# Learning with Loops: Applying Feedback to Teaching System Dynamics to Undergraduates

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**Abstract**

This paper examines the effectiveness of different delivery methods for teaching System Dynamics to undergraduate engineering students. The paper presents the findings from a survey of the learning styles of the student population and compares that to the current breakdown of the course content by learning style. It presents the findings of several classroom assessment techniques that were conducted over the course of a semester to evaluate the effectiveness of the delivery methods utilized in the course. The classroom assessment techniques focused on an evaluation of the effectiveness of readings, lectures, labs, and case studies in teaching the material. Additionally, students participated in two self-confidence surveys mid-semester and at the end of the semester, which evaluated their confidence in their ability to accomplish the course objectives and the content delivery methods. Based on this evaluation, the paper presents recommendations for improving the content delivery methods of the course to take advantage of the student population's learning styles.

**Key Words:** System Dynamics, Undergraduate Education, Learning Styles, Classroom Assessment Techniques

## Introduction

This paper examines the effectiveness of different delivery methods for teaching System Dynamics to undergraduate engineering students. As System Dynamics is a new concept and methodology for these students it presents a unique challenge for both the students and the instructors. The paper presents the findings from a survey of the learning styles of the student population and compares that to the current breakdown of the course content by learning style. Additionally, it presents the findings of several classroom assessment techniques that were conducted over the course of a semester to evaluate the effectiveness of the delivery methods utilized in the course. Based on the alignment of the course content to the student population's learning styles and the evaluation of the delivery methods, the paper then presents recommendations for improvements to the course and continued evaluation to further incorporate the student feedback into the course.

## Background

System Dynamics is a methodology for studying the feedback relationships that create the dynamic behavior observed in complex systems (Sterman 2000). So, it would only be appropriate that a course that teaches System Dynamics incorporates feedback into the evaluation process to improve learning. One of the major concepts in System Dynamics is causal loop diagrams, which map causal relationships between variables in a system (Sterman 2000). Figure 1 presents a causal loop diagram of the feedback relationship this paper utilizes to improve the quality of learning in this course. As learning increase, the quality of course feedback should also increase. With improved course feedback, one can improve the teaching material and thus the learning experience of the students.

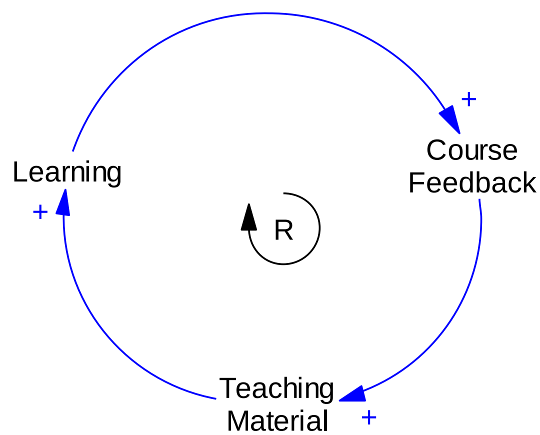


**Figure 1: Causal Loop Diagram of Classroom Feedback**

SM484 is a simulation elective in the Department of Systems Engineering at the United States Military Academy for the three majors that are offered to systems engineering, engineering management, and systems management cadets. This course teaches techniques in system dynamics thinking and analytical techniques to understand cause and effect relationships in complex systems. It includes the use of causal loop diagrams, stock and flow diagrams, and behavior overtime simulations. The course applies these concepts and principles to military, government, and business applications such as physical systems, human decision processes, and business processes (US Military Academy 2012). The course is comprised of 40 lessons, to include 16 computer simulation labs. It culminates with the completion of a semester long project that applies System Dynamics to a military related problem. Cadets present the results of their research in individual and team briefings throughout the semester. Also, cadets examine the ethical implications in the development and application of System Dynamics models and potential impacts of their models. The course objectives for SM484 are:

1. Apply system dynamics methodology to the solution of large scale, complex problems
2. Create models of dynamic systems, operations, and processes

3. Apply system dynamics modeling techniques to simulate behavior over time of systems, operations, and processes
4. Develop policies and controls to improve systems, operations, and processes
5. Interpret the output from continuous time simulations of system dynamics models as an aid for decision making
6. Recognize the ethical considerations involved with gathering and analyzing data, using quantitative models, validating assumptions, and reporting results

The students enrolled in SM484, System Dynamics Simulation, participated in the Felder-Solomon Index of Learning Styles as part of this research to determine their learning style. The index will be discussed in further detail in the literature review portion of this paper, but categorizes students along four dimensions of learning styles (Felder and Solomon 2001). Figure 2 presents the results of 41 student responses to the questionnaire. Students were either categorized at the ends of the spectrum or as neutral if there results did not place them into either end of the dimension. As shown, a majority of the students are Active, Sensing, Visual, and Sequential learners, which is consistent with previous surveys of engineering students. This breakdown provides a guide for how material should be delivered to this population of students and could assist in determining shortcomings in the current curriculum of the course.

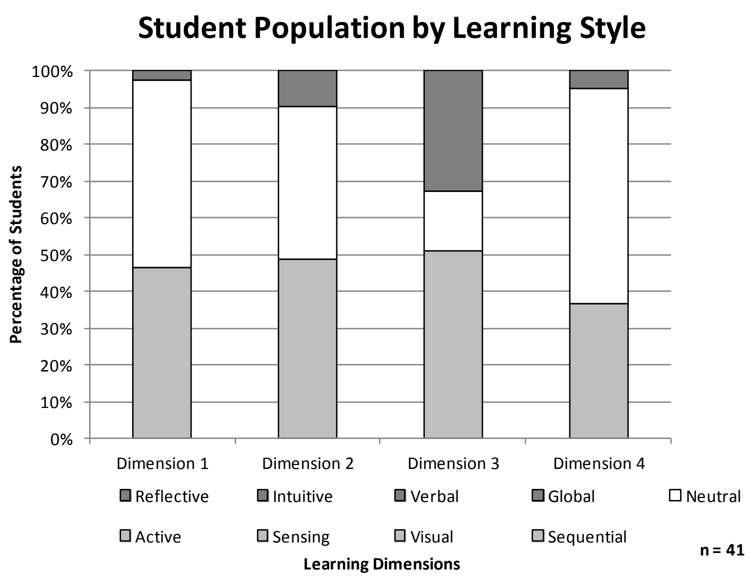


**Figure 2: Student Population Breakdown by Learning Style (Students 2011)**

A similar breakdown of the course material was developed to determine how the course content aligned with the student learning styles. The course includes a total of 120 hours of in class and out of class time, assuming that students put in two hours of out of class effort for every hour of class. The in class activities include lectures, labs, case studies, and additional time to work on the course project. The out of class activities include readings, homework, preparation for case studies, and the course project. Each of these activities is placed on the learning dimension scales for processing, perception, input, and understanding based on the definitions of these dimensions. Figure 3 presents the outcome of this analysis and shows that the course is generally well balanced between the two sides of each learning dimension.

However, the current breakdown of the course material does not align with the student population, which could lead to some difficulties in comprehension of the material.

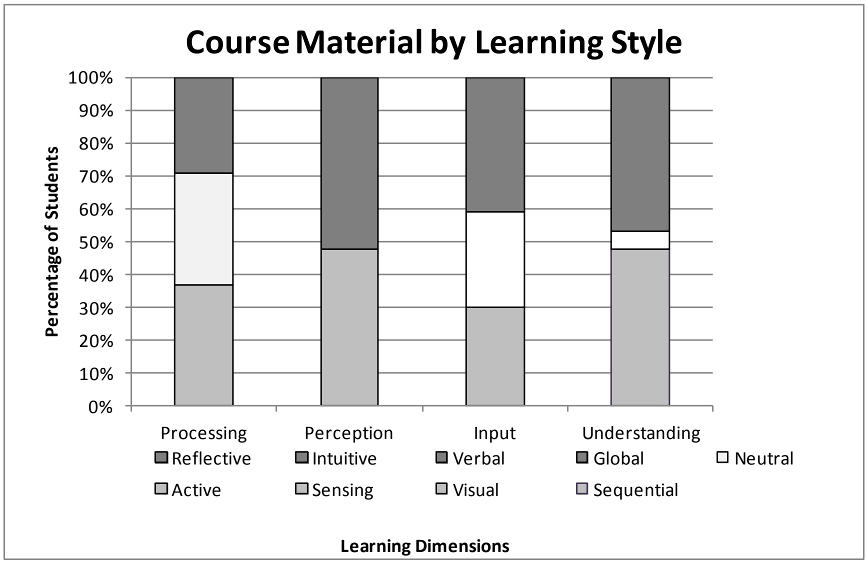


**Figure 3: Course Material by Learning Style**

## Literature Review

The literature review focuses on three areas that provide researcher for the methodology behind this paper: teaching system dynamics, learning styles, and classroom assessment techniques. As the paper focuses on teaching system dynamics, this portion of the literature review focuses on researching best practices or any lessons learned from teaching the material to students. The learning style portion of the review focuses on the Felder Silverman dimensions of learning and its application to engineering education. Finally, the classroom assessment technique portion of the review examines how these techniques can be utilized to determine the effectiveness of teaching methods and materials.

The literature for teaching System Dynamics to undergraduate students is relatively sparse and it appears that more work has been put into teaching System Dynamics in K-12 education. However, there were a few articles that specifically addressed System Dynamics education at the undergraduate level and some of the material from K-12 education applies regardless of the student population.

One of the areas of focus for literature regarding high school education is the incorporation of System Dynamics simulation in high school course outside of the traditional engineering discipline (Forrester 1992). System Dynamics is becoming well established in a few high schools throughout the country and being used to teach topics ranging from Biology to Shakespeare. The emphasis being on the development of simple structures that are visible across disciplines (Forrester 1992). One huge area of success is in the use of computer simulations to create a unique learning environment in which the teacher acts to guide groups of students through a simulation in the classroom. This enables students to learn from each other as they work in groups to create the simulation and allows them the flexibility to learn about the material outside of the classroom (Brown 1990). Additionally, the concepts of System Dynamics demonstrate to students how they can link different disciplines through the modeling and simulation process (Mandinach and Cline 1994). This encourages students to apply the methodology to areas they are interested in and increases participation in classes. Although these examples are from high school education, they show the impact System Dynamics and simulations can have on the educational experience for students. These lessons learned can be leveraged to improve the learning experience in undergraduate education.

Ossimitz summarized several approaches to teaching systems thinking and the resulting change in students' ability to apply systems thinking to a problem (2000). He provides an overview of how systems thinking can be taught and details how curricular-oriented efforts can be applied. The studies he summarized attempted to answer two questions: Can systems thinking be taught in an ordinary school environment? To what extent can System Dynamics method facilitate the development of Systems thinking and action skills? Based on four studies he found that students and teachers were very interested in System Dynamics as a method for understanding complex systems. Additionally, he found that with a teaching unit of about 20 hours on system dynamics modeling and simulation there was a tremendous shift in the way that students thought about and visualized a complex system. In a pre-instruction test, most students use pictorial or verbal descriptions of the system; however, after the 20 hours of instruction in System Dynamics, almost all students utilized some form of causal diagram (Ossimitz 2000). He also found that students gave very positive comments regarding the curriculum and the use of simulations in class. Again, this provides examples of the impact teaching System Dynamics through the use of simulations can improve the learning experience for both students and teachers.

Learning styles are characteristics of student behavior that indicate how they gain understanding in respect to the learning environment. Learning styles are not an indication as to the intelligence of a student, nor is any one learning style superior to the others; they are just different (Felder and Brent 2005). As teachers, we must be aware of the different learning styles and ensure that our instruction utilizes a balanced approach to teach to all learning styles. In 1988, Richard Felder and Linda Silverman developed a learning model for engineering students that focused on five dimensions: Processing, Perception, Input, Understanding, and Organization (1988).

The processing dimension places students on a scale from being active learners to reflective learners. Active learners understand and retain information by doing something active, either applying the material or explaining the material to others. Whereas, reflective learners tend to be more comfortable thinking about the material and processing it on their own. The perception dimension ranges from sensing learners, who prefer to learn facts, to intuitive learners, who prefer learning potential relationships. The input dimension quantifies how students receive and retain information as presented either as visual learners or verbal learners. Visual learners remember material they see, pictures, graphs, diagrams, or demonstrations; whereas, verbal learners get more out of written or spoken words. The understanding dimension captures how students apparently learn over time. Sequential learners gain understanding through a linear process, while global learners tend to put concepts together to make large leaps in understanding (Felder and Solomon 2003). The fifth dimension, organization, is broken down into inductive and deductive learners. Inductive learners learn best in environments that enable discovery based learning, while deductive learners gain a better understanding when they progress from fundamentals to applications (Felder and Silverman 1988).

Felder and Solomon developed an Index of Learning Styles, which enable students to take a short questionnaire to determine where they fit on four of the five initial dimensions. This questionnaire provides teachers with an excellent tool to determine the learning style population of their class (Felder and Solomon 2001). Additional work has focused on the validation of this questionnaire as a measurement tool. In 2003, Zywno conduced a detailed statistical analysis of the validity of the Index of Learning Styles to determine if it provided a valid tool for assessing student's learning styles. In terms of construct validity, she found that over time, groups of engineering students, regardless of location, shared common learning styles and were generally Active, Sensing, Visual, and Sequential learners (Zywno 2003). She concluded that the Index of Learning Styles was a suitable tool for assessing the learning styles of engineering students. Additionally, test reliability measurements have been taken to determine if student responses are the same when they re-take the test. They found there was a high correlation coefficient between the test and re-test results, so the test reliability is satisfactory (Livesay, et al. 2002). So, as a measurement tool for learning styles, the Index developed by Felder and Solomon provides valid and reliable results.

Additionally, Felder has expanded his work to identify some common uses and misuses of the index. First, he clarifies that the dimensions are continua, not polar categories, so an individual student can be mildly, moderately or strongly aligned towards a certain dimension. Also, he states that these characteristics only suggest behavioral tendencies and are not intended to be predictors of behavior or indicators of learning strengths and weaknesses. Finally, he points out that the intent behind identifying learning styles is not to label individual students and modify instruction to fit their labels (Felder and Spurlin 2005). However, the intent of the index is to gain a better understanding the student population and design effective instruction that will present material in a manner consistent with their student's learning styles.

This portion of the literature review focuses on the utilization of classroom assessment techniques to evaluate the educational experience a student receives. Classroom assessment techniques (CATs) are designed to monitor learning throughout the semester to assess how students are learning (Angelo and Cross 1993). Different CATs are specifically designed to measure student's progress in different types of learning, so they can be chosen based on the type of learning a teacher wishes to assess (Angelo 1991). One of the major benefits of CATs when compared to formal evaluations, such as tests and quizzes, is that they are anonymous and ungraded so students are more willing to provide honest feedback (Nilson 2010).

Angelo and Cross present over fifty different Classroom Assessment Techniques from which teachers can select appropriate assessments and modify them to meet the individual needs of their students (1993). They are grouped by the type of learning that is being assessed by the teacher. CATs such as the memory matrix, muddiest point, and focused listing assess student's learning of prior knowledge, recall, and understanding (Angelo and Cross 1993). These assessment techniques are the most widely applicable and easiest techniques to use and can be utilized to assess a variety of delivery methods. Analytical memos, categorizing grid, and pro and con grids assess student's ability to analyze and decompose information and problems to better understand and solve the problems (Angelo and Cross 1993). The technique of what's the principle assesses the student's ability to problem solve and evaluates not only the mastery of knowledge, but also the ability to determine the techniques required to solve a problem (Angelo and Cross 1993). CATs such as application cards and student-generated test questions assess the student's skill in application and performance, which are essential to learning at the college level.

Additionally, students can assess their awareness of their attitudes and values through the use of course-related self-confidence surveys to supplement formal evaluations (Angelo and Cross 1993). They also present the CATs by academic discipline; however, System Dynamics can spread between engineering, business and management, social sciences, and even biology, so a wide range of CATs are appropriate for assessing student learning of System Dynamics.

These classroom assessment techniques provide a tool to evaluate the course and the effectiveness of different presentation methods of the course material. Over the course of the semester, six different assessment techniques evaluated course lectures, labs, case studies, and readings. Additionally, a self-confidence survey assessed the students' assessment of their ability to accomplish the course objectives at the midpoint and end of the semester.

## Methodology

The methodology behind the course evaluation was to utilize several classroom assessment techniques throughout the semester to specifically evaluate different delivery methods for teaching System Dynamics. Specific classroom assessment techniques (CATs) provided valuable feedback on the effectiveness of these methods in teaching the course concepts. Table 1 presents the plan for conducting the classroom assessment techniques throughout the semester, to include the lesson they will be conducted, they method evaluated, the type of technique, the time conducted, and the action taken by the students.

| CAT | Lesson | Method Evaluated | Technique | Time | Action |
|---|---|---|---|---|---|
| 1 | 6 | Reading | Muddiest Point | End of class | Have students write down the item they are most confused about from the reading |
| 2 | 8 | Lecture | Memory Matrix | End of class | Have them write down a matrix the concepts of SD with the tools they have learned |
| 3 | 10 | Lab | Application Card | End of class | Have students write down how they could use this, score based on a 0-3 scale. |
| 4 | 14 | Case Study | Focused Listing | End of class | Have cadets list concepts from the case study based on an overall concept for the case study |
| 5 | 16 | Reading | Muddiest Point | Beginning of Class | Have students write down the item they are most confused about from the reading |
| 6 | 18 | Lab | Memory Matrix | End of class | Have them write down a matrix the concepts of SD with the tools from previous lessons |
| 7 | 20 | All | Self-Confidence Survey | Out of Class | Send electronic survey to cadets evaluating their confidence on a 1-5 scale for course objectives covered to this point |
| 8 | 31 | Labs / Lectures | What's the Principle | End of Class | Have the students write down the principles behind the business cycle, score them if they wrote a principle that fits the topic. |
| 9 | 36 | Reading / Lecture | Application Card | End of class | Have students write down how they could use System Dynamics in the future, score based on a 0-3 scale, 0 if they write down no clue, 1 if some answer, 2 if mostly correct, 3 if completely correct. |
| 10 | 38 | All | Self-Confidence Survey | Out of Class | From the course level end of course feedback questions, which ask the confidence of cadet's ability to execute the course objectives. |

**Table 1: Semester Classroom Assessment Technique Summary**

The muddiest point CAT assessed the readings from lessons 6 and 16 to determine how effectively the textbook presented the learning points for the lesson. The muddiest point CAT is one of the most efficient CATs because it takes relatively little effort to execute, but provides a great deal of information return. It provides information on what the students find unclear or confusing from a particular reading or lecture (Angelo and Cross 1993). Lesson 6 focused on four major learning objectives: link and loop polarity, causation versus correlation, mathematics of causal loop diagrams, and creating causal diagrams. The muddiest point CAT also evaluated the textbook during Lesson 16 based on the following learning objectives: define a delay, describe a material delay, describe an information delay, determine the order of a delay, and incorporate feedback into stocks and flows. To turn the data into useful information about the effectiveness of the textbook in covering these objectives, each time a student identified one of these topics as unclear it subtracted from the overall score. If a student was unclear about multiple learning objectives, it subtracted from both learning objectives.

The memory matrix CAT assessed the lecture during lesson 8 and the computer lab during lesson 16. The memory matrix assessed students' ability to recall and organize course material into categories provided by the instructor (Angelo and Cross 1993). It is very useful for evaluating student's ability to recall basic facts and principles in courses that have a high level of information content, such as an introduction to System Dynamics. For lesson 8, the memory matrix focused on the following learning objectives: Apply stock and flow diagramming notation, classify and object as a stock or flow, and model stocks and flow mathematically. Table 2 presents a sample of the matrix that was given to students upon the completion of the lecture.

| | Notation | Units | Mathematics | Example |
|---|---|---|---|---|
| Stock | | | | |
| Flow | | | | |
| Auxiliary Variables | | | | |

**Table 2: Memory Matrix - Lesson 8**

To score the memory matrix, a point was deducted for each incorrect answer in the matrix. Five of the boxes applied to the objective of apply stock and flow diagramming notation, three boxes applied to classifying an object as a stock or flow, and two of the boxes applied to modeling stocks and flows mathematically. A similar technique was used during lesson 18 to evaluate the effectiveness of a computer lab in presenting learning objectives that focused on co-flows, aging chains, and delays.

The application card CAT assessed the lab during lesson 10 and the lecture and reading for lesson 36. This CAT prompts students to think of possible applications of the material that they learn and indirectly makes them connect new concepts with prior knowledge. It also enables them to see the relevance of what they are learning and how they can apply it to an area of their interest (Angelo and Cross 1993). For lesson 10, the application cards focused on students' ability to apply the concept of stock and flow modeling. For lesson 36, the application card asked students to write down how they could use System Dynamics in the future in an area they are interested in. For both of these lessons, the responses were scored on a scale of 0 to 3, 3 being a completely correct application of the concept, a 1 if they have some answer, and a 0 if they just responded as not having a clue how to apply the concepts.

The focused listing CAT evaluated the effectiveness of the production-distribution game and case study in teaching the learning objectives for lesson 14. This CAT focuses students on an important concept from a particular lesson and asks them to list several ideas that are related to the important concept (Angelo and Cross 1993). During this lesson, students participated in the production-distribution game, more commonly referred to as the beer game, to gain an understanding of how structure drives behavior, the impact of delays, and the consequences of overreaction based on mental models. To transform the data into useful information, each correct response counted towards one of the key concepts from the lesson and a percentage was calculated based on the total number of respondents.

The "what's the principle" CAT evaluated a block of lectures and labs as well as the students' understanding of what System Dynamics principles applied to the business cycle. This assessment technique assesses the student's ability to understand a problem and determine what type of principle or concept to apply to that problem (Angelo and Cross 1993). During this block of lessons, students received one lecture and two computer labs that presented the concepts behind the business cycle and the sources of oscillation. Student responses were scored based on a 0-3 scale, 0 if they write down no clue, 1 if some answer, 2 if mostly correct, and 3 if completely correct.

The final classroom assessment technique is the self confidence survey, which evaluated the students' confidence in their ability to apply the course objectives in both lesson 20 and lesson 40. Additionally, the survey focused on assessing the delivery methods used throughout the semester and how effective they were in presenting the material. These surveys are useful in courses where students are trying to learn new skills, such as System Dynamics. The self-confidence survey CAT assesses students' level of confidence in their abilities and enables instructors to more effectively structure assignments (Angelo and Cross 1993). The survey asked students to rate their ability to accomplish each of the course objectives and rate them from strongly agree to strongly disagree. The same survey was distributed during lesson 20 and lesson 40 to assess the change in the students' confidence over the course of the semester. To transform the data into useful information, their responses were scored from 5 (strongly agree) to 1 (strongly disagree) and averaged across all student respondents. A similar technique was used to score and evaluate the different delivery methods used throughout the course.

## Results

The results of the learning style evaluation, classroom assessment techniques, and self-confidence surveys provided valuable insights into the structure and methods for teaching System Dynamics to undergraduates. The current course structure is extremely balanced between the different types of learning styles; however, the distribution of students is not as balanced within the learning dimensions. The classroom assessment techniques focused on the effectiveness of lectures, labs, case studies, and readings in presenting the materials. Finally, the survey assessed both the students' confidence in their ability to accomplish the course objectives during lesson 20 and 40 and the effectiveness of the delivery methods. Appendix 1 contains the complete results from the CATs.

The results of the learning style survey for students matches previous surveys of engineering students in that most students tend to be more active learners, sensing learners, visual learners, and sequential learners. For the processing dimension, of the 41 students surveyed, 19 showed a tendency towards active learners and only 1 was a reflective learner. In the perception dimension, 20 students were sensing learners, 4 were intuitive, and the remaining students were neutral in this dimension. The input dimension was more balanced between the verbal and visual learners in the course with about 50 percent of the students being visual learners and about 35 percent being verbal learners. In the understanding dimension, a majority of the students surveyed were neutral, but a larger percentage of students were sequential learners. However, the course material is generally balanced between the two ends of the spectrum for each learning dimension.

The lectures were assessed during lessons 8, 31, and 36 through the use of the memory matrix, "what's the principle", and application card CATs. During lesson 8, the memory matrix CAT evaluated the effectiveness of the lecture in presenting the learning objectives. It found that the lecture was every effective in presenting how to apply stock and flow diagramming notation and classifying an object as a stock or flow, with a score of 93 and 94 percent respectively. However, it was not very effective at presenting how to model stocks and flows mathematically, scoring only a 35 percent. CAT 2 in Appendix 1 presents the breakdown of results from this assessment. Based on this CAT, a more active method of teaching the mathematics behind stocks and flows may benefit the group of students who tend to me more active learners. So, a lecture might not be the best delivery method for this objective. The "what's the principle" CAT assessed the lectures and labs that covered the concepts behind the business cycle and the sources of oscillation. These lectures and labs scored a 72.4 percent based on student response, which CAT 8 in Appendix 1 summarizes.

The application card CAT evaluated both the effectiveness of the reading and lecture in presenting potential applications of System Dynamics in the future during lesson 36. The results of this CAT show that neither the textbook nor the lecture effectively pressed these concepts with a score of 52.3 percent. However, as this lesson was towards the end of the semester, these results may be skewed as students were less inclined to do the readings towards the end of the semester. CAT 9 in Appendix 1 shows the scoring of this CAT.

Based on the student survey distributed at the end of the semester, the lectures were very effective at presenting the material, which agrees with the results of the classroom assessment techniques. The students rated the lectures between strongly agree and agree that the lectures contributed towards their learning with an average score of 4.29. So, lectures will continue to be an essential component of teaching System Dynamics; however, the CATs identified potential areas of improvement to teach some material differently to support the learning styles of the students in the course.

As discussed by Ossimitz, computer simulation labs are extremely effective in teaching System Dynamics to students (Ossimitz 2000). Labs were assessed during lessons 10 and 18 with the application card and memory matrix classroom assessment techniques. The results of these two CATs are consistent with Ossimitz's observations and show that the labs are moderately effective at presenting the material. During lesson 10, the lab scored a 77.8 percent based on the results of the application card CAT. The memory matrix CAT assessed the learning objectives associated with co-flows and aging chains during lesson 18. A majority of the lab focused on aging chains and delays which scored 63 and 70 percent respectively on the memory matrix. However, the co-flow learning objective scored a 36 percent based on the students' performance on the memory matrix. Based on these scores a lab appears to be the correct delivery method; however, it may benefit students to separate the co-flows and aging chains into two distinct labs. Also, on the end of course self-assessment survey, students rated the labs as 4 out of 5, which indicate that they agree that the labs contributed to their understanding of the material. So, the labs appear to significantly contribute to student learning and should be sustained in future courses.

Although the course utilizes several case studies over the course of the semester, only the production-distribution game during lesson 14 was assessed with a CAT. The focused listing CAT required students to list the major concepts that were included in the case study. For this particular case study it focused on the following concepts: structure drives behavior, delays, causes of oscillation, the importance of communication, and the impact of mental models and overreaction to a shock to the system. The results of the classroom assessment technique were not very good. The highest scoring concept was the concept of delays in a system, which only scored a 45 percent with 44 students participating in the CAT. Most concepts scored between a 20 and 40 percent as shown in CAT 4 in Appendix 1. The worst scoring concept is that structure drives behavior, which only scored a 16 percent, and is probably the most important concept that the production-distribution game hopes to demonstrate. So, I think the production-distribution game on its own is not an effective method for teaching these concepts and it must be reinforced with lectures and other labs to solidify the concepts for students. This CAT also showed how the sequencing of lessons in the course needs improvement as these concepts should be taught directly after the game so that students have experience with delays and oscillation. It would be interesting to repeat this CAT upon completion of the lectures on delays to see if there is any improvement.

Additionally, students found that case studies were extremely effective in teaching the course materials. During the end of term self-confidence survey, students strongly agreed that the case studies contributed to their understanding of the course content. CAT 10 in Appendix 1 presents the results of the survey and show that case studies received a 4.38 score out of 5 possible. The students definitely enjoy the case studies as examples of real world applications of System Dynamics and several of them mentioned to keep the case studies or add more case studies in their comments on the survey.

The readings were assessed during lessons 6, 16, and 36 through the use of the muddiest point and application card classroom assessment techniques. The muddiest point CAT evaluated the readings during lesson 6 and 16. During lesson 6, it evaluated the effectiveness of the textbook in presenting concepts behind causal loop diagrams based on responses from 48 students. The CAT found that the textbook was very effective in teaching students how to create causal diagrams and the mathematics behind causal loop diagrams, with only two or three students identifying these as unclear concepts. However, during that lesson, 13 students identified the concept of determining link and loop polarity to be unclear. Overall the textbook presented 86 percent of the learning objectives in a clear manner for this lesson. CAT 1 in Appendix 1 presents the breakdown of results from this CAT. During lesson 16, the muddiest point CAT again evaluated the effectiveness of the textbook in presenting concepts behind delays. A majority of the students found the concepts presented by the textbook to be clear with 88 percent of the learning objectives identified as being clear. The only area in which the textbook appeared to be unclear was in the objective of determining the order of the delay, which was unclear to 9 of the 29 students who responded. CAT 5 in Appendix 1 presents the results from this classroom assessment technique.

Additionally, the survey of students during lesson 20 and lesson 40 specifically asked how effective the textbook readings were in delivering course material. Based on the student survey at the end of the semester, the textbook received a score of 2.71 out of 5, which indicates that students did not find the textbook to be effective in presenting the material. However, the results of the classroom assessment techniques seem to indicate that the textbook is effective at teaching the learning objectives. So, there is an obvious bias in the student surveys which indicates that they feel the textbook is not effective in presenting the material when directly asked about the text.

The student self-confidence survey assessed students' confidence in their ability to perform each of the seven course objectives. The students participated in the survey during lesson 20, with 23 respondents, and during lesson 38 with 21 respondents. CAT 7 and CAT 10 in Appendix 1 present the results of the survey to include student evaluations of the delivery methods. Table 3 presents the results of the survey by course objectives. Over the course of the semester, it appears that students became more confident in their ability to accomplish the course objectives.

| | **Course Objectives** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Lsn 20** | 4.26 | 3.96 | 3.87 | 3.91 | 4.00 | 4.00 | 3.83 |
| **Lsn 40** | 4.24 | 4.19 | 4.19 | 4.14 | 4.24 | 4.29 | 4.38 |
| **Change** | -0.02 | +0.23 | +0.32 | +0.23 | +0.24 | +0.29 | +0.55 |

**Table 3: Student Self-Confidence Survey Results**

The only objective that decreased slightly was objective 1: apply system dynamics methodology to the solution of large scale, complex problems. However, it only decreased by 0.02 points. The other course objectives saw significant gains as the students gained a better understanding of System Dynamics.

## Recommendation

Overall, it appears that the methods used in this course are effective at teaching System Dynamics to undergraduate students. The balance of lectures, labs, case studies, and readings appeal to a diverse group of student learning styles. Also, the results of the confidence survey indicate that the students become more confident in their ability to accomplish the course objectives between the middle of the semester and the end of the semester. However, analysis of the classroom assessment techniques identifies several areas that could be improved upon for future iterations of this course.

The first recommendation is to increase the number of case studies and real-world applications of system dynamics used in class. Students found the case studies to be extremely effective in presenting the concepts taught in the course, as indicated on their self-confidence surveys. Case studies appeal to the active learners in the groups, which comprised almost 50% of the class and another 48% being neutral in the processing dimension. Students get to actively participate in the case study discussions and in the case of the production-distribution game and the management flight simulators utilized, actually run the company from the case study. However, case studies alone will not be sufficient to teach some lesson objectives, as the focused listing CAT after the production-distribution game indicated. So, case studies can be effectively used to supplement learning objectives for the course, but should not be the sole method for delivering course content.

The next recommendation focuses on the sequencing of lessons, specifically the lessons following the production-distribution game. In the current syllabus, the production-distribution game is followed by a lesson on delays; however, there is a large gap between that lesson and the lessons on supply chain and then the business cycle. Some of the lessons learned from the production-distribution game are lost because of the large gap in time. So, by teaching all of these together, it would be possible to sustain the lessons learned from the production-distribution game and tie those to the concepts of a supply chain System Dynamics model.

The final recommendation is to separate co-flows and aging chains as one lesson in the computer lab did not sufficiently cover the material to ensure students understood all learning objectives. The lab proved to be effective in teaching aging chains and provided a review of delays as indicated by the high scores, 70 percent, on the memory matrix. However, the lab did not sufficiently present the concepts of co-flows as students only scored a 36 percent on the memory matrix for this topic. By splitting these two topics into separate lessons, students will have more time to apply the concepts of both co-flows and aging chains in a computer lab environment.

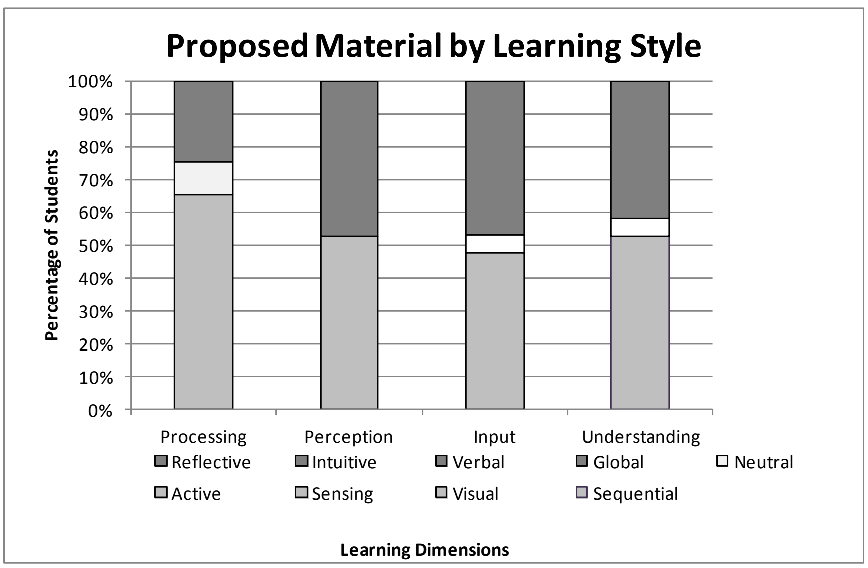


**Figure 4: Proposed Course Material by Learning Style**

Figure 4 presents the new breakdown of the course material by learning styles with the recommended changes to the course. With the addition of two case studies, the processing dimension shifts towards more active learning, which aligns with the student population. The other changes keep the course remains balanced between the remaining three dimensions, which will ensure that all student learning types are covered without catering to one specific type.

Additionally, for future academic work, it would be beneficial to repeat this process with the changes to determine if they had any effect on student understanding of the learning objectives. The number of students involved in this study was relatively small as the course only had 48 students and some CATs only captured information from about 20 students. More data points would increase the accuracy of the assessment and potentially provide additional insights into the delivery of material. Also, additional CATs could determine the effectiveness of the recommended changes to the course to see if they improved student understanding of the material.

## Conclusion

This paper presents an examination of the effectiveness of different delivery methods for teaching System Dynamics to undergraduate engineering students. Several classroom assessment techniques analyzed the effectiveness of lectures, textbook readings, labs, and case studies in delivering the course material. Overall, the course is effective at increasing the students' confidence in their abilities to accomplish the course objectives as indicated on the students' self-confidence surveys. However, the CATs identified several areas for improvement of the course to include the addition of more case studies, a better sequencing of lessons, and the separation of two topics to increase understanding. The assessment provided valuable insights into the effectiveness of the delivery of material and the methods for teaching System Dynamics to undergraduate engineering students.

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**About the Author**

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## Appendix 1: Individual Classroom Assessment Technique Results

### CAT 1 - Lesson 6

The muddiest point CAT was used to evaluate the effectiveness of the course text book in teaching learning objectives for this lesson. There were four major learning objectives for the reading. If students found one of these learning objectives to be unclear from the reading then a point was deducted from the score for the textbook. Responses were taken from all 48 students in the course. If a student was unclear about two of the learning objectives, then points were deducted from each of the learning objectives.

| Learning Objective | Identified as Unclear | Total | Percentage |
|---|---|---|---|
| Link and Loop Polarity | 13 | 48 | 73% |
| Causation vs Correlation | 9 | 48 | 81% |
| Mathematics of CLDs | 3 | 48 | 94% |
| Creating Causal Diagrams | 2 | 48 | 96% |

### CAT 2 - Lesson 8

The memory matrix CAT was used to evaluate the effectiveness of the lecture in teaching learning objectives for this lesson. There were three major learning objectives for the lecture. If students wrote the wrong concept in the memory matrix, then a point was deducted from that learning objective. Responses were taken from 27 out of 48 students in the course. Apply stock and flow diagramming notation applied to 5 boxes in the matrix, Classify an object applied to 3 boxes, and Model stocks and flows mathematically applied to 2 boxes.

| Learning Objective | Incorrect | Total | Percentage |
|---|---|---|---|
| Apply stock and flow diagramming notation | 10 | 135 | 93% |
| Classify an object as a stock or flow | 5 | 81 | 94% |
| Model stocks and flows mathematically | 35 | 54 | 35% |

## CAT 3 - Lesson 10

The application card was used to evaluate the effectiveness of a lab in presenting material for students and determining if they could then use this information for application to other systems. Student responses were scored based on a 0-3 scale, 0 if they write down no clue, 1 if some answer, 2 if mostly correct, 3 if completely

| Response | Number | Points |
|---|---|---|
| Completely Correct | 12 | 36 |
| Mostly Correct | 16 | 32 |
| Some Answer | 2 | 2 |
| No Clue | 0 | 0 |
| Total | 30 | 70 |
| | | 77.8% |

## CAT 4 - Lesson 14

The application card was used to evaluate the effectiveness of a case study in presenting material for students and determining if they could identify the major concepts that the case intended on focusing on. Each correct response counted towards the corresponding concept, also the "Other" response captures any feasible responses outside of the original intended responses. Responses were collected from 44 cadets.

| Concepts | Identified | Total | Percentage |
|---|---|---|---|
| Structure drives Behavior | 7 | 44 | 16% |
| Delays | 20 | 44 | 45% |
| Causes of Oscillation | 9 | 44 | 20% |
| Importance of Communication | 15 | 44 | 34% |
| Mental Models / Overreaction | 14 | 44 | 32% |
| Other | 19 | 44 | 43% |

## CAT 5 - Lesson 16

The muddiest point CAT was used to evaluate the effectiveness of the course text book in teaching learning objectives for this lesson. There were four major learning objectives for the reading. If students found one of these learning objective to be unclear from the reading then a point was deducted from the score for the textbook. Responses were taken from all 29 students in the course. If a student was unclear about two of the learning objectives, then points were deducted from each of the learning objectives. 7 did not do the reading.

| Learning Objective | Identified as Unclear | Total | Percentage |
|---|---|---|---|
| Define a Delay | 1 | 29 | 97% |
| Describe a material Delay | 0 | 29 | 100% |
| Describe an Information Delay | 4 | 29 | 86% |
| Determine the Order of a Delay | 9 | 29 | 69% |
| Incoporate feedback into Stocks and Flows | 3 | 29 | 90% |

## CAT 6 - Lesson 18

The memory matrix CAT was used to evaluate the effectiveness of the lecture in teaching learning objectives for this lesson. There were three major learning objectives for the lecture. If students wrote the wrong concept in the memory matrix, then a point was deducted from that learning objective. Responses were taken from 43 out of 48 students in the course. Co-flows, aging chains, and delays each accounted for three boxes in the memory matrix.

| Learning Objective | What they do | Notation | Example | Total Incorrect | Total | Percentage |
|---|---|---|---|---|---|---|
| Co Flows | 18 | 40 | 24 | 82 | 129 | 36% |
| Aging Chains | 8 | 24 | 16 | 48 | 129 | 63% |
| Delay | 4 | 20 | 15 | 39 | 129 | 70% |

*Notation created a majority of errors

## CAT 7 - Lesson 20

| |
|---|
| Mid-Course Survey CAT was used to evaulate the cadet's ability to accomplish the course objectives. Additionally, the survey focused on the delivery methods for the course material. The survey was distributed to all cadets during lesson 20 as a mid point in the semester |

| | |
|---|---|
| Respondants | 23 |

**Question: I am confident in my ability to:**

| Course Objectives | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Average |
|---|---|---|---|---|---|---|
| Apply system dynamics methodology to the solution of large scale, complex problems | 3 | 17 | 5 | 0 | 0 | 4.26 |
| Create models of dynamic systems, operations, and processes | 3 | 18 | 1 | 0 | 1 | 3.96 |
| Apply system dynamics modeling techniques to simulate behavior over time of systems, operations, and processes | 3 | 15 | 4 | 1 | 0 | 3.87 |
| Develop policies and controls to improve systems, operations, and processes | 4 | 13 | 6 | 0 | 0 | 3.91 |
| Interpret the output from continuous time simulations of system dynamics models as an aid for decision making | 5 | 14 | 3 | 1 | 0 | 4.00 |
| To prepare and present the results of system dynamics analysis in oral and written form | 4 | 16 | 2 | 1 | 0 | 4.00 |
| Recognize the ethical considerations involved with gathering and analyzing data, using quantitative models, validating assumptions, and reporting results | 4 | 14 | 4 | 0 | 0 | 3.83 |

**The following contributed to my learning and understanding of System Dynamics**

| Methods | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Average |
|---|---|---|---|---|---|---|
| Lectures | 5 | 14 | 1 | 3 | 0 | 3.91 |
| Labs | 11 | 10 | 2 | 0 | 1 | 4.43 |
| Textbook Readings | 0 | 2 | 12 | 7 | 3 | 2.65 |
| Case Study | 8 | 11 | 2 | 2 | 0 | 4.09 |
| Homework | 4 | 10 | 7 | 1 | 1 | 3.65 |
| Course Project | 5 | 10 | 8 | 0 | 0 | 3.87 |

## CAT 8 - Lesson 31

The "what's the principle" assessment was used to gage the students understanding of the Lab material and how which principle applied to the Supply Chain and Labor Model. Student responses were scored based on a 0-3 scale, 0 if they write down no clue, 1 if some answer, 2 if mostly correct, 3 if completely

| Response | Number | Points |
|---|---|---|
| Completely Correct | 19 | 57 |
| Mostly Correct | 6 | 12 |
| Some Answer | 7 | 7 |
| No Clue | 3 | 0 |
| Total | 35 | 76 |
| | | 72.4% |

## CAT 9 - Lesson 36

The application card was used to evaluate the effectiveness of the reading and lecture to determine if students could identify potential applications for System Dynamics in the future. Student responses were scored based on a 0-3 scale, 0 if they write down no clue, 1 if some answer, 2 if mostly correct, 3 if completely

| Response | Number | Points |
|---|---|---|
| Completely Correct | 10 | 30 |
| Mostly Correct | 11 | 22 |
| Some Answer | 17 | 17 |
| No Clue | 6 | 0 |
| Total | 44 | 69 |
| | | 52.3% |

## CAT 10 - Lesson 38

End-Of-Course Survey CAT was used to evaulate the cadet's ability to accomplish the course objectives. Additionally, the survey focused on the delivery methods for the course material. The survey was distributed to all cadets during lesson 38 at the end of the semester. Hopefully should see an improvement in the ability to accomplish the course objectives.

| | |
|---|---|
| Respondants | 21 |

**Question: I am confident in my ability to:**

| Course Objectives | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Average | LSN 20 |
|---|---|---|---|---|---|---|---|
| Apply system dynamics methodology to the solution of large scale, complex problems | 6 | 14 | 1 | 0 | 0 | 4.24 | 4.26 |
| Create models of dynamic systems, operations, and processes | 6 | 14 | 0 | 1 | 0 | 4.19 | 3.96 |
| Apply system dynamics modeling techniques to simulate behavior over time of systems, operations, and processes | 5 | 15 | 1 | 0 | 0 | 4.19 | 3.87 |
| Develop policies and controls to improve systems, operations, and processes | 6 | 12 | 3 | 0 | 0 | 4.14 | 3.91 |
| Interpret the output from continuous time simulations of system dynamics models as an aid for decision making | 7 | 12 | 2 | 0 | 0 | 4.24 | 4.00 |
| To prepare and present the results of system dynamics analysis in oral and written form | 7 | 13 | 1 | 0 | 0 | 4.29 | 4.00 |
| Recognize the ethical considerations involved with gathering and analyzing data, using quantitative models, validating assumptions, and reporting results | 8 | 13 | 0 | 0 | 0 | 4.38 | 3.83 |

**The following contributed to my learning and understanding of System Dynamics**

| Methods | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree | Average | LSN 20 |
|---|---|---|---|---|---|---|---|
| Lectures | 7 | 13 | 1 | 0 | 0 | 4.29 | 3.91 |
| Labs | 8 | 7 | 4 | 2 | 0 | 4.00 | 4.43 |
| Textbook Readings | 0 | 4 | 8 | 8 | 1 | 2.71 | 2.65 |
| Case Study | 10 | 9 | 2 | 0 | 0 | 4.38 | 4.09 |
| Homework | 7 | 12 | 2 | 0 | 0 | 4.24 | 3.65 |
| Course Project | 8 | 13 | 0 | 0 | 0 | 4.38 | 3.87 |