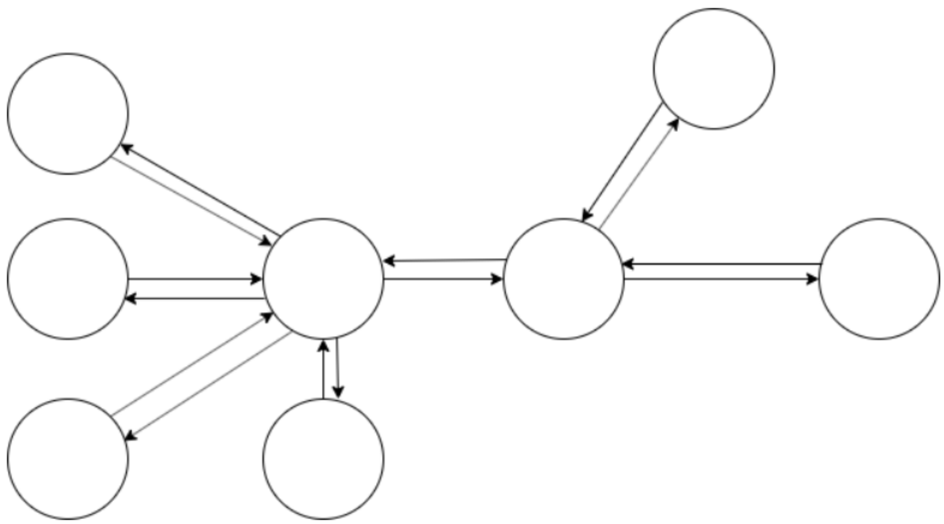

Figure 5: Abstracted System Architecture Graph depicting a system whose elements are all within the same component and have bi-directional data flow

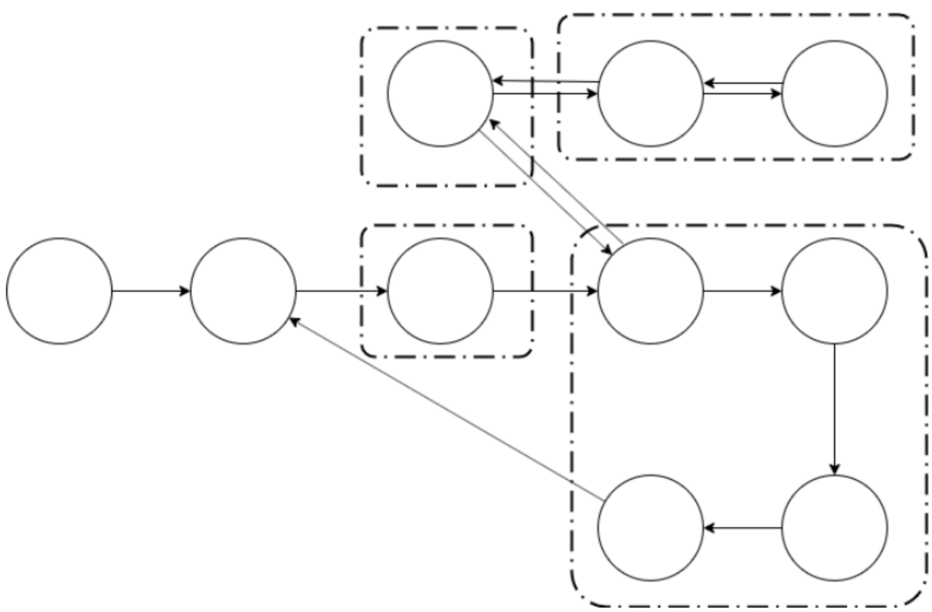

Figure 6: Abstracted System Architecture Graph depicting a system whose elements are located in different physical locations and have some unidirectional data flow

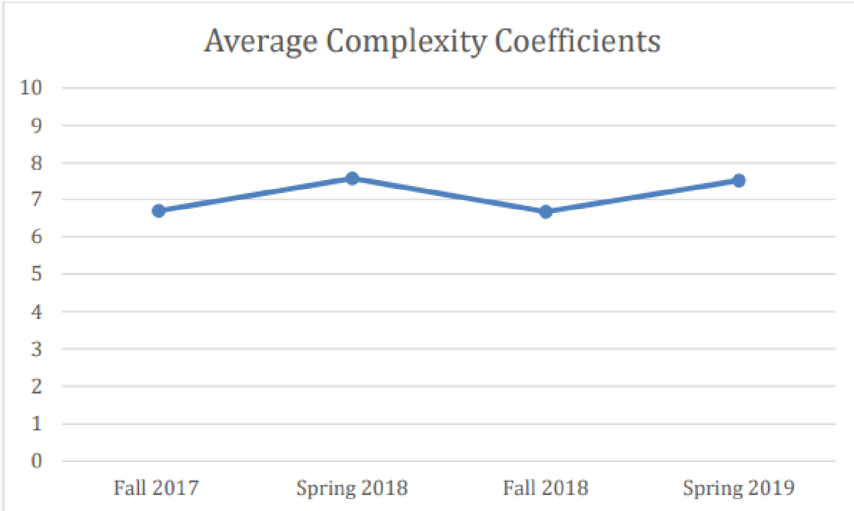

Figure 7: Cyclomatic Complexity Coefficient Averages demonstrating minimal to no difference between averages of recent semesters

Discussion

The research shows how each element of the five variables are interrelated and affect each other [7,13, 19]. A pattern found in the research was that students described the same behavior: when one variable decreased, the rest of the variables were also negatively affected.

Teamwork is the category with the most impact on the others based on the student's perception. As Brooks et al. and Pfaff et al. mention, aspects such as a free rider can significantly lower motivation and change the team members' mindset on the importance of working in groups [21, 22]. Huang and Chen also mention how teamwork can impact project management when tasks are not equally distributed, as in the presence of a dictator student who tries to monopolize all the tasks [19]. These effects impact the project's complexity as the students may not complete their prototypes [2, 7, 19].

Many groups demonstrated the presence of a free rider student during the two-year observations period. This problem was most common among teams who had problems with communication and scheduling. One such team could not meet consistently face-to-face due to a member having work outside of class time that conflicted with team meetings. Another team suffered from a free rider problem because the team never successfully communicated their expectations in the prototype area that the individual was developing. Contrary to the free rider problem, the results contained only one case where individuals tried to accomplish all the work by themselves.

Project complexity appeared much less than any of the other categories within the two years. Most projects were complex enough for the subjects, based on the students' answers during interviews, and became too complex by the students' actions or external factors such as the client changing requirements. This increase in complexity due to changing requirements is similar to the uncertainty complexity mentioned by Turner and Cochrane [7]. One reason why project complexity was low could be due to the years of experience the faculty used to assess student projects. The course professors identify if the projects are adequate within the first phase of the semester and correct them if possible.

Motivation and mindset were difficult to differentiate during the two-year observation period because of the interrelatedness of their effects on behavior. Most subject teams demonstrated a fixed mindset initially in each semester. Regardless of the interventions and workshops offered during the first phase, subjects were still only concerned with their final course evaluation. They were not concerned with whether they acquired and developed their engineering skills. Their behavior is an example of controlled motivation. Subjects also admitted to a decrease in motivation as the semester progressed, which supports the statements made by Schmidt and Adams [24]. Subject teams who had successful project completion outcomes in all phases of the semester and the final course evaluation expressed that they had multiple goals starting the course. These subject teams cared about making an appropriate product and attaining a high grade at the end of their work. This behavior supports the work by Valle et al. where they state that multiple goals are essential for successful student outcomes [15]. This behavior also references Self-Determination Theory as these subjects demonstrated integrated regulation motivation [12].

Project management proficiency was easier to observe because the project manager's actions include teamwork and complexity. One prominent observation from this category was of a team whose project manager stopped coming to class and became less involved with the project due to personal reasons. Although the rest of the team kept working, they confused the steps to take to proceed and doubted whether the goals and objectives were clear. Another team suffered a similar problem where their project manager had to leave for a month, and they delegated their responsibility to a team member. However, they decided to establish the protocol for their continued working relationship at the last minute. Their teamwork collapsed, and their project was almost unacceptable by the course's standards.

The overall result of all observations is that the majority of subjects do not have the necessary skills to work on the projects even when they align with their previous knowledge. Some projects are successful because at least one team member is an exceptional subject who becomes the center of the project and helps direct everyone to a common goal. This observation is similar to the findings in Curtis et al.'s work, where companies depend on exceptional individuals with years of experience to accomplish complex projects [2].

Furthermore, the results from the analysis on the complexity coefficient of projects demonstrated that there is no significant difference in the complexity of accepted projects. Figure 7 evidences this explanation by showing no significant difference in complexity between the semesters. However, although there are no significant differences, the results demonstrate that the project's complexity links to successful prototype completion. Subject teams that performed better usually had a higher complexity coefficient within the 6 to 9 range. In other words, subject teams who had more challenging tasks performed better than those who had fewer challenging tasks. One subject team in particular whose performance was below the expected had a complexity coefficient of 3 due to their project’s scope definition. The students demonstrated the necessary technical skills and knowledge to reach the capstone course, but their performance lacked behind similar students with appropriately complex projects. This result supports the conclusion brought by Vos et al. [16].

Recommendations

The variables that impact a project's complexity and successful prototype completion change throughout the development life cycle. Complexity is an important issue at the beginning of the project when establishing features and requirements but becomes less prominent as the project progresses. Complexity only becomes a constant problem when subjects do not clearly state an appropriate work plan. Motivation and mindset are team-independent variables to assess before forming a team. These are variables inherent to an individual. Management should assess these individual aspects before forming teams and determine the needs of each individual to maintain a high level of motivation and an appropriate mindset throughout the project. Teamwork needs constant monitoring a few weeks after the team formation. Early, periodical peer assessments are necessary to deter common teamwork problems. Additionally, teamwork is dependent on correct project management decisions. Project management encompasses all activities that occur from the start of a project, such as work monitoring, team planning, schedule setting, and goal setting. Project management also affects all other variables.

After the project commences, the most critical variables are motivation and mindset. These significantly affect teamwork after team formation. Having multiple goals and high motivation levels with the appropriate mindset assures that teamwork can be more successful. Afterward, project management and teamwork become the critical variables. Motivation and mindset are affected by the decisions of project management and teamwork processes. When these aspects are not appropriate, motivation lowers, and mindset may shift entirely. The variables keep deteriorating as the project progresses. Giving appropriate time off and allowing more freedom of choice during the midway point of a project while lowering administrative or overhead activities can increase motivation. Finally, if goals and the amount of work are apparent, the project complexity does not become a problem in the long term. The most influential elements that affect the overall complexity of a small team developing an engineering prototype are the actions and behaviors taken by them.

Conclusion

The variables found to impact project complexity in capstone engineering projects worked by small teams of 10 team members or less are teamwork, motivation, mindset, project management, and cyclomatic complexity. This result implies that when technical skills and knowledge structures are similar throughout the teams, project complexity depends on team members’ non-technical skills. Therefore, capstone course professors must assess students’ non-technical skills at the start of the semester to predict when interventions will be necessary. Students with fixed mindset, controlled motivation or ammotivation, low teamwork skills, or low project management ability have a higher risk of causing problems for their team and, thus, not completing the project. It is also essential for professors to allow students more autonomy in their choices of which project to work on, which members to pair with, and what work methodology they wish to use.

After evaluating their student's non-technical status, capstone professors should analyze projects using the cyclomatic complexity formula. This formula can give a clear idea about the project's complexity through its resulting coefficient and aid professors in guiding students to the correct level of complexity for their project. However, it is the responsibility of the professors to determine the range of values acceptable for their course. Since students arrive at the course with similar technical skills and knowledge, this range should apply to all students. They should also provide information on successful project management and teamwork practices for students to use.

Additionally, professors must re-assess students at the course's midway point as it is typical for motivation and mindset to lower. Reminding students of their freedom of choice and praising their effort can positively affect their mental state and help them persevere. Similarly, professors should provide peer assessment forms regularly throughout the semester to deter free riders and determine teamwork or project management problems. Incorporating these practices into their capstone course design should increase their successful project completion rate.

Future Work

This study has practical and theoretical limitations due to the resources available. Therefore, future work will focus on researching whether these results apply to other areas of engineering and with different populations. Additionally, this case study evaluated teamwork, project management, and motivation qualitatively through verbal and written communication with subjects. Future work should apply quantitative evaluation methods for these variables to further develop an assessment procedure for capstone professors and managers.

References

[1] M. Schneider and M. Somers, "Organizations as complex adaptive systems: Implications of Complexity Theory for leadership research," in *The Leadership Quarterly*, vol. 17: 351-365, [Online] 2006.

[2] B. Curtis, H. Krasner, and N. Iscoe, "A Field Study of the Software Design Process for Large Systems," in *Communications of the ACM*, vol. 31: 1268-1287. [Online] 1988.

[3] J. Vanhanen and T.O. Lentinen, "Software Engineering Problems Encountered by Capstone Project Teams," in *International Journal of Engineering Education*, [Onine] 2004.

[4] D. Rickles, P. Hawe, and A. Shiell, "A simple guide to chaos and complexity," in *J Epidemiol Community Health*, vol. 61(11): 933-937, [Online] 2007.

[5] A. Gupta and S. Anish, "Insights From Complexity Theory: Understanding Organizations Better," *Indian Institute of Management*, Bangalore. [Online] 2014.

[6] A. Gupta and S. Anish, "Insights From Complexity Theory: Understanding Organizations Better," Indian Institute of Management, Bangalore. [Online] 2014. Available: http://tejas.iimb.ac.in/articles/12.php

[7] T. M. Williams, "The need for new paradigms for complex projects," in *International Journal of Project Management*, vol. 17: 269-273. [Online] 1999.
[8] A. Ranganathan and R. H. Campbell, "What is the Complexity of a Distributed Computing System?," Understanding Complex Systems, University of Illinois-Urbana Champaign, [Online] 2005.
[9] A. J. Dutson, R. H. Todd, S. P. Magleby, and C. D. Sorensen, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone," in *Journal of Engineering Education*, [Online] 1997.

[10] R. H. Todd, S. P. Magleby, C. D. Sorensen, B. R. Swan, and D. K. Anthony, "A Survey of Capstone Engineering Courses in North America," in *Journal of Engineering Education*, [Online] 1995.

[11] J. W. Thomas, "A Review of Research on Project-Based Learning," The Autodesk Foundation, San Rafael, California. [Online] 2000.

[12] M. Gagné and E. L. Deci, "Self-Determination Theory and Work Motivation," in *Journal of Organizational Behavior*, vol. 26: 331-362. [Online] 2005.

[13] D. S. Yeager and C. S. Dweck, "Mindsets That Promote Resilience: When Students Believe That Personal Characteristics Can Be Developed," in *Educational Psychologist*, vol. 47(4): 302-314, [Online] 2012.

[14] S. Viswanathan, "Implementation of Effective Capstone Projects in Undergraduate Manufacturing Design Engineering Program," in *American Journal of Engineering Education*, vol. 8: 45-60. [Online] 2017.

[15] A. Valle, R. G. Cabanach, J. C. Núñez, J. González-Pienda, S. Rodríguez, and I. Piñerio, "Multiple goals, motivation and academic learning," in *British Journal of Educational Psychology*, vol. 73: 71-87. [Online] 2003.

[16] N. Vos, H. van der Meijden, and E. Denessen," Effects of constructing versus playing an education game on student motivation and deep learning strategy use," in *Computers & Education*, vol. 56: 127-137. [Online] 2011.

[17] D. E. Boyd, "The Growth Mindset Approach: A Threshold Concept in Course Redesign," in *Journal of Centers for Teaching*, vol. 6: 29-44. [Online] 2014.

[18] S. A. Ambrose, M. W. Bridges, M. C. Lovett, M. DiPietro, and M. K. Normal, *How Learning Works: 7-Research Based Principles for Smart Teaching*, San Francisco, CA: A Wiley Imprint, 2010.

[19] E. Huang and S. Chen, "Estimation of Project Completion Time and Factor Analysis for Concurrent Engineering Project Management: A Simulations Approach," *Sage Publications*, vol. 14: 329-341. [Online] 2006.

[20] G. Asproni, “Motivation, Teamwork, and Agile Development,” in *Agile Times*, vol. 4: 1-9. [Online] 2004.

[21] E. Pfaff and P. Huddleston, “Does It Matter if I Hate Teamwork? What Impacts Student Attitudes toward Teamwork,” in *Journal of Marketing Education*, vol. 25: 37-45 [Online] 2003.

[22] C. M. Brooks and J. L. Ammons, “Free Riding in Group Project and the Effects of Timing, Frequency, and Specificity of Criteria in Peer Assessments,” in *Journal of Education for Business*, vol 78: 268-272. [Online] 2003.

[23] E. A. Kapp, “Improving Student Teamwork in a Collaborative Project-Based Course,” College Teaching, vol. 57: 139-143. [Online] 2009.

[24] B. Schmidt and J. Adams, “Motivation in project management: the project manager’s perspective,” in *Project Management Journal*, vol. 39: 60-71.

[25] P. Y. Martin and B. A. Turner, “Grounded Theory and Organizational Research,” in *The Journal of Applied Behavioral Science*, vol. 22: 141-157. [Online] 1986.

[26] Y. Chun Tie, M. Birks, and K. Francis, “Grounded Theory Research: A design framework for novice researchers,” in *SAGE Open Medicine*, vol. 7. [Online] 2019.