Paper ID #44595

Implementation of a Semester-long, Real-World Problem Project in a Critical Systems Thinking Course

Prof. Mary E. Johnson Ph.D., Purdue University at West Lafayette (PPI)

Mary E. Johnson is a Professor and Associate Head for Graduate Studies and Research in the School of Aviation and Transportation Technology (SATT) at Purdue University in West Lafayette, Indiana. She earned her BS, MS and PhD in Industrial Engineering from UTArlington

Mr. Gustavo Adolfo Sanchez, Purdue University at West Lafayette (PPI)

Gustavo is a Ph.D. student in the School of Aviation and Transportation Technology at Purdue University. He began his PhD study in Aviation Technology and Management at Purdue University in 2022, under the supervision of Dr. Mary E Johnson. Gustavo earned an M.S. in Aviation and Aerospace Management from Purdue University and an M.S. in Aeronautical Military Sciences from Colombian Air University. He has experience as a helicopter pilot, safety manager, and undergraduate program director at the Colombian Air Force Academy. His research interests include helicopter operations, advanced air mobility, and aviation safety.

Implementation of a Semester-long, Real-World Problem Project in a Critical Systems Thinking Course

Gustavo A. Sanchez & Mary E. Johnson
School of Aviation and Transportation Technology
Purdue University
West Lafayette, Indiana 47906
Email: sancheg@purdue.edu; mejohnson@purdue.edu

Introduction

In a world that is becoming increasingly interconnected and dynamic, the Critical Systems Thinking (CST) course is designed to provide graduate students with tools to understand complex systems and develop solutions for real-life problems. The graduate course attracts students from aviation, technology, and engineering undergraduate programs. The CST focuses on enhancing graduate-level students' cognitive ability to solve complex problems by exposing the students to a comprehensive understanding of systems thinking through theoretical and practical knowledge, and equipping students with the necessary skills to assess and analyze complex systems using systems thinking theory. The students in this course possess a diverse range of experiences, most of which are academic rather than professional.

In a previous version of the CST course in this program, students read textbooks and cases that led to discussions of the systems and archetypes. In 2017, the CST course adopted hands-on discovery activities (HODAs) to increase student engagement by providing different learning experiences. In 2020, due to the COVID-19 pandemic restrictions, the instructor changed the curriculum by reducing the number of HODAs and including a semester-long project where students proposed solutions to complex problems in aviation using CST skills. In 2022, CST students used systems thinking techniques on a semester-long project to analyze the shortage of aviation mechanics in the U.S. The students worked in small teams that proposed solutions from a variety of perspectives.

This paper analyzes the goals, preparation, and execution of semester-long real-life aviation problems in a CST course. The analysis of the in-class activities includes understanding the students' and instructors' perspectives regarding the advantages and disadvantages of combining Problem-Based Learning (PBL) and CST methodologies in higher education. This paper aims to shed light on the effectiveness of PBL as a teaching methodology and its potential for improving student learning outcomes during a CST course.

Literature review

Aviation systems are complex systems. Systems thinking theories, tools, and techniques may be used to identify stakeholders' relationships, internal dynamics, and processes. The Critical System Thinking (CST) approach clarifies the relationship of interdependence between the components of a system and emphasizes that a system is greater than the sum of its parts[1]. CST was introduced during the 1980s as an alternative to the traditional *hard* systems thinking approach[2]. This *soft* approach provides a tool for intervening and solving complex societal problems, bridging the gap between social theory and practice[3].

As a methodological tool, CST helps to incorporate different perspectives and analyze a problem while identifying the relationships and dependencies among the stakeholders in the system[4]. After its introduction in operational research, the CST has been used in various fields, such as healthcare[5], management[6], engineering[7], and education[8]. Within the CST framework, the systems archetypes represent models or patterns that help to explain complex systems, providing a visual representation of the dynamics within the system[9].

The students used the systems thinking approach during the CST course to analyze the aviation mechanics shortage from different perspectives. In higher education, Problem-Based Learning (PBL) emphasizes using real-life problems to create learning experiences[10]. With PBL, students perform tasks similar to the ones they may encounter while working in the industry and develop leadership, communication, and problem-solving skills[11]. Unlike traditional teaching methods, PBL fosters higher-order analytical skills, and teachers and students are responsible for the learning process[12]. Several studies have explored the benefits of using PBL and CST in the context of higher education. PBL and CST in a graduate-level veterinary course was used to develop systems thinking skills and foster student collaboration and teamwork[13]. In STEM higher education, a study[14] describes one of the benefits of using PBL as one tool to develop students' problem-solving skills and higher-order cognitive skills. In the book *Reshaping Engineering Education*,[15] the authors use PBL to address real-world problems and social needs as the foundation for the learning process.

Critical Systems Thinking (CST) Course

The Critical Systems Thinking (CST) course is an elective in a graduate-level aviation and aerospace management program at Purdue University. The CST course introduces the students to the systems thinking approach to solving problems. During the CST course, the instructor uses case studies, directed readings, and systems theory to improve students' critical thinking skills. The CST course encourages students to use an interdisciplinary approach to solving technological and social problems by fostering teamwork and proposing innovative and sustainable solutions. The CST course objectives encompass using the systems thinking methodology to frame complex issues in the aviation industry. Weekly readings from *The Fifth Discipline Fieldbook*[16] prepared the students to understand the concepts related to systems theory and mental models.

The CST course was modified in 2017 to introduce hands-on discovery activities (HODAs). Students used HODAs to experience, explore, and analyze systems in a friendly, game-oriented classroom environment[17]. In 2020, the use of HODAs was limited due to pandemic restrictions on interactions in the classroom. Therefore, a real-life, open-ended, semester-long, complex problem group project was added to explore the use of system archetypes and models. The instructor selected team members from different programs and cultural backgrounds to simulate a realistic working environment[18]. In 2022, the semester-long project teams developed models for understanding an aviation problem from differing perspectives. The semester-long projects addressed the U.S.'s projected aviation maintenance worker shortage of 800,000 people over the next two decades from different perspectives.

Course Organization

The CST course is designed for 16 weeks of classes to cover the materials established on the syllabus. The CST course had five components 1. Lectures, 2. HODAs, 3. Writing assignments, 4. Exams, and 5. Semester-long project. During the first part of the course, the students were introduced to concepts such as critical thinking, systems archetypes thinking, and mental models in the lectures. At the beginning of the semester, the students were introduced to the final project requirements, and teams were established with students from diverse cultural and educational backgrounds. During the first eight weeks, in-lecture HODAs were used to model systems archetypes; short essays and system models were required elements of the writing assignments to apply the archetypes to aviation or aerospace.

Case studies and HODAs in class were developed during two weeks of the CST course to improve leadership, teamwork, and communication skills. A midterm examination covered the concepts related to systems archetypes and mental models described in the textbook used in this course. The midterm examination allowed the instructor to evaluate the students' comprehension of the concepts covered during the CST course. At the end of the course, the students presented their system archetypes to the class and proposed solutions to the aviation mechanics shortage using a written report and presentation in class. Table 1 summarizes the weekly plan used during the CST course.

Table 1. CST Course - Weekly Timeline.

Week	***Lecture Topics***	***In Class Activities***
1 to 8	Introduction to CST and Systems Archetypes	Hands-on activities and written assignments; Start the project
9 to 12	Mental Models	Directed readings and discussions; Project updates
13 to 14	Case Studies and Personal Mastery	Communication skills, teamwork, and leadership; Project updates
15 - 16	Final Project	Presentations, feedback form, and written report

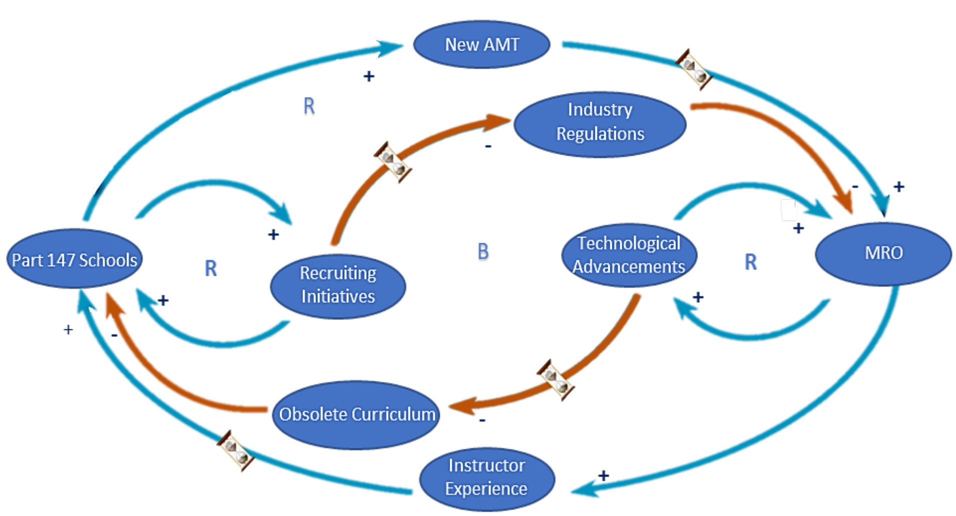
Final Project Description

Due to the Covid-19 pandemic restrictions, the instructor modified the curriculum in 2020, including a written final report and presentation about a semester-long project on a current aviation issue[19]. Since that time, the students now work in small teams to apply systems theory during their process to propose solutions to complex problems in aviation. During the CST course, teams present their intermediate results to receive feedback from the instructor and their peers. The final report starts with an executive summary and an introduction to the topic from the team’s perspective. After the literature review section, the paper presents discussions of systems thinking in educational contexts and the current problem – the shortage of aviation mechanics in the U.S. The final report presents the team’s findings from previous researchers on the shortage of aviation mechanics and identifies the regulations, stakeholders, and key variables to explain the system's behavior. The instructor provides the students with a template that includes a detailed description of the deliverables and the timeline for submissions during the semester. The final report template includes this table of contents:

1. *Executive Summary*
2. *Introduction*
3. *Summary of Literature Review on Systems Thinking*
4. *Background on the FAA Certificated Mechanic Shortage*
5. *The Key Variables in the Story*
6. *System Archetypes*
7. *Breakthroughs for this Model*
8. *Team Discussion*
9. *Conclusion*
10. *References*

During the CST course, the students explored how different elements within a system influence each other, leading to a holistic understanding of the aviation mechanics shortage. Each team took a different perspective from the other teams: 1) Mechanics, 2) Airlines, 3) Aircraft manufacturers, 4) Federal Aviation Administration (FAA), 5) Part 147 schools, and 6) Maintenance Repairing and Overhaul (MRO) companies. The team used modeling and archetypes to visualize the dynamics within the aviation mechanic shortage from their perspective. The students examined how educational policies, technological advancements, economic factors, and labor market trends collectively impacted the availability of training and retaining aviation mechanics. Figure 1 presents one visualization of the shortage of aviation mechanics from the mechanics perspective. During the project update sessions, each team presented their preliminary findings and received feedback in class. The course culminated with a final presentation where each team presented their findings and submitted a written report. In this process, each team demonstrated their understanding of systems thinking and their ability to apply CST concepts to real-life challenges in aviation.

Figure 1. Student’s Aviation Mechanics Shortage – System Archetype Diagram.



Student Perspective

This section provides perspectives of one graduate student in terms of working in a diverse team, topics covered during the course, and using semester-long projects during the CST course. Integrating diverse viewpoints and skill sets enhances collective intelligence for the graduate student, enabling the teams to better understand complex problems. In the aviation industry, working on projects with people from different countries is an expected situation. The CST course gives the students an opportunity to improve their communication and leadership skills in a controlled class environment while proposing solutions to a real-life project. The language barriers represent an additional challenge the students overcome by applying mental models such as the "*Ladder of Inference*"[16]. Exploring the same problem from different perspectives provides opportunities to understand the usefulness of the systems archetypes by experiencing the benefits of using multidisciplinary approaches for problem-solving purposes.

Using PBL, combined with the CST course, proved to be a beneficial learning approach. Systems theory concepts applied to PBL experiences foster a shared responsibility for knowledge acquisition and application, which deepens their engagement and solidifies their learning experience. Developing critical system thinking skills in a graduate-level course is a challenging endeavor. The HODAs were fundamental in achieving the CST course goals and developing systems thinking skills. The project updates represented one of the most valuable experiences in this course. Providing and receiving feedback from other students increases student engagement during the CST course and reinforces the aviation industry's collaborative spirit. In addition to questions after each presentation, the feedback form in Figure 2 was used by the team members to provide and receive feedback after presenting project updates.

Figure 2. Feedback Form – Project Update.

CRITICAL SYSTEMS THINKING COURSE / CST-640

Feedback Form - 2022 Project Update Presentation

Presenters' Names: ____

Reviewer's Name: ________________________

1. *What is the main idea of this project?*
2. *Do the identified variables make sense to you? What questions do you have?*
3. *What part(s) of the system archetype make sense to you? What questions do you have?*
4. *List some notable metrics proposed for breakthrough for the model proposed.*
5. *What do you feel is the primary contribution of THIS presentation to YOUR body of knowledge in Critical System Thinking or mechanical shortage in aviation?*

This is an example of one of the student's responses, providing feedback to one team after a project update presentation using the feedback form:

> *"FAA regulations have a significant impact on the ability of schools to train new aviation mechanics. However, there are initiatives to solve the problem. It is necessary to continue studying the effects of each of them from the perspective of the FAA. The analysis carried out by the team members is very important because they allowed me to understand the problem from the FAA perspective by applying the concepts covered in this course".*

Instructor Perspective

It is my experience in this course that while the course material is interesting on its own, the students seem to be more engaged when the material is applied to current, pressing issues in their discipline. There are individual and team activities. The reading materials provide the basis and structure for learning more about application of system thinking and dynamics, and are supported by lectures. The HODAs are selected to bring to life the system archetypes as we progress through the materials from relatively simple archetypes toward more complex archetypes. The HODAs may be individual activities during class, or team activities during class, depending on the archetype. The written assignments are prepared by each of the students to discuss the archetype, describe an example of that archetype in aviation or aerospace, and develop a diagram that reflects the systems dynamics of that archetype. Students present their archetypes during class for feedback and discussion of the concepts. The HODAs provide the scaffolding to develop understanding and skills to better support a team problem-based learning experience.

While the HODAs are relatively simple in terms of diagrams, the semester long project focuses on a larger, more complex problem that is facing the industry. The differing perspectives to understanding and attempting to solve a complex problem with no established solution stretches the learning experience that results in models that may not have been possible without the reading, HODAs, and simpler models developed throughout the course. In addition, the students gain an appreciation for identifying perspectives, understanding other views and experiences, and developing a model of a complex problem. The presentations of the semester long projects are interesting in terms of student development of the problem and the model, and in terms of the transformation in the level of communication skills, questions asked by the other students, and teamwork skills.

Conclusions

The semester-long project offered in the CST course aims to provide students with an immersive learning experience that closely simulates real-life problem-solving scenarios and industry work environments. The project is designed to equip students with practical skills and knowledge that are highly relevant to the aviation industry, thereby better preparing them for their professional careers. Using PBL during a CST course offers an alternative for improving students' leadership, communication, and teamwork skills.

PBL fosters an innovative approach to solving problems associated with aviation in the context of a graduate-level course where real-world experience is limited. Diverse teams are an important component of the project. Diverse experiences and educational perspectives provide exposure to approaches that may or may not be familiar to the team members.

References

[1] R. D. Arnold, and J. P. Wade, “A Definition of Systems Thinking: A Systems Approach,” *Procedia Computer Science*, vol. 44, pp. 669–678, n.d.2015. https://doi.org/10.1016/j.procs.2015.03.050

[2] M. C. Jackson, “The origins and nature of critical systems thinking,” *Systems Practice*, vol. *4*, ED. 2, pp. 131–149, Apr. 1991. https://doi.org/10.1007/BF01068246

[3] M. C. Jackson, “Critical systems thinking and practice,” *European Journal of Operational Research*, vol. 128, ED. 2, pp. 233–244, Jan. 2001. https://doi.org/10.1016/S0377-2217(00)00067-9

[4] Y. Bentley, G. Cao, and B. Lehaney, “The Application of Critical Systems Thinking to Enhance the Effectiveness of a University Information System,” *Systemic Practice and Action Research*, vol. 26, ED. 5, pp. 451–465, Oct. 2012. https://doi.org/10.1007/s11213-012-9253-9

[5] G. Nicholas, S. Sharma, M. Walton, M. Hepi, and S. Hide, “Critical collaboration model: an enhanced model to support public health collaboration,” *Health Promotion International*, vol. 37, Jun. 2021. https://doi.org/10.1093/heapro/daab075

[6] R. Chowdhury, *Systems Thinking for Management Consultants Introducing Holistic Flexibility*, Springer Singapore. 2019.

[7] M.A. Rodenas, and M.C. Jackson, “Lessons for systems engineering from the Segura River reclamation project: A critical systems thinking analysis,” *Systems Research and Behavioral Science*, vol. 38, ED. 3, pp. 368–376, Mar. 2021. https://doi.org/10.1002/sres.2789

[8] R. Muñiz, M. Woolsey, S. Keffer, and S. Barragán, “A Systematic Review of Critical Systems Thinking (CST) in the Education Field: Gaps and Opportunities for Systemic Change Toward Racial Equity,” *International Journal of Educational Reform*, vol 32, ED. 3, pp. 251–268, Mar. 2023. https://doi.org/10.1177/10567879231157372

[9] E. Garnsey, “Exploring a critical systems perspective,” *Innovation: The European Journal of Social Science Research*, vol. 6, pp. 229–256, Jan. 1993. https://doi.org/10.1080/13511610.1993.9968350

[10] J. R. Savery, “Overview of Problem-Based Learning: Definitions and Distinctions,” *The Interdisciplinary Journal of Problem-Based Learning*, vol. 1, pp. 1-9, May, 2006. https://doi.org/10.7771/1541-5015.1002

[11] J. Bigelow, “Using Problem-Based learning to develop skills in solving unstructured problems,” *Journal of Management Education*, vol. 28 pp. 591–609, Oct. 2004. https://doi.org/10.1177/1052562903257310

[12] T. Barrett and S. Moore, *New approaches to problem-based learning: revitalising your practice in higher education*. Routledge, 2011.

[13] T.J. Irabor, O. Kambere-Kavulikirwa, M. Humbel, T, Manfredini, and N. Antoine-Moussiaux, Exploring the Potential of a Serious Game Framework in Developing Systems-Thinking Skills. *Journal of Veterinary Medical Education,* vol. 3, pp. 38-49, Aug. 2023. https://doi.org/10.3138/jvme-2023-0048

[14] U. Zoller, “From Algorithmic Science Teaching to “Know” to Research-Based Transformative Inter-Transdisciplinary Learning to “Think”: Problem Solving in the STES/STEM and Sustainability Contexts,” *In Insights from Research in Science Teaching and Learning,* vol. 1, pp. 153–168, Jun. 2016. Springer International Publishing. https://doi.org/10.1007/978-3-319-20074-3_11

[15] F. Habbal, A. Kolmos, R.G. Hadgraft, J.E. Holgaard, and K. Reda, “Teaching and Learning Strategies”. *In: Reshaping Engineering Education. Springer, Singapore, 2024.* https://doi.org/10.1007/978-981-99-5873-3_6

[16] P.M. Senge, A. Kleiner, C. Roberts, R.B. Ross, and B.J. Smith, *The fifth discipline fieldbook*. New York, NY: Doubleday Dell Publishing Group, 1994.

[17] Y. Feng, L.E. Holtaway, M.E. Johnson, and S.R. Condon, "Student perspective on using hands-on discovery activities in a critical systems thinking course", *in ASEE Annual Conference & Exposition. Tampa, FL, USA, June 15-19, 2019*. http://peer.asee.org/33299

[18] S. Gupta, M. E. Johnson, and J. Wang, "Motivation and Impact of Diverse Student Teams in Graduate Projects". *in ASEE Illinois-Indiana Section Conference, Anderson, IN, USA, April, 2022.* https://peer.asee.org/42135

[19] M. E. Johnson, and Y. Feng, "Connecting Critical System Thinking Principles with Hands-On Discovery Activities". *in ASEE Virtual Annual Conference Content Access, Virtual Conference, July,2021.* https://peer.asee.org/36837