A Systems Engineering Analysis of Team Approaches in Higher Education

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Team environments are becoming a standard for teaching project management and integration in higher education institutions as well as engineering workplaces. Engineering and technology curricula especially have an emphasis on group work and collaboration, and now extend beyond a physical classroom into distance learning environments. This paper emphasizes additional challenges and demands for effective team collaboration with respect to three distributions of system inputs.

This paper addresses these three concepts of distributed team performance in a systems engineering course, specifically a multidisciplinary, case- and project-based approach to systems engineering taught in a “hybrid learning” environment. This paper discusses these complexities of distributed team coordination and performance as a system of interest from four different perspectives of Systems Engineering. In comparison to many “traditional” single-focus approaches to systems engineering, this paper highlights four distinct traditions, all utilizing similar descriptions of terminology and principles. The paper further assesses efficacy and effectiveness of team communications, and identifies further considerations that might be helpful to educators, prospective students and perhaps even professionals who work in team environments.

Practitioner Summary: This paper provides a summary of multiple perspectives on systems engineering (SE), and how those multiple perspectives also help improve the design of a course intended to teach SE concepts. A particular challenge involves multiple sources of variability of student backgrounds, locations, and learning expectations that must be acknowledged and addressed. Measuring the performance and success criteria of a new course in a hybrid learning environment is difficult and highly sensitive to student and instructor expectations. Thus, clear definitions of “measures of effectiveness” are essential to develop, and share with students, to support peer-level learning and capitalize on a variety of student experiences and perspectives with SE topics.

Keywords: team communication, hybrid learning, team performance, team effectiveness

1. Introduction

As the profession of Engineering evolves to meet the challenges of the 21st Century, there are increasing demands in the US and other countries to consider greater integration and focus of “soft skills” to supplement the mathematical and technical needs of engineers (National Research Council, 2004). Engineering and technology curricula especially have an emphasis on group work and collaboration, and now extend beyond a physical classroom into distance learning environments. Many universities now offer courses that are taught on-campus, which are video-taped and shared with distance students as online courses. Distance students have access to these recordings and all course materials, and participate through the course educational website. Combined with curricula that involve collaborative teamwork, these “hybrid” environments incorporating both traditional, campus-based students and professionally embedded, distance students could demonstrate a significant advancement of the learning environment as well as the skills developed by new as well as continuing engineers.

The success of such hybrid courses requires navigation of three distinct course and organizational sources of variability. The first source (the “hybrid learning environment”) describes the combination of local on-campus students and widely distributed distance learning students. Teaching such a course to a multidisciplinary population of both undergraduate and graduate students, in addition to the “hybrid” of distance and on-campus students, represents a more variable range of experience and relevant expertise than a single-discipline, homogenous population. The third source of variability represents the organization
of course assignments to support course-related expertise between the students (rather than simply professor-led lectures) to support course learning goals. These sources of variability, further discussed in section 2, present a need to design a course that is more robust across the types of students enrolled, their respective expertise, the location and technology resources available to those students, and the assessment materials used to stimulate growth and critical thinking in the subject area.

In essence, the question of how to design such a hybrid systems engineering course is, in itself, a systems engineering design problem. By definition, an open engineering system involves inputs, outputs, transformations of matter and energy, and feedback processes in a complex and dynamic environment—this approach has already been described to considering the design, evaluation, and improvement of engineering education (Caldwell, 1993). The role of both technical (learning technologies, available classrooms, streaming media production facilities) and social factors are of great importance in such system considerations, highlighting a sociotechnical (Trist, 1981) systems engineering (STSE) approach. Although these combinations of sociotechnical and technical systems engineering approaches are not frequently integrated in this approach to science, technology, engineering and math (STEM) education, the existing tools from these traditions can help improve our understanding of our goals, processes, and analyses of new hybrid learning environments.

The research question we would like to answer is “What are the factors that contribute to team effectiveness and efficacy with respect to students charged with learning new material, with new skills, in a new learning context?” The specific focus of analysis for this paper will be a course currently taught at a Midwestern US university that explores perspectives in Systems Engineering, which employs the use of team environments distributed between on-campus and distance learning students.

2. Method

To answer the research question, we employed an iterative approach to identify factors and challenges representing four perspectives, or “flavors,” of systems engineering (SE) (Caldwell, 2009).

2.1 Introduction to System Definition

The specific focus for this paper is a course on “Perspectives on Systems Engineering,” currently taught at a Midwestern US university and expressly intended to support both on-campus and distance learning students. A graphical representation of this course describes a system that receives diverse experiences of students and produces course outcomes (see Figure 1). There also exist iterative feedback loops that contribute to stabilizing the system and enhancing the quality of output.

![Figure 1. System drawing of a hybrid learning course, including three distributions of inputs, course process, outputs, and feedback loops.](image-url)

2.2 System Goals and Scope
The system has two goals, as defined in the syllabus for the course. These objectives are as follows: (1) “to enable and improve discussion of Systems Engineering (SE) using four distinct approaches (perspectives) on SE and its role in socio-technical systems” and (2) “to provide to students an introduction to various quantitative and qualitative approaches to SE”. With these goals in mind, the intended outcomes can improve the varied range of SE and its applications. The scope of this system addresses the students, instructors (including teaching assistants), and course materials included in a one-semester delivery of the course. Course materials, multimedia, and assignments can vary based on student enrollment.

2.3 System Inputs

The system inputs include the three distributions of student characteristics defined in the introduction. These distributions are (1) on-campus and distance students in a hybrid learning environment, (2) diverse experience profiles and sources of expertise of students, and (3) student-contributed expertise to support peer learning through course materials and assignments. Each of these inputs requires special consideration regarding transformation and feedback.

The first distribution is comprised of on-campus and distance students interacting within a “hybrid learning” environment. That is, some students are on campus, physically attending lecture and socially interacting with instructors and fellow students in person. Other students, however, are in a completely different environment while still experiencing the same course. This environment is comprised of videos being watched one to 48 hours (or more) after the lecture is recorded, and discussion boards in an on-line forum. For instance, distance students could be at another university in another country, with only the course website as an interface for instruction. Additional supplementary communication can be offered, of course, to increase distance student accessibility to instructors and fellow students, but this is largely up to the instructor and other students to offer individually. This distribution offers some unique challenges with respect to communication delays, social interactions of learning, and availability of instructor resources, as well as the effect of cultural factors on material context.

The second distribution includes the diverse experience profiles and sources of expertise of students at both undergraduate and graduate levels, and traditional full-time and practicing professional full-time students, and from multiple disciplines of engineering practice. The course under analysis, for instance, included a wide range of expertise in all of these categories. Students of at least three different engineering disciplines participated in the 16-week course, pursuing Bachelors through PhD degrees, and with levels work experience ranging from none to senior level experience. With such a diverse pool of knowledge, many unique perspectives emerged in discussions and assignment topics, which created a broad range of applications for students to analyze and pursue. This distribution is of particular importance to diversity of course material and scope.

The organization of course assignments and flow of course-related expertise between the professor and students are represented in the third distribution. In a traditional lecture course, the professor is the acknowledged expert in a particular field, and the lectures and course assignments (such as homework and exams) are intended to demonstrate student mastery of material within the field. By contrast, case method and project courses are intended to capitalize and emphasize student experience and insight to provide individual and peer learning. This distribution is perhaps the most crucial to the instructor to help guide student expectations, decisions, timelines, and feedback mechanisms, especially early in the semester.

2.4 System Transformations and Process Feedback Loops

Addressing the inherent differences in the three distributions that feed into this system process, one should evaluate the implications of each type of distribution and the respective transformation experienced in the course delivery process. Feedback loops between and within the system transformations are also described to clarify stabilizing mechanisms in the system.

Longstanding research in team performance and task coordination has emphasized issues of effective “taskwork” (project activity relevant to completing explicit project goals) and “teamwork” (managing effective interpersonal exchanges to improve clear understanding and positive team dynamics) (Caldwell,
The challenges of group work and collaboration in hybrid course learning environments require an additional integration of “pathwork”, which can be defined as effective support and use of information technology to exchange ideas and task activity across separations of distance and time (Caldwell, 2002; Garrett & Caldwell, 2011).

The role of pathwork to supplement taskwork and teamwork is necessary to support hybrid and distance learning experiences. Modern information technology available to educators and students offers different channels of communication, and can support additional teamwork and taskwork interactions among team members—if managed effectively. A physical spread of participating students introduces challenges regarding lack of synchrony in the distribution of materials and communications to, from, and between team members, especially when considering time differences. Businesses and educators alike feel the challenge of asynchronous and distributed communications. Such a challenge is only exacerbated by the characteristic of students with contrasting work experiences, priorities, and schedules. Students who work full-time have professional expectations to complete tasks related to their organizational roles, which can often include travel. Scheduling variability can constrain availability of team members and directly affect team success. Addressing this distribution in the course requires individuals and teams to work to proactively maneuver these scheduling and resource availability constraints with their classmates to produce high-quality outcomes while still respecting individual needs, such as work-life balance and personal schedules.

The second distribution undergoes a different kind of transformation that involves the convergence of different levels and sources of expertise to improve and challenge teams through diversity. Individuals from different disciplines, education levels, and experience levels can create highly effective teams. A 1991 survey regarding multidisciplinary team-based projects found that teamwork produces solutions that individuals cannot (Denton, 1997). These teams, working to complete case studies, discussions, and projects, rely on different perspectives to strengthen analysis and output. This transformation can directly benefit teamwork through well-organized pathwork, which offers opportunities for all team members to contribute efficiently. Communication, of course, must be established to determine standard methods. Following thereafter, applications beyond the educational website, such as Google Drive and DropBox, can be utilized to share and collaborate on documentation and team output. This distribution also predisposes teams to distribute taskwork in such a way that draws on individual strengths in particular areas, leading to effective and fulfilled members. A specific challenge faced by this distribution involves overcoming or bridging experience barriers to ensure effective collaboration and understanding of individual contributions.

The third distribution of inputs can help define, enhance, and draw upon pathwork to increase course effectiveness. Instructors in hybrid learning environments are committed to providing the same level of education to all students enrolled in the course, which can sometimes require extended availability in both time and method of communication. Additionally, with such a diverse distribution of expertise enrolled in the course in a given semester, assignment of teams to balance education level, work experience, discipline, and individual interests can be a significant exercise. Instructors must provide material that is both interesting and relevant to the second distribution of inputs, and through channels that are accessible and reliable to the first distribution. The transformation of this third distribution is the adaptation of instruction throughout the process, which changes each term as new students with diverse backgrounds in distributed networks enroll in the course.

These distributions are not static or removed. The internal feedback loop to both students and instructors during the course is comprised of assignment grades and individual feedback from instructors. This may also include, for the instructor, quality of discussions in online forums or the classroom. Assessment outcomes allow students and instructors alike to understand individual, team, and class performance in the core areas of the course.

2.5 System Outputs and Output Feedback Loops

Course outcomes are the system outputs, stated under the system definition. Student growth and understanding of the course concepts and material is the measure of success of the effectiveness of the
course transformations, and is reflected in relative grading outcomes as well as quality of discussions in online forums or the classroom, which will be further discussed in the SE analysis.

Course grade results act as a feedback loop to both students, regarding their understanding and performance, and instructors, regarding overall student performance and any significant trends or deficiencies. This is especially relevant to courses being taught for the first time, as this information is particularly helpful in evaluating course design, material and media effectiveness, and student satisfaction. Another mechanism of feedback employed in many university classrooms is course evaluation assessments, which allow students to anonymously provide feedback regarding the course and the instructor. Both forms of feedback are valuable in balancing or correcting the course, material or instruction, which is discussed further in the SE Analysis.

3. Systems Engineering Analysis

With a strong definition and supporting discussion of the system goal, scope, and components, we present a robust analysis from four perspectives of SE. These four traditions are described as: Systems Thinking; Cybernetic Operations / Mathematical Analysis; Component-Whole Relationships; and Project Management.

3.1 Systems Thinking (SE1)

The Systems Thinking model is a metaphoric use of the principles of engineering systems and systems dynamics, and can be seen as a “casual” synonym for a global, high-level analysis of a complex phenomenon (Caldwell, 2009). From this perspective, there is less focus on quantitative or mathematical aspects, and more emphasis on relationships and social / environmental factors. SE1 is often used to describe or analyze social behaviours, non-complex systems, or even to describe a complex system in non-technical terms (Caldwell, 2009). By defining the course in terms of a system (see Section 2 above), we have essentially completed an analysis from the SE1 perspective.

3.2 Cybernetics and Operations Mathematical Analysis (SE2)

The second perspective of SE is rooted in mathematical modelling of a system. This tradition is strongly quantitative, and seeks to define and quantify variables, constraints, parameters, and objectives (Caldwell, 2009). The question of how to define and measure success is difficult to answer and is often called the “criterion problem” (Hartnett, 1979). Being able to define success is a critical factor in designing a hybrid learning course and while some measures of success may appear arbitrarily qualitative, such as rating a professor or course work fair to excellent, other measures of success, such as student enrollment numbers and student performance ratings are quantitative. From this perspective, this SE2 analysis focuses on the cybernetics of quantifying success in this hybrid learning environment.

The student feedback loops depicted in figure 1, and briefly outlined in section 2.4, provide one measure of success for the course, especially during the first times the course is taught. The summative feedback discussed in the system definition is obtained via evaluation forms for the course. In the SE4 analysis, we discuss how this information may be used for the management of the course as it retaught to new audiences, or how it can be used more dynamically towards optimization of the third distribution of inputs. After students complete the course, a quantitative evaluation of the population performance could be collected and analyzed for trends. Instructors may be interested in performance differences of the first two distributions of inputs, which could affect the third distribution in future offerings of the course.

The internal feedback loop within the course process can be used in this same manner to gauge understanding of the students. This may be a more realistic measure of success, considering that the variation of the second distribution is not constant semester to semester. New inputs may influence how performance is rated, especially from the students’ perspectives. Plainly stated, success can be rated by semester rather than an average over numerous semesters. Because the existing feedback mechanism currently in the system of analysis is almost purely related to grades of assignments, there is an opportunity to include additional formal student feedback to understand changes in “success” during one term, thus creating a more sensitive formal feedback mechanism that can respond to specific events in a curriculum.
There are additional opportunities to evaluate not only course and instructor, but also specific aspects of course execution, when considering distributions of student location, experience, and contributions to peer learning. The physical distribution of students presents measures of communication, distance, and latencies that could be of value in studying effectiveness of hybrid learning environments and any changes therein due to different methods of communication and use of available technology.

### 3.3 Engineering Component-Whole Relationships (SE3)

SE3 emphasizes the importance of relationships between subsystems and between larger systems, and the implications of those relationships with respect to system integration. SE3 recognizes the need to consider factors outside the system of interest for more effective and efficient integration with other systems. A systems approach without considerations to component-whole relationships at higher and lower levels of analysis could lead to poor performance or even system failure. A visualization of this flavour of SE is shown in figure 2.

![Component-Whole Diagram](image)

Figure 2. A Component-Whole Diagram in a hybrid learning environment.

From an SE3 perspective, the course can be analysed with distribution interactions in mind, as well as the course itself as credit for individual students in their respective curricula. As mentioned throughout the system definition, the three distributions of students as inputs combine to create a wide range of potential student enrollment. In addition, there could be social aspects of the student distribution that are affected by the asynchronous communication of the first distribution. Cultural aspects of student expectations regarding lecture vs. case methods (the “third distribution”) can also affect how the course is managed.

Additionally, the role of the course in the curricula of different major programs is a factor to be considered by students, advisors, and instructors. The perceived importance of the material, presented in the course syllabus and reinforced throughout the course, can directly impact student performance and shared experience. Hence, it is important for the instructor to recognize the needs and expectations of students from multidisciplinary backgrounds with different levels of experience in order to design a successful and effective course system. This is further discussed in the SE4 analysis.

Another important point specifically relating to the second distribution from an SE3 perspective is the influence of the instructor on individual student views of other disciplines, and how this can affect team performance. Denton explicitly addresses team effectiveness and how to overcome ignorance or stereotyping of disciplines outside of one’s own practice (Denton, 1997). With respect to the course a socio-technical system, this point, though social in nature, has potentially significant impact on success of the individuals and the team as a whole.

### 3.4 Project Management (SE4)

The fourth perspective of SE represents management of projects from start to completion, and includes tools such as budget, risk and stakeholder analyses, timelines, and customer satisfaction (Caldwell, 2009). SE4
draws upon the high level of SE1, the quantitative measures collected and analysed in SE2, and the component-whole relationships of SE3 to build a management standard for running the course as a project, whether within one term, or as an ongoing program as the course is taught on a consistent basis.

Previously discussed points regarding feedback to the instructor provide a basis for an SE4 analysis, particularly with respect to the distribution of course materials and methods that affect peer contributions to student learning. The more autonomy instructors are given to design courses, the more this point becomes relevant to the success of the course. Instructors in hybrid learning environments may need to incorporate non-traditional factors into selection and design of course material, and provide multiple feedback mechanisms to effectively support and measure student understanding and success. These factors might include discussion forums that are easily accessible and understood by students, perhaps even with additional social enhancements, such as profiles, live chat capability, or agreement features. Another factor is the technical flexibility of the students themselves, who must, in a team environment, employ methods of collaboration outside the course technology platform. As discussed in SE2 and SE3, diversity of experiences in the second distribution also play an important role in course design to ensure that the material is relevant and useful to students enrolled in the course.

Distributed teams present additional challenges to learning environments, in which team meetings and group-level writing assignments are particularly challenging to schedule. Anticipating the inherent delays in this kind of system, the course design must provide suitable time for team assignments to increase the probability of collaboration (and hence success). Furthermore, the design should not impose brittle organizational or technology requirements upon teams that interfere with team performance. Authors have noted, even before the current era of social media, that system design should be local and allow users to design their own information environments (Davenport, 1994; Jones & Jasek, 1998). This suggests that students should be able to create customized environments within their teams to satisfy team and individual preferences for communication and productivity. The variety of possibilities for pathwork in distributed teams with respect to information and communication technologies (ICTs) can enhance communication of context and shared understanding (Garrett & Caldwell, 2011)

4. Results: Effectiveness and Merit of Processes and Outcomes

In the practice of Systems Engineering, it is important not only to define the components, interactions, and management, but also a measure of “Does this system do what it was intended to do?” To address this need, measures of the effectiveness of the course design (system) can adopt the SE2 perspective. Measures of effectiveness, as well as conceptual organization of those measures into figures of merit, represent concepts of our intended goals for system performance, and what metrics help to capture those goals in relevant and meaningful ways (Buede, 2000; Sindiy, DeLaurentis, and Caldwell, 2010). Appropriate definitions of figures of merit for the hybrid course processes, as well as course learning outcomes, are useful in measuring success of the course guiding decisions for course management (from an SE4 perspective).

Feedback from course and instructor evaluations could create a valuable quantitative dataset that can help determine student satisfaction, assuming that the forms are (1) designed to assess perceived value of the course from the student’s perspective and (2) are administered at meaningful frequencies (more than once) and points in time (not only at the end of a semester) to enable mid-semester adjustments. Should these requirements not be met, the evaluations would yield little to no value in measuring course “success” based on instructor’s experience. Assessment outcomes in the form of grades can also be used in an SE4 approach to help guide course design, and any changes therein. Both of these feedback mechanisms can provide valuable information with which to manage course communications using quantitative metrics. A great example of this type of feedback is featured in (Caldwell, 1993), in which “fast feedback” tools were used to assess instruction environment and techniques.

Additional definition and elaboration of measures of effectiveness and figures of merit can further strengthen course-level program management, through collection of information about technical aspects of communication and teamwork, as well as more frequent student feedback assessments to confirm the effectiveness of materials and project assignments. The “fast feedback” tools could be useful in collecting perceptions and preferences of students, but may not represent outcome measures of skills gained.
5. **Further Considerations**

As illustrated throughout this paper, SE can be a useful tool in representing and improving team approaches in higher education. However, this methodology of defining and analysing a process as a system can also be applied in other settings that require distributed or multidisciplinary teams. Using a SE approach can help facilitate further research on both real-world modifications of the course, as well as describe elements of systems engineering in a more accessible way across the distributions of student experience, domain discipline, and location. Further research is also indicated to enable the design of software simulations of the knowledge transfer, team coordination, and information flow processes regarding learning new material and integrating hybrid teams.

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**References**


