Student Perspectives on Using Hands-on Discovery Activities in a Critical Systems Thinking Course

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Student Led Paper

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**Introduction**

At a large midwestern university, students in an aviation and aerospace engineering technology program may choose to take a graduate course on Critical Systems Thinking (CST). This course explores the application of critical systems thinking to complex problems in aviation and aerospace industries. The course materials use systems theory textbooks and case studies that explore the practical applications of critical systems thinking for aviation and aerospace industries and for other complex socio-technical issues. Two course objectives are to understand how to frame complex issues in terms of systems thinking methodologies, and to evaluate options and alternative solutions to complex problems.

As an important component of student learning, hands-on discovery activities (HODA) are used to illustrate CST principles and models which allows students to experience the behavior of systems and to better understand CST. The hands-on discovery activities are at first led by the instructor. The students form teams and then lead the learning experiences for the class as the semester progresses. Getting to lead a game, or being assigned to do so, engages the students on an entirely different level as opposed to being a participant. The student team leaders are now peer-teachers that must be able to lead the activities and probe the students for understanding of the models and system behavior demonstrated in the activities. This paper presents a roadmap for using hands-on discovery activities that may better engage students of the current generation. The paper presents the learning objectives, two of the successful activities, student perspectives on leading and learning, and lessons learned on how to implement these activities in the classroom.

**Literature Review**

Systems thinking [1], [2], [3] is applied to understand complex system behavior in many settings such as tourism [4], nursing [5] and education [6]. There continue to be publications seeking to understand and define systems thinking [1], [7], [8]. Systems thinking may help reveal the roots of complex behaviors and enhance understanding [1], [3], [8]. With understanding, we may be able to better predict the behaviors of complex systems and make adjustments to improve the system outcomes. The need for systems thinking stretches beyond science and engineering. Systems thinkers are needed to prepare for an increasingly complex and globalized “systems of systems” future that will have ripple effects throughout the world [8].

A top-down development of K-12 mathematics curriculum incorporated systems thinking by including it in the grade 11 mathematics classes, the students analyze systems from different social and science domains to gain systems thinking abilities [9]. The course focuses on introducing various methods of diagramming system, such as stock-flow diagrams, causal loop diagram, and equation style notations, to students. An uncommon aspect of the curriculum is that...
students are encouraged to question and discuss the underlying assumptions and limitations used in process modeling [9]. A 1994 study was reported to show that students can learn systems thinking skills very quickly and were using causal loop diagrams after only one hour of instruction [9]. The main result of the study is that “the variable ‘teacher’ has by far the greatest influence upon explaining the differences between the pre-test and post-test achievements” [9]. According to this paper, the teacher has more influence on student performance than factors studied of student age, gender, computer experience, or mathematics grade [9].

An in-depth review of using games as a pedagogical tool in engineering classes found that 1) researchers consider the linkages between learning objectives and other contextual variables when studying games used in learning, and 2) “for instructors, results support the merit of non-digital games as resource-effective means of transforming engineering learning processes, and suggest that teaching processes will likely change based on the game’s intended learning contribution” [10]. In a study with data from 205 interviews with senior systems engineers at 10 companies primarily in the aerospace industry sector, “there is consensus on primary mechanisms that enable or obstruct systems thinking development in engineers” [12].

Experiential learning, such as work and life experiences, is one of the three mechanisms that enable systems thinking development, and was the top ranked mechanism with 40% or more of the interviewees including work or life experiences [12]. The second mechanism was individual characteristics and traits, listed as: “thinking broadly, curiosity, questioning, open-minded, communication, tolerance for uncertainty, strong interpersonal skills, and thinking outside the box”; the third mechanism is a “supportive environment” [12].

**Critical Systems Thinking Course**

Critical Systems Thinking (CST) is a course in the MS Aviation and Aerospace Management program in the college serving Engineering Technology majors at a midwestern university that explores the application of critical systems thinking to complex problems and as applied to aviation and aerospace industries. Using systems theory and case studies, students investigate alternative solutions to complex problems with global impact. In 2017, this graduate level course was transformed from a 100% lecture/discussion format to now include 40% of the course dedicated to hands-on discovery activities (HODA). HODAs give graduate students a chance to explore the application of critical systems thinking methodologies to complex problems, especially in the aviation and aerospace industry. Students develop critical thinking skills that embrace holistic perspectives by learning systems theory and implementing hands-on discovery activities. The HODAs are one way to provide students a supportive environment for experiential learning. There are six learning objectives for the class:

1. Understand how to frame complex issues in terms of systems thinking methodologies.
2. Able to synthesize information from multiple sources to develop a comprehensive strategy.
3. Critically evaluate options and alternative solutions to complex problems.
4. Develop an appreciation for key aviation industry concerns as visionary industry leaders.
5. Develop an eye to see and seize opportunities for innovation within industry.
In this paper, the hands-on activities were designed for the students to immerse themselves into a system, participate in the system, and experience the behavior of an operating system first-hand. These activities are sometimes thought of as games; however, these games were connected to the first three of the learning objectives. The students led games and participated in games. The team that led the games was responsible for obtaining structured written feedback from the participants, developing their own reflective feedback and developing a full written report of the game.

**Roadmap for Using Hands-on Discovery Activities (HODA) in a CST Course**

In 2017, Hands-on Discovery Activities (HODA) were incorporated into an existing CST course that had not been taught since 2014. This gap was convenient because few students in the program remembered the way the class had been taught formerly, and therefore, the instructor had the opportunity to reset student expectations of the course with little or no resistance. To transform the course, the instructor decided to incorporate hands-on, non-digital activities as a way to enhance student engagement in critical systems thinking concepts and theories. The course focused on lectures, case studies, and small scale HODAs. The HODAs needed to be able to be completed during a 75-minute class period.

Hands-on activities or non-digital games have been shown to be effective in engineering courses [10]. This CST course is in an aviation and aerospace management program in an engineering technology college. In this course, the HODA were developed from two primary sources: *The Systems Thinking Playbook* [11], and the instructor’s experience in facilitating process improvement teams and developing training. The lecture contents were primarily developed using *Thinking in Systems: A Primer* [8]. These two text resources had previously been used in other systems engineering courses at a midwestern university, but not both at the graduate level or for engineering technology courses. The structured hands-on discovery activities (HODA) were selected to engage students in the topics in the course description and learning objectives. The timing and selection of the HODA was intended to coincide with the lecture topics. Ideally, the students would be able to practice what they learn in one class session by experiencing a related HODA in a following class session. In this way, the HODAs and lectures would reinforce each other.

In this course design, the students provided feedback on the student-led activities. This feedback would be used to improve the HODA selection and timing to reinforce the connections between the lectures and the hands-on discovery activities. Figure 1 shows the roadmap for using hands-on discovery activities in this CST course.

Structured hands-on discovery activities are an essential part of this CST course. All of the HODAs are non-digital games. The initial HODAs are led by the instructor and are interspersed in early class sessions. As part of the course, students formed groups to lead specific HODA for the other students. The HODA are peer-to-peer interactions where the roles of specific students change between participant and leader throughout the semester. To lead the discovery activities in class, the student teams were instructed to follow the five steps shown in Figure 1. In addition, the students developed and agreed to a simple list of rules for participating in all the HODA; the primary rule is to listen to the leaders and play the game. Each of the five steps is expanded in
the next sections of the paper. Assessment of student learning was primarily through the student reflections presented in the student written feedback and student leader report.

Step 1. Prepare before the class.

As the leaders of the HODA, the team members study the materials thoroughly before the class to become familiar with the rules, steps, and outcomes of the game, and to procure and prepare all of the equipment used in the game. The team practices the HODA to be sure that the leaders know the steps and the timing so that they may conduct the HODA smoothly. In order to guide the students more systematically during the Step 3 Debrief the HODA, the student team frames a model that can describe the system being demonstrated, analyzes the model, and proposes some questions that could facilitate student discussions during the debrief. Five basic questions were given to the teams to be discussed at the end of the HODA. In addition, the teams each developed five more questions based on the HODA and the system being explored. The five basic questions for the debrief are:

- What is the tie to the theory?
- What went well? What didn’t go so well?
- What changes to the HODA would make it more realistic or better emulate a real world situation: rules changes, equipment changes, context changes?
- What are the connections to the aviation and aerospace industry?
- What does the causal loop diagram look like for this system?

Figure 1: Roadmap for using hands-on discovery activities
Step 2. Lead the HODA in class.

On the day of the HODA, the student leaders of the HODA take control of the classroom. Based on their preparations, all is anticipated to go as planned. The participants listen to the leaders and to the best of their abilities, follow the instructions. The idea is that the leaders explain the rules clearly, show how to use the equipment as necessary, and lead the game. One crucial task of the team in this step is to inspire students to find alternative solutions and try these solutions in the system. The student team leaders need to observe and record patterns of behavior, changes in the systems, results, and outcomes.

Step 3. Debrief the HODA.

The student team is responsible for leading the debriefing part at the end of the activity. Students share their observations, thoughts, and comments about the game. As students listen to others in the group, some notice that the viewpoints are not shared equally by all, even though they all were doing the same activity in the same place under the same rules. Asking students about the tie to theory encourages students to seek a better understanding of system behaviors demonstrated in the activities, and make connections to the lecture materials.

Step 4. Collect each student’s feedback.

Each student is required to write and submit a feedback report based on the questions provided by the leading team and the discussion in the debriefing step. Students practice CST principles by identifying the essential elements of a system, recognizing the interconnections between different system components, understanding the existing feedback in a system, and drawing a system diagram. A critical section of the report is for each participant to identify ways this HODA may be experienced in an aviation or aerospace environment.

Step 5. Write a report.

The leading team collects each student’s feedback report and writes a final report using an outline developed by the instructor and modified using student inputs. The report is comprised of a cover sheet, executive summary, table of contents, introduction and explanation of the hands-on discovery activity, debrief, observations from the team leader perspective, feedback and ties to critical systems thinking, suggestions for improvements, connections to aviation, bibliography, and appendix containing student participant feedback.

Examples of HODAs

*The Systems Thinking Playbook* [11] by Sweeney and Meadows contains 30 activities designed to allow participants the feeling of working within different system archetypes. Many of the hands on discovery activities (HODAs) in this course, such as Dog Biscuits & See Saws and Moon Balls [11], bring into the forefront some of the numerous benefits of system games. The activities demonstrate the operation of system structures in a simplistic format and thereby aid in understanding complex systems [11]. HODAs are incalculably beneficial to the participants as they provide the opportunities to test a number of problem-solving strategies in a short span of
time, whereas large scale projects have reaction times of many months and the solutions require
time to implement. The participants gain experience processing the feedback from the
implemented solutions and how to improve what was once considered “the best way” to
accomplish a task. Through immersion into the HODA, the students experience a dynamic
system that they have previously only read about.

Two examples of HODAs are highlighted in this section that focus on two systems thinking
activity demonstrating balancing loops. The dog biscuit is the fulcrum and a ruler is the see saw.
Using rules governing the activity, teams attempt to load the see saw with objects while keeping
the see saw balanced. As objects are loaded onto the ruler, balancing the ruler on the dog biscuit
becomes more difficult. In the CST game Moon Ball [11], participants are able to see and
experience causal loop diagrams first-hand. Moon Ball gives the unique chance for the proposed
best plan to be edited in real time demonstrating to participants the behavior of complex, living
systems in action. HODAs are able to impart a parallel learning process of team problem solving,
team learning within systems, and experiencing complex behaviors within basic systems. The
student perspectives in this paper are from the reports from the student authors.

Dog Biscuits & See Saws

In Dog Biscuits & See Saws [11], a dog biscuit is placed on a table in front of a team of three
students. In class, there would be multiple teams of three students. The students balance the ruler
across the biscuit, then try to pile as many objects as possible onto the ruler in 60 seconds
without the ruler touching the table. Two team members are workers, and the third one is an
observer. Before each trial, each team has one minute to discuss their strategies. After each trial,
the resulting number of objects loaded onto the ruler and the strategy each group applied are
recorded.

Part of the HODA is for each student to develop a system diagram based on their perspective.
The system diagram in Figure 2 is a student’s system diagram based on the experiences in the
HODA and on the theories presented by Meadows [8].

![Student System Diagram Using Links and Loops for a Balancing Loop HODA.](image)
In the HODA final report, students provided feedback based on their perspectives using a conversational and informal tone. Leaders and participants prepared their perspectives. The writing of the perspectives provides an opportunity for leaders to reflect on the learning experience. One example of a student leader perspective from the Dog Biscuits & See Saws activity is:

“Having an effective strategy in place for any anomaly in operating procedure is extremely beneficial to overall success. I feel that this game brought to light the sensitivity of a system to change, even when introducing a new facet as small as a paperclip into a system. The system must then acclimate to the foreign object or invading species and that takes time. This game impressed upon me the reality that change does not happen overnight (I knew this prior but the magnitude of the statement did not dawn on me until I sat down to digest the events that took place).”

One example of a participant’s feedback is:

“The game was an attempt to have the participants focus on how a simple system such as a see-saw and ruler can be extrapolated into a bigger picture of a highly complex system. In learning any new skill such as drawing a stock and flow representation of an event, one must start small in order to learn the fundamentals of a process before launching into a more tangled, convoluted system.”

A very important data point to support the effectiveness of this game is that 91% of the student participants recognized the system model illustrated in the HODA. Of all the eleven participants in class, ten students recognized that the Dog Biscuits & See Saws was a balancing loop and identified the delay in the system which could lead to oscillation. Some students connected the HODA with the physical balancing systems that exist in the aviation industry. For example,

“The first thing that comes to mind in relation to aerospace is the process of balancing a compressor rotor when vibrations and oscillations are present. Overcorrecting the balancing process on one side can offset the balance on the other, and vice versa. Additionally, this process requires the input of engineering to inflow information regarding the necessary changes to make when improper balancing occurs.”

Some students thought about the connection to aviation from the perspective of how their team worked together to maintain the balance. For example,

“The trial we did that the players should keep their eyes closed is just like the way pilots and ATC make their communication in air. For common circumstances, the pilots in air aren’t aware of the position information of other aircraft and they don’t even know the actions they made at larger scope (for a commercial airplane in cruising attitude) just like the players in the game. And the observer was giving the instructions and monitored the outcome of the reaction and tried to improve the situation by adjusting the actions of players just like ATC.”
It is important to note that this student was a general aviation pilot of small, relatively inexpensive, fixed wing aircraft, and that the systems available on-board are not usually the same as those available on the relatively more expensive aircraft used in commercial airlines or military operation.

Moon Ball

Moon Ball [11] is a group activity where 8-30 participants attempt to hit a ball as many times as possible while keeping it in the air for 2 minutes. The group has 3 tries to complete the activity, each with 2 minutes to plan and then 2 minutes to implement the plan. The score is the number of legal hits during each round of the activity. There were different rules for the Moon Ball presented by the student leaders. The first three trials, the basic rules from the text were used [11]. The student leaders added 3 trials where the team members were required to remain silent during the game (after the 2 minute discussion during the planning).

Part of the HODA is for each student to develop a system diagram based on their perspective. The system diagram in Figure 3 is a student’s system diagram based on their experiences in the activity. Figure 3 shows a stock and flow diagram of a causal loop, while Figure 2 shows a links and loops diagram for a balancing loop.

![Figure 3: Student System Diagram Using Stocks and Flows for the Moon Ball HODA](image)

The Moon Ball scores (the maximum number of hits during each trial) were:

1) 31
2) 36
3) 12
4) 42 (silent after the planning period)
5) 42 (silent after the planning period)
6) 22 (silent after the planning period).

One may notice that trials 3 and 6 have very different scores than the other four trials. This was primarily due to the students deciding to try a radically different strategy during trials 3 and 6.
Student reflections were written by both the leaders of the game and the participants. The student reflections focused on the relationship to CST theory and the bigger picture of game elements. The student team leaders noted in their report that the HODA was a system with delay and feedback, involved dynamic learning, and highlighted the role of communication in the system.

One participating student wrote:

“Besides being glaringly un-athletic, I feel that the Moon Ball game brought to light the importance of routine and procedures. While they may seem mundane and slow, having a predetermined order to hitting the ball in game helped us in the respect of ensuring we knew what to expect. If people are comfortable with their knowledge and what to do/when to do it, they are more likely to be successful and nerves will not be an issue. Performance anxiety for this was a serious concern and seeing that in every system it is present to some degree is important. Not all individuals in a system are confident and able to meet the mark every time.”

A description of how the game enhanced group dynamics and systems thinking from the student leader team is:

“Another systems element that was possible to observe during the game is that when players were allowed to discuss new strategies, they focused on ways to improve their performance for the future, rather than discussion what went wrong during the last trial. They kept creating new ideas to improve their future performance. This shows how system dynamics models explore possible futures and ask "what if" questions.”

“During the game, there weren't any leaders who gave orders to the other players. Instead, everyone in the group was able to contribute with their ideas of how to improve their performance. The fact that all of the players felt they were in an environment where they could just throw their ideas, make it possible to observe a real team working together. We were able to observe how all of the pieces of the system (players) came together as one strong unit to achieve the same objective. Also, the feedback stage of the game went well because everyone was able to express how they felt during the game and the different connections to systems thinking they were able to observe.”

The student leader team described how this system is similar to those in aviation:

“This game portrays a situation where the beach ball can be considered the airplane and the players can be thought of as ATC, ground crew, check in crews at airports, luggage handling, etc. The objective of the players during the game was to keep that ball in the air as long as possible, while increasing their hit scores. This situation can be seen in aviation where ATC needs to make sure that aircrafts stay safely in the air; ground crews and check in crews at airports need to make sure that processes run smoothly so that the airplane leaves on time.”

“During the game, it was possible to observe how if any of the players was not ready to receive the ball either by not being at their position or delayed with some other
distraction, the whole game would be affected and the score would have to be restarted. This is a situation that occurs in aviation because if there is not precise communication between ATC and pilots, then it is not safe for the plane to stay in the air; this is the same situation where players need to communicate between each other to maintain the ball in the air. Also, if any of the ground crews, check-in crews or luggage handling personnel gets delayed in their work, it will affect the departure time of the aircrafts. Therefore, this system is a group of units that need to work together and be connected through communication in order to reach their goals. This same situation happens in airports where a lot of different functions need to communicate and work together to make sure that airplanes depart on time.”

**Lessons Learned**

HODA provides students a chance to “feel” and “experience” the CST principles and models that they have learned in class from lectures and from reading the texts. The schedule of the HODAs should coincide with the lecture. The ideal condition is that the HODA which students lead and conduct in one class could reinforce the lecture contents they learned in the previous class.

The debriefing part is a good opportunity for students to discuss and share their perspectives about the HODAs. Students could analyze the HODAs with the CST principle and extrapolate the simple system into a bigger picture of a highly complex system. When students build a connection between the CST principles in the HODA and the aviation and aerospace industries, this helps students to understand the aviation and aerospace industry more comprehensively. This connection would be used to guide student discussions on applications of CST in aviation and aerospace industries. Leading debriefings also helps students to be better prepared to be successful in aviation and aerospace careers. In the Moon Ball student leader report, a summary of lessons learned illustrates the effectiveness of the activities as a way to learn CST:

“The feedback from the participants indicated that many lessons were learned from the Moon Ball game. Routines and procedures are important so people know what to expect, and are therefore more likely to be successful. Good discussion and planning helps progress, and working with a group is helpful for new ideas. It is difficult to work within an interdependent system because constant adjustments must be made to realize a common goal. Communication is critical to success, and it includes more than just speech; eye contact and body movement are important. This is exemplified by the fact that the best scores were obtained during “no talking” trials.

An important lesson learned is that a system can still perform its task even if certain components are not as efficient as others. A resilient system can operate with a consensus and a common goal. It is important to test and try new approaches, and the participants must speak up and not be afraid to give ideas and suggestions. Finally, creating a strategy and executing it are completely different accomplishments.”

The numerous games led by the instructor during class were not always understood by the students to be HODAs. Requiring a written report would emphasize the CST principles and the implicit connections to aviation and aerospace. The report would be each student’s answers to
the five basic questions used in the debrief presented earlier in this paper. In addition, the inclusion of specific games that are tied explicitly to aviation and aerospace may enhance the learning experiences, especially in the earlier HODAs.

**Future Research**

More research is needed to explore and understand critical systems thinking pedagogies using hands-on discovery activities. This paper provides student perspectives, lessons learned, and a roadmap for linking the activities to a CST course. Student reflections and discussions are helpful in assessing learning. Both the instructor and the students learned more about their own understanding of critical system thinking applications to the aviation and aerospace industry, and the connections to the systems thinking theories and archetypes. This learning was assessed by student reflections presented in the written participant feedback and the written leader reports. Based on these reflections, the instructor could get a feel for the level of learning and applications to aviation and aerospace. Next steps might include a combination of qualitative and quantitative approaches to assessing the use of hands-on discovery activities. These qualitative and quantitative assessments may help future researchers understand the pedagogy and benefits of hands-on discovery activities.

Once a formal method for assessing CST is available, the hands-on discovery activities can be compared to other learning techniques, such as lectures and discussions. One consideration is that the course described in this paper is often the students’ first exposure to CST. Future research could follow up with the students who participated in the hands-on discovery activities to find out how the students applied the knowledge in subsequent classes, work, or life.

**Conclusion**

As an important component of student learning, hands-on discovery activities were used in a graduate level course in aviation and aerospace management to illustrate CST principles and models, and to allow students to experience the behavior of systems. Real life working experiences and other life experiences are a key to enabling systems thinking development, but not always a practical way to develop knowledge and skills in a classroom environment. As a potential substitute or augmentation to real life and work experiences, hands-on discovery activities appear to be a viable substitute that enhances student learning of CST.

The discussion and analyses in the student-led debriefing give students a chance to think about the CST principles behind the HODAs. A roadmap for applying hands-on discovery activities is presented, as well as two examples of hands-on activities that illustrate systems thinking principles. Feedback from student leaders and participants demonstrates that hands-on discovery activities could reinforce the lectures and successfully help students to build the connections between the CST principles and the systems in the aviation and aerospace industries. Connections to aviation and aerospace were varied and included propulsion systems, interactions between pilots and air traffic controllers, and ground handling procedures, among others. Such connections would help students to understand the aviation and aerospace industries more comprehensively. Future work could focus on a mixed methods approach to assessing the hands-on discovery activities.
References


