Connecting Critical System Thinking Principles with Hands-On Discovery Activities

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Introduction

Aviation and aerospace engineering programs may benefit their students by offering a course on Critical System Thinking (CST). The Master of Science in Aviation and Aerospace Management at Purdue University offers a CST course as an elective. The objectives of this course are to understand the basic principles of CST, to explore how to apply critical system thinking to complex systems in aviation and aerospace industries, and to evaluate potential solutions to complex issues. Traditional teaching methods in a CST course may include lectures, modeling, and case studies. Research has indicated that real-life experiences and other life experiences are crucial to enable students to learn system thinking principles [1]. Traditional teaching methods in a classroom environment may not provide these experiences. Hands-on discovery activities (HODAs), as a potential substitute for real-life experiences, may provide students an opportunity to enhance CST learning in the classroom [2]. By leading and participating in hands-on discovery activities in class, students may experience the CST principles they were exposed to in lectures and case studies. One key principle of this CST course design is that the lectures and structured hands-on activities should reinforce each other.

This paper presents the system archetypes and principles that are included in the CST course, as well as a list of HODAs that are used to illustrate system archetypes and principles. The paper discusses the objectives, preparation, and implementation of one HODA used in the CST course. The learning outcomes are assessed through students' feedback reports that include a discussion of the hands-on activity, a depiction of the system archetype, connections to industry. In addition, this paper presents changes made to the HODA activities due to the COVID-19 safe practices guidelines.

Literature Review

Systems thinking [3], [4], [5] emphasizes the understanding of interdependence among parts in a complex system. The principles and systems tools are widely used in different areas, such as engineering, social sciences, tourism [6], nursing [7], and education [2], [8]. Systems thinking helps to identify the behavior and the interactions of a complex system, and to expand the range of potential solutions to complex problems [9].

A previous study interviewed 205 senior system engineers to explore their opinions about the mechanism of systems thinking development [1]. The three most important mechanisms that could help to improve systems thinking are work and life experiences, individual characteristics and traits, and environment [1]. Work and life experiences may not be a basis for common ground among university students, as those that have little or no outside work experience in aviation or aerospace have difficulty relating to discussions brought forth by those students who do have these types of experiences. Without common ground, these experiences may be difficult to discuss with students. Because work and life experiences are important to systems thinking, a set of hands-on discovery activities would be a substitute that improves the learning of critical systems thinking [2]. A roadmap showing how to include HODAs into a graduate level CST course is provided [2]. One key principle of the CST course design is that the arrangement of the HODAs needs to reinforce and amplify the lecture topics [2]. The aim of the basic structure of the course is to provide specific theory and applications prior to doing the HODA that illustrates that same theory and application [2].

Systems Thinking Course

A graduate level course in a Master of Science program in aviation and aerospace management (MSAAM) at Purdue University includes a course titled “Critical Systems Thinking”. This course is one of many electives that may be taken as part of the graduate program. The course was developed over a decade ago, and after a three-year hiatus in offering the course, it was recently redeveloped in 2017. The course explores application of CST to complex problems.

The course originally was primarily a lecture and discussion format that featured books such as *The Lexus and the Olive Tree* by Thomas L. Friedman [13] and articles in the news and recent journals. This particular book focuses on globalization and the complexities that accompany it. While aviation and aerospace industries are global in nature, there was a need to develop critical systems thinking skills in understanding the nature of systems, systems behavior models, and system diagrams. The redeveloped course format augments the lecture and discussion format by adding active learning through hands-on activities designed to enact systems archetypes and behaviors [2]. In the fall 2019 semester, the primary textbook was *The Fifth Discipline Fieldbook* by Peter Senge, et al. [11], and supplemented by *Thinking in Systems: a Primer* by Donella Meadows [1], and *The Systems Thinking Playbook* by Linda Booth Sweeney and Dennis Meadows [10]. The course has no prerequisites and is suitable for students with STEM and non-STEM backgrounds.

The first objective of the course is to understand how to frame complex issues in terms of systems thinking methodologies. The previous version of the course did not include diagramming using systems methods such as causal loops and graphs of behavior over time. The redeveloped course includes these methods [2]. One of the ways this course objective is accomplished is the use of hands-on activities discovery activities to set up and operate a system, observe its behavior, model the system, and then relate the system to aviation and aerospace systems [2]. The hands-on discovery activities (HODA) are selected by the instructor. In the early stages of the course, the instructor conducts several HODAs. The students form teams to conduct HODAs and are assigned HODAs on the class schedule, shown in Table 1. Hands-on discovery activities (HODA) are selected by the instructor. HODAs in table 1 in all capital letters are from *The Systems Thinking Playbook*. The instructor also uses ideas for HODAs based on *Fast Cycle Time* [12], and those from the instructor’s experiences in industry.

Procedure

The overall steps in this study are to design the course topics and HODAs to coincide, enable teams to conduct the HODAs, use information found in student feedback reports to evaluate the effectiveness of the HODAs, and compare the 2019 course results to the 2017 course results for this HODA. The effectiveness of the HODA is based on 1) the number of students that recognized the underlying system in the HODA; 2) the number of students that used appropriate systems tools to describe the system; and 3) the number of students that connected the underlying systems thinking principles with the aviation industry. One HODA was selected for this study as one of the authors was on the student team that led the HODA. The students in this class typically come from a wide array of undergraduate majors such as professional flight, airline or airport management, aeronautical engineering technology, business administration fields, mechanical engineering, aerospace engineering, several computing science fields, among others. Demographic details of the students (e.g. gender, undergraduate major, graduate level) are not presented due to small sample size (11in 2017 and 14 in 2019) and subsequent ease of identifying specific students involved. For example, there may be only one male student with a BS in aerospace engineering or only two female students with a BS in professional flight. Students in this class were all enrolled in the MSAAM program.

One Hands-on Discovery Activity – Dog Biscuits & See Saws

Objectives

This CST course requires students to analyze systems using the system tools, such as archetypes, system diagrams, and causal loops. Before using the system tools, students need to learn to identify the underlying system behavior and the correct system structure. The ability to detect the existing systems would be a big challenge for students having little relevant life or work experience. The systems thinking game called "Dog Biscuits & See Saws" [10] is one of the HODAs that could provide a way to gain experience in system behavior and archetypes by conducting the HODA during class. The balancing system archetype [11] may be explored by using Dog Biscuits & See Saws.

The Dog Biscuits & See Saws HODA uses common materials to provide students an engaging, playful, and physical model of a balancing system. By exploring the behavior of the balancing system, students may grow their awareness of archetypes present in systems that can be sensed and felt. The students may develop the ability to detect and identify the presence of the balancing system structure. Students could also have a better understanding about the elements and operating philosophy of the balancing system, as well as the role of delays in complex systems.

Preparation

Students are assigned to teams to lead a HODA during the semester. Each student team has at least two weeks to prepare to lead the game in class. The instructor provides each team the guideline materials from *The Systems Thinking Playbook: Exercises to stretch and build learning and systems thinking capabilities* [10] by Sweeney and Meadows. The materials explain the objectives of the HODA, how to run the HODA, and how to lead the debriefing session after the HODA. Students are asked to play the game and are encouraged to possibly revise the rules or add some suitable content based on their understanding of the HODA and from their own life experiences.

Table 1. Course weekly plan and HODAs used in the course.

Week	Lecture Topics	Assignments Due (Related to Archetypes)	Systems Thinking Hands-on Activities Archetypes Modeled by Students
1	CST. Mind grooves.	Get textbook *The Fifth Discipline Fieldbook* and follow reading plan.	Games led by instructor on mind grooving.
2	Systems zoo and you (*Thinking in Systems*)	Description of an aviation or aerospace system that has illustrates a reinforcing loop and draw the system diagram. Class discussion	Games led by instructor on viewpoints (CIRCLES IN THE AIR and MIND GROOVING). Previous years' projects
3	Systems archetypes	Use videos and case studies from *The Fifth Discipline Fieldbook* to develop models using Archetype 2 and Archetype 3. Class discussion	Games led by instructor (9 dots/4 lines; Simple Instructions; not from textbooks).
4	Applying systems archetypes	Description of an aviation or aerospace system that has illustrates Archetype 1 and draw the system diagram. Class discussion	Form Groups. Choose the game.
5	Archetype family tree; systems gridlock	Description of an aviation or aerospace system that has illustrates Archetype 3 and draw the system diagram. Class discussion	Get the materials together. Start practicing those games.
6	Systems gridlock	Description of an aviation or aerospace system that has illustrates Archetype 4 and draw the system diagram. Class discussion	MOON BALL. Archetype 1 Fixes That Backfire.
7	Process mapping	Description of an aviation or aerospace system that has illustrates Archetype 5 and draw the system diagram. Class discussion	DOG BISCUITS & SEE SAWS. Balancing Loop, and Archetype 1 Fixes That Backfire
8	Personal mastery	Other assignments; not Archetypes	COMMUNITY MAZE. Archetype 1 Fixes That Backfire
9	Mental models	Other assignments; not Archetypes	AVALANCHE. Archetype 1 Fixes That Backfire
10	Mental models	Other assignments; not Archetypes	5 EASY PIECES. Archetype 5 Accidental Adversaries
11	Skillful discussion	Other assignments; not Archetypes	GROUP JUGGLE. Archetype 2 Limits to Growth, and Archetype 4 Tragedy of the Commons
12	Arenas of practice	Other assignments; not Archetypes	CANDY GAME (*Fast Cycle Time*). Archetype 2 Limits to Growth
13	Arenas of practice.	Watch "Water at Ayole" film and study the case in *The Fifth Discipline Fieldbook* to develop complex systems models in groups	Enriched models beyond the basic 5 archetypes; in groups. Discuss roles of Archetype 3 Shifting the Burden, traps and how to find solutions. Emphasize 5 whys.
14/15	Presentations	Project presentations	
16	Final Exam		

Note. All HODAs led by student teams are from *The Systems Thinking Playbook* [10], except for the Candy Game which is adapted by the instructor from a beanbag toss game in *Fast Cycle Time: How to Align Purpose, Strategy, and Structure for Speed* [12].

To illustrate the use of the HODAs, one example of a balancing system is presented in this paper. This particular activity is a way to gain experience in balancing systems and a way to understand systems with human and mechanical components.

Details on Dog Biscuits & See Saws are found in [10]. In the CST course, the student leaders prepare identical game kits for each team with one ruler, a dog biscuit or similar object, a manila file folder, and some small objects (usually a mix of coins and paper clips). The dog biscuit acts as a fulcrum and each team balances the ruler across the biscuit. Each team has three students.

Two students are "workers" and try to pile as many objects on the ruler as possible in 60 seconds while keeping the ruler balanced. The other student is an "observer" whose role is to watch the interactions between the workers and the system, and to tell "workers" what to do when delays are introduced into the system. After each try, each team discusses the system based on their experience and observations. Figure 1 is a demonstration of the HODA using an eraser instead of a dog biscuit. Any fulcrum, such as a candy bar, eraser, or cookie, could be used.

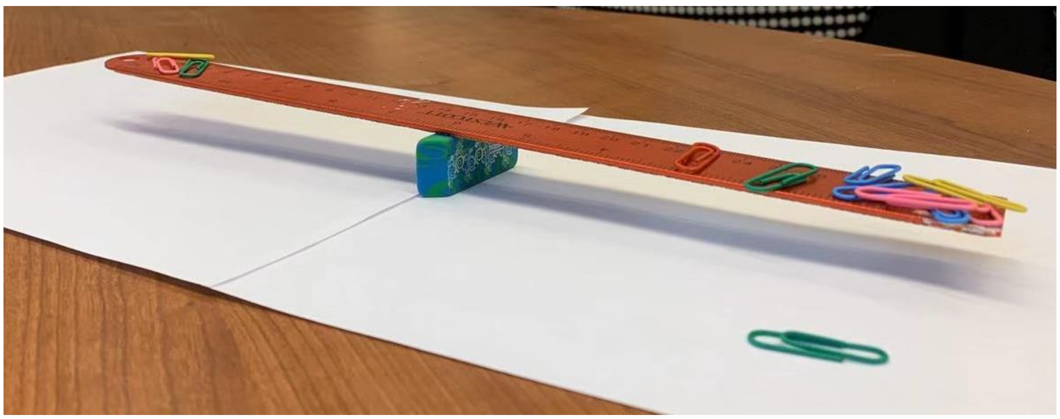

Figure 1. A Demonstration of Dog Biscuits & See Saws

In the class in 2017, the team leading the HODA adopted five trials. The first four are in [10]; the last one is a modification. The rules for each trial are:

1. Team members could communicate with each other, and there is no barrier in the system.
2. A manila folder is placed between two workers as a barrier so that each worker could only see his or her side of the ruler.
3. The folder is still between the two workers. The two workers are not allowed to talk.
4. Workers close their eyes and make movements by following the observer's directions.
5. All barriers are removed. There is no folder between two workers. The teammates may observe and communicate with each other.

The last trial is not included in the original HODA as detailed in [10]. The student team's idea to add the last trial is to enhance student's awareness of the impact of delay on the performance of a system by experiencing the switch from the hardest system to the easiest system.

Implementation

Dog Biscuits & See Saws is scheduled for week 7 of a 16-week course, as shown in Table 1. The arrangement of the HODA coincides with the schedule of lecture topics so that it occurs after introduction of the balancing system and archetypes. The HODA is led by three students. Students leading the HODA helps to create a safe learning environment. Students may feel more comfortable to explore their behaviors and share their perspectives, if the HODA and the debrief are led by their classmates. Leading the game is an opportunity for the team leaders to enhance the leadership and management skills. It is important to emphasize to the HODA leaders that the students doing the HODA are not to be told which archetype(s) are applicable. The students should be allowed to experience the systems archetypes and think for themselves which archetype fits best. While it would be faster and easier if students were told which archetypes are present in the HODA, it is important at the graduate level that the students be allowed to use higher orders of thinking to identify the archetypes, discuss options with the class members, and present their evidence as to which archetypes fit best.

Debriefing

The debriefing aims to inspire students to extract experience and observations related to systems thinking from the HODA and practice the systems tools they learn from CST course by explaining their experience and observations. The original debriefing has four steps [10]: “tell the story; graph the variables; make the system visible; and identify the lessons” (pp.7-9). An additional step, which is to explore the connection between the HODA and the aviation industry, is included in the CST course by the instructor. In the CST course, the debriefing includes in-class debriefing and an after-class full report.

In-class debriefing

The in-class debriefing led by the team leaders is conducted immediately after the HODA. The leaders guide students to discuss their observations and reflections on the system structure existing in the HODA using a series of steps.

Step 1. Tell the story.

The first step is guided by the questions “what happened in the HODA”, “what do you think went well during the HODA” and “what do you think did not going well”. Each team is encouraged to share their strategies applied in the HODA, their experience, and observations.

Step 2. Graph the variables and make the system visible.

In this step, each team draws a graph to show the numbers of objects they successfully put on the ruler during each try. The behavior over time diagram helps students to detect patterns and identify the underlying system based on the patterns [10]. This is an important step toward system identification. The diagram helps students in explaining and understanding the impact of various elements, such as delay or good/bad strategies, on the performance of the balancing system. The students then use the behavior graph to develop a system diagram.

Step 3. Identify the lessons.

The student leaders ask questions such as “what is the tie to the theory”, “what is the system in the HODA”, and “what do you feel about working in the system”. This is the step where students attempt to connect the HODA with the CST principles.

Step 4. Explore the connections to the aviation industry.

As most of the students in the CST class come from the graduate program in aviation management, the instructor encourages students to expand the application of the CST to the aviation and aerospace industry. In this step, students are asked to share some examples in the aviation industry which they believe are connected to the HODA. The connection could be similar system structure, similar system barriers, or the style of teamwork. Students are encouraged to share any examples they come up during the HODA. For example, most students see the connection between weight and balance for aircraft loading and the Dog Biscuits & See Saws. More in-depth thought may lead students to draw connections to the cooperation required in the national airspace system such as the interactions between air traffic control and pilots.

After-class report

Each student is required to follow a template to report their insights and reflections on the HODA. The template requires each student to answer a series of questions which are similar to the topics covered in the in-class debrief. Students draw a diagram to describe the cause and effect relationships between system elements.

When the revised course first opened in 2017, students were asked to draw the diagram using the causal loop. The instructor then found out that some students had trouble using the causal loop as the causal loop needs students to have a thorough understanding of the system they want to describe. The instructor changed to use the archetype templates found in *The Fifth Discipline Fieldbook* [11] in the 2018 and 2019. The archetype templates help guide students to describe systems and fit the behavior to an archetype. The students identify the different elements of the system by themselves. Due one week after the HODA, the students turn in their after-class reports to the student leaders of the HODA. The student leaders write a final report based on their own observations and the reports of the participants.

Evaluation Based on Students Feedback

To evaluate the effectiveness of the use of HODAs in the CST class, the authors chose to look at student feedback. Student feedback includes the participants after-class report and the student leaders’ final report. The performance of the HODA is evaluated 1) the number of students that recognized the underlying system in the HODA; 2) the number of students that used appropriate systems tools to describe the system; and 3) the number of students that connected the underlying systems thinking principles with the aviation industry.

Recognized the balancing system

When answering the question about "ties to the theory", 10 of the 11 students (91%) in 2017 identified this system as a balancing system. In 2019, 13 out 14 students (93%) identified this as a balancing system. Some students mentioned that the balancing of the ruler helped to visualize the increase and decrease of the gap between the target and desired level.

Appropriate tools to describe the system

Figure 2 is a causal loop drawn by the team leaders in 2017. Many students, especially those who were new to systems thinking, found that it was hard to describe a system using the causal loop methods described in [9]. These methods focus on stocks and flows. Students needed to figure out which elements should be included in the loop and which elements should be excluded. Students also needed to identify the connections between different elements along with the direction of the flows. Students with limited practical experience in flow systems struggled to develop these models [2]. In 2017, 5 students out of 11 (45%) were able to produce a causal system diagram representing the system.

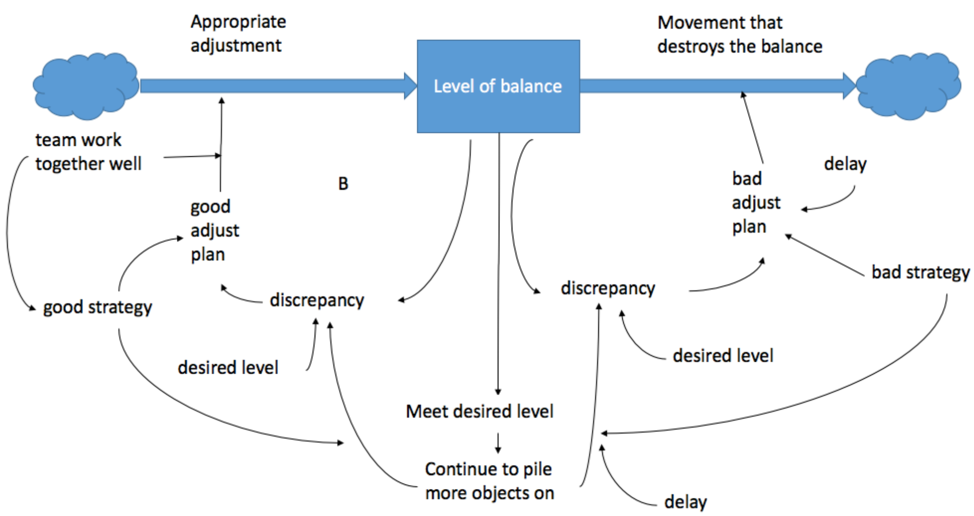

Figure 2: Student Causal System Diagram with Feedback Loops for the HODA

To address this problem, the instructor started with causal loops, then enhanced the system archetypes in the 2018 course to include both [9] and [11]. In 2019, the instructor heavily used the archetype templates [11]. Students are encouraged to refer to templates when they describe different systems in terms of behavior, components, and flow. Figure 3 is an archetype drawn by one of the authors for the same HODA, as a compilation of models shown in the student reports. The students frequently identified Archetype 1 Fixes That Backfire [11] as the underlying system. In 2019, 13 out of 14 (93%) students used the archetype template correctly. The archetype templates are more straightforward and help guide the students to identify the necessary system elements and links.

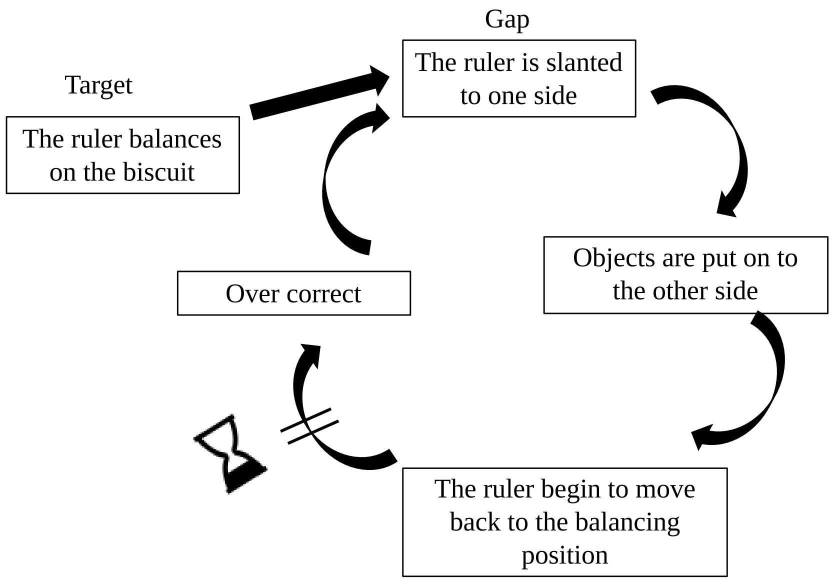

Figure 3. Balancing System Archetype 1 to Describe Behavior in the HODA.

Different kinds of barriers are introduced into the HODA during the second, third, and fourth trials. Most of the students linked the barriers to the introduction of a delay in a balancing system. For instance, some students mentioned in their after-class report that larger the delay is in the system, the larger oscillation the ruler would be from the target.

As during the in-class debriefing, each team listed the number of objects they piled on the ruler in each try. Some teams did quite well even when there was a big barrier in the system, while some other teams could not even put one object on the ruler successfully. To explain the differences, students discussed the different strategies they used to deal with the barriers. In the debriefing reports, five of the 11 students in 2017 wrote how effective strategies could eliminate the impact of delay on a balancing system. In 2019, 8 of the 14 students discussed potential strategies to eliminate the impact of a delay on the system.

Connections to the aviation industry

In class discussions about the connections of the balancing system to the aviation industry is a good opportunity for participants to apply the system tools and principles into their major areas. Students were able to come up with some examples of the connections with the aviation industry during the in-class debriefing. In the reports, students explored more examples from different perspectives. In both 2017 and 2019, each of the students was able to link the balancing system to their knowledge and experiences in the aviation and aerospace industries. Some students talked about the physical balancing of a propeller or rotor, some students discussed the delay in the information feedback between pilots and air traffic control, and some students talked about the airport ground operations. Links to aircraft weight and balance (weight distribution effect on the location of center of gravity) and to the availability and pricing of airline tickets were also mentioned.

Students did not limit their discussions about what they learned from the HODA in the systems thinking topics. Some students talked about the importance of seeing the whole picture and considering the interdependencies between different parts in one system, both of which are important features of a “systems thinker” [8]. Some students discussed the importance of communications within the team members, as well as the team learning. One example of a team leader’s lessons learned is from one the authors:

> “This game related directly to learning: learning from their previous experience and from other teams. Before every trial, we would give participants some time to discuss their previous performance and ways to improve. They did improve their performance by doing so. For example, every team got a better score in the last trial compared to their first trial, which had the same limitations. This was because they accumulated experience and learned from previous trials.”

Discussion

Based on the data of the performance of the Dog Biscuits and See Saws activity, it is an appropriate HODA for students who are just beginning to learn systems thinking. The performance of the HODA is evaluated by 1) the number of students that recognized the underlying system in the HODA; 2) the number of students that used appropriate systems tools to describe the system; and 3) the number of students that connected the underlying systems thinking principles with the aviation industry. The aggregated data from 2017 and 2019 are summarized in Table 2. These data are not the course grades assigned for the HODA.

Table 2. Comparison of Assessment Data for a HODA (number of students successfully satisfied the criterion out of total number of students in the course)

Criteria	**2017**	**2019**	**Improvement**
Recognized the underlying system	10/11 (91%)	13/14 (93%)	negligible
Appropriate Systems Tools Used	5/11 (45%)	13/14 (93%)	48% point rise
Connection to aviation and aerospace industries	11/11 (100%)	14/14 (100%)	negligible

The rules, as well as the underlying systems thinking principles of this balancing system, are simple so that students could be engaged while not being confused by another highly complex system. Students also practiced identifying the delays that were introduced into the balancing system in later trials, as well as tried different strategies to reduce the impact of the delays on the performance of the system. Through this activity, students gained a real-life experience operating a balancing system and were able to connect this system to aviation and aerospace systems.

The discussion about the connections to the aviation and aerospace industry is a crucial part of the HODA. Students are encouraged to extrapolate the simple system in the HODA into a bigger picture of a highly complicated system in aviation. Students not only practiced the system principles and tools they learned, but also deepened their understanding about the industry. Students learned more than how to identify and depict the archetypes. In Dog Biscuits & See Saws discussions and reports, students also argued the importance of evaluating the system in a bigger picture and paying attention to the interactions among system parts. Students may become better “systems thinkers” by exploring HODAs.

Students leading the other students in these activities is an effective way to stimulate their initiative and motivation. However, the performance of the student leaders may impact the effect of the HODAs. The instructor may need to provide more details beyond the several guidelines about how to prepare and lead the HODA. In addition, the student teams should prepare the debriefing steps and questions at least two sessions before the HODA is played in class. This will allow time for feedback to the teams so they may improve prior to the class. More information on a suggested roadmap for using HODAs in class, and a discussion of student perspectives is found in [2].

In Fall 2020, the university made many changes due to the COVID-19 pandemic. First of all, in order to prepare for on-campus instruction to begin in August 2020, there were numerous measures put in place to protect the faculty, students, and staff. One of the measures was to reduce the number of people allowed in spaces; another measure was to sanitize surfaces, wash hands, and maintain social distance, among many other measures. These changes to university operations made it necessary to drastically change the course. The instructor reduced the number of HODAs played by selecting HODAs that could either be demonstrated with a limited number of students or conducted at six-foot distances. For example, the HODA of a balancing system in this paper was done in class as a demonstration using student participants; moon ball [10] and community maze [10] were not conducted because these HODAs require closer interactions. No HODAs were removed for being suspected of being ineffective. In 2020, the course was moved from a classroom with movable tables and chairs to a fixed tables and chair theater style classroom to ensure appropriate social distancing. In this 2020 version of dog biscuits and see saws, the instructor used a six foot long table at the front of the classroom with a student seated at each end and replaced the 12 inch ruler with a yard stick to make it easier for students to place objects on the see saw while staying more than six feet apart and to make it easier for students to see the action. The dog biscuit was replaced with a 2"x4"x4" block of wood to raise the fulcrum high enough to allow movement of the yardstick. The paper clips were replaced with an assortment of heavier items such as washers, fasteners, coins, and other objects.

To solve the problem of how to convey concepts without the use of many of the HODAs, the instructor added a semester-long project where students worked in teams to analyze a current industry issue to develop a systems diagram of links and causal relationships. The project selected by the instructor was the Boeing 737-800 MAX grounding. The teams each took a different perspective (e.g. engineering design, quality of training, among others). Each team drew initial systems diagrams by starting with a systems archetype sketch an sketches of behavior diagrams. Each team studied the available literature from academic, industry, and news sources to determine an archetype that fit the system under study. Each team prepared a report and presented their systems diagram to the class. The instructor provided a detailed report template with a description of the contents of each section of the report. The outline of the report included these sections:

Cover Page
Executive Summary
Table of Contents
Introduction
Summary of Literature Review on Systems Thinking

Background on the Boeing 737-800 MAX
Key Variables in the Story and Patterns Over Time
System Archetype
Breakthroughs for this Model
Team Discussion (team interactions, lessons learned and ladders of inference)
Summary
Conclusion
References
Appendix: presentation slides

In future semesters, the instructor plans to continue this type of project while pandemic restrictions are in place. The students commented informally with the instructor that they liked the project because it helped them apply what was learned in class to an industry relevant current problem. The discussions in class with each report presentation indicated that the students were very interested in each other's reports. There were students who asked the presenting teams questions on assumptions, sources of information, and specific causal loops in the diagrams. All of the student teams were able to develop the causal loop diagrams and explain the diagrams to the class. The instructor plans to consider rebalancing the number of HODAs and the size of the report after pandemic restrictions are lifted or revised. This study focused on one HODA. In future work, a more comprehensive evaluation of the effectiveness of each of the HODAs is recommended. The authors are discussing plans to use or modify some of the HODAs for possible inclusion in undergraduate aviation courses. If adapted to other disciplines, the authors encourage the instructors to actively connect the HODAs to behaviors and system diagrams in their discipline, whether this is instructor-led presentation or discussion, or student-led projects, discussions, or homework, or other active learning techniques.

Conclusion

The critical systems thinking class before 2017 used textbook and case studies. Students discussed systems based on the textbook and their own experiences. However, students' experiences may vary from each other. Some of the students may have a lot of related experience in their lives while some may have little. Beginning in 2017, the lectures and case studies were augmented by HODAs that were designed to provide students unique opportunities to feel and analyze the systems presented in lectures. The HODAs are also included to provide students with some common experiences on which to base discussions of the system principles.

One HODA was presented to provide details on conducting the activity, the report structure, and the performance assessment of the HODA as a learning tool. Student feedback from after-class reports and team leader's final reports was used to evaluate the performance of the HODA. Students recognized the balancing system in the HODA, and identified the delay in the system successfully. The number of students that could correctly depict the system improved from 45% to 93% when the instructor changed the tool from causal loops to archetype templates. The students were able to connect the system in the HODA to systems in aviation and aerospace. Therefore, this initial study of a HODA may indicate that HODAs may enhance students understanding about the systems thinking. Further study with more classes is needed to determine if other types of HODAs impact CST learning.

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