Learning to Teach System Dynamics in Agricultural and Resource Management Before and After the Competence Development Framework

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Abstract: This paper presents the design, evaluation, and effectiveness of achieving student learner outcomes of a first- and second-time taught system dynamics (SD) modeling course to students at a minority serving institution focusing on agricultural and natural resource management disciplines. The first course design incorporated concepts from four other SD courses taught at other institutions but in similar disciplinary environments (the "applied" sequence), as well as from expert SD educators (the "canonical" sequence; Richardson 2014a). The second course was revised with the goal of strengthening the assessment tools and evaluation procedures based on the learning outcomes outlined in the SD competence development framework (Schaffernicht and Groesser, 2016). The adjustments made struck a healthier balance between the applied and canonical sequences, supported a more active learning environment, and aided in stronger achievement levels in learning outcomes for the year 2 cohort despite them being slightly poorer performers compared to the year 1 cohort. Although no major adjustments in the course content were made between courses and only a few minor changes in the weekly course outline, future adjustments will focus on strengthening course content through addition of modeling examples and case studies to widen the number of applications students are exposed to.

1. Introduction

As system dynamics (SD) continues to be more widely used and applied in ever more diverse disciplines and problem contexts, teaching and learning SD in an effective, efficient and meaningful (lasting) way remains a challenge, particularly for new and expanding SD programs. Although there are many great textbooks available that describe SD, the characteristics of complex systems, the modeling process and its applications (e.g., Grant et al., 1997; Hannon et al., 1997; Sterman 2000; Grant and Swannack 2008; Ford 2009; Fisher 2011), little pedagogical guidance exists outside of established SD programs on navigating such material (from both instructor and student perspectives) in such a way that makes it relevant and meaningful to learning. This is particularly true in agricultural and natural resource management settings (most commonly housed in land grant or state educational universities) that study problems of extreme complexity but have been laggards in adopting SD as a complementary or useful methodology.

For students and managers in the agricultural and natural resources (AGNR) professions (e.g., agroecosystem management; cropping and livestock production; wildlife or soil and water conservation; etc.), where systems are inherently complex due to the biologic, geologic, economic, social, policy and climatic characteristics of the systems and where delays are just as powerful and oftentimes longer than in corporate settings, possessing a systems-oriented mental model is often purported while the implemented strategies remain linear and symptom-driven. This linear mental model has become the norm and is perpetuated in the fragmented and siloed departments in AGNR education that is also observed in other fields of study.

Contemporary AGNR problems have been growing around the world, are increasingly affecting the livelihoods of people, continuity, vigor, and social capital in of local communities, and food system security in general. These 21st century challenges operate a wide range of scales from local to global and encompsasses such problems as climate variability and change (Akerlof et al., 2012; Sheffield et al., 2012; Corlett and Westcott 2013; Trenberth et al., 2013), water resource scarcity and management (Taylor et al., 2012; Haddeland et al., 2014; Savenige et al., 2014; Walsh et al., 2015), soil erosion and land degradation (Seto et al., 2012; Nepstad et al., 2013; Van den Bergh and Grazi 2013; Mahmood et al., 2014), biodiversity loss (Bellard et al., 2012; Cheung et al., 2012; Pauls et al., 2013), and food security (Wheeler and von Braun 2013;; Shindell et al., 2012; Vermuelen et al., 2012; van Ittersum et al., 2013; Teixeira et al., 2013), among others. These complex problems overlap, feeding back on one another in ways not visible on the surface, making sustainable and regenerative resource management even more challenging.

In order to improve and enhance the educational experience and outcomes of AGNR managers to better address these 21st century challenges, Texas A&M University-Kingsville's (TAMUK) Department of Agriculture, Agribusiness, and Environmental Science in 2003 implemented an innovative graduate curriculum grounded in systems thinking and SD. However, the main priority to date has been qualitative systems thinking (e.g., constructing Iceberg Diagrams, describing reference modes and mental models, identifying reinforcing, balancing, and archetype feedback structures). In 2016, the primary author identified the lack of rigorous SD opportunities an overall weakness of program implementation and a shortcoming to students, especially those that performed well and were attracted to systems analysis after taking the introductory courses. In response to this, a formal SD course was added for graduate students in spring semester 2016 and is currently being taught Spring 2017.

Between the times that the two courses were taught, a competence development framework for learning and teaching SD was created to guide future efforts in SD education (Schaffernicht and Groesser, 2016). The competence development framework outlines seven skills and 265 learning outcomes along four development stages from beginner to proficient (after Dreyfus and Dreyfus 1980). Each skill, development stage, and learning outcome were based on Bloom's revised taxonomy (Anderson et al., 2001) and accounts for increasing levels of dynamic complexity (defined by the number of feedback loops; Groesser, 2012; Senge 1990; Sterman 2000).

The purpose of this paper is to describe the learning and teaching experience (from both instructor and student perspectives) before and after the guidance provided in the competence development framework (see Schaffernicht and Groesser, 2016). We first provide an overview of the university setting and context along with a description of students typical of TAMUK. Then we describe how the initial course design was developed and implemented followed by the course adjustments based on the competence development framework, including some qualitative and quantitative outcomes from each experience. We conclude with some lessons learned and future directions.

2. University setting and student context

Texas A&M University-Kingsville (TAMUK) is located in Kingsville, TX, is a member university of the Texas A&M University System, and has a current enrollment of over 8,300 students.

TAMUK offers undergraduate and graduate degrees for ≈60+ majors in five colleges (Agriculture and Human Sciences; Arts and Sciences; Business Administration; Education and Human Performance; and Engineering). The courses of interest presented in this paper were offered through the College of Agriculture, Natural Resources, and Human Sciences, which offers undergraduate degrees in Agriculture Science (including options in either Teaching Certification or Plant and Soil Science), Agricultural Business (including a Ranch Management emphasis), Animal, Rangeland and Wildlife Sciences, and Human Sciences. Although students arrive at TAMUK from over 30 U.S. states and almost as many countries, TAMUK's core service region includes 50+ counties of south Texas (Figure 1). TAMUK's is a designated Hispanic Serving Institution (HSI), with a student body demographic ranging between 60-70% Hispanic, most of which are first generation college students.

In general, the majority of our students' educational backgrounds are from rural schools in south Texas. However, a consistent number of students from northern and central Mexico also attend given that TAMUK is the nearest school with agricultural-related majors. For the most part, the student body comes from schools in rural areas with an extreme variability between high school performance measures. In general, most tend to be better prepared in the sciences than in mathematics or language arts. The factors are important for the present study given that the majority of graduate students are recruited from the undergraduate pool already on campus. These factors create a difficult, but not necessarily insurmountable, challenge for instructors implementing SD courses. Students typically feel weaker in mathematics, have more difficulty communicating in writing (particularly important for developing variable names, notes, and dynamic hypotheses), and, if students completed undergraduate training at TAMUK, are not confident in computer skills since computer applications are not emphasized in the undergraduate curriculum at this time.

For the two cohorts of students included in the course evaluation that follows, five were Hispanic, six Caucasian, and one African. Except for two international students (one from Mexico and one from Nigeria), only two were from a region north of San Antonio and three were from the Rio Grande Valley along the U.S.-Mexico border (McAllen/Edinburg to Brownsville; Figure 1). Six students received previous undergraduate training at TAMUK in agriculture science or animal, range, and wildlife science. Two doctoral students received M.S. training in range management or wildlife science from TAMUK or an international institution. One student had received an MBA in finance from an international institution.

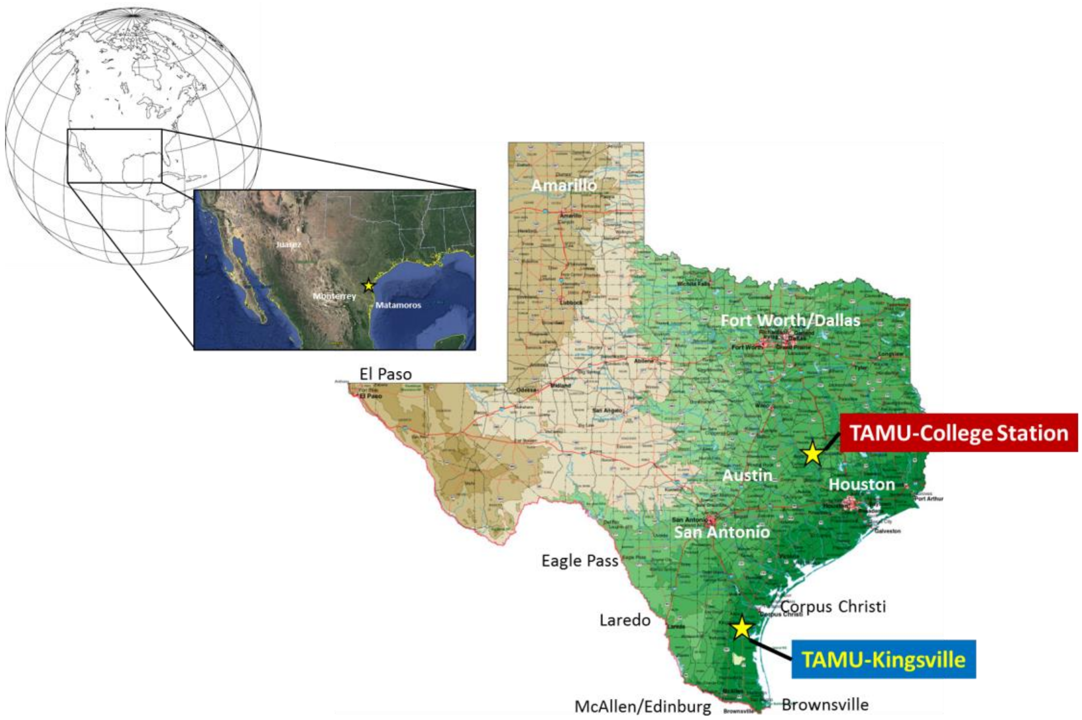

Figure 1. Location of Texas A&M University-Kingsville (TAMUK) in relation to Texas A&M University (College Station), the major population centers in Texas, and its international neighbor Mexico. The green-to-brown east-west gradient represents a precipitation changes from wet to dry across the state.

3. Initial course design matrix and evaluation of student-learner outcomes

In preparing for the course, the lead author found the traditional SD resources (many of which noted above) less attractive given the subject matter is generally less relevant to agriculture and natural resource students in TAMUK programs and due to the assumed quantitative skill needed to begin. Therefore, using personal contacts, basic web searches, and the catalog of courses on the System Dynamics Society resources website (located at systemdynamics.org/courses/), several SD courses taught from agricultural or natural resources departments or from similar institutions were identified. The instructor aggregated the available resources from each of these courses (including but not limited to syllabus material, course handouts or presentations, homework assignments, reading materials, example models, etc.).

Using the materials available for each course, a course comparison matrix was created to aid in design of the first TAMUK SD class (Table 1). The matrix includes 4 courses from 3 universities, taught at 2 land grant universities and 1 state research university in departments ranging from ecology, wildlife and fisheries management, agriculture sciences, and engineering. A noticeable trend in each of these courses was that the exercises generally did not follow designed course activity sequences described by master SD instructors (e.g., the "canonical sequence", Richardson 2014a,b, and c). The "canonical" sequence has been described as: 1) exploring existing models; 2) copying models; 3) adding structure; 4) correcting or improving structure; 5) modeling a 'canned'

Table 1. Course matrix used to compare alternative course content and sequences to aid design of the TAMUK SD course.

	University setting and department where comparison SD course was taught			
Course activities by week	**State research university- Ecology**	**Land grant- Agricultural Science**	**Land grant- Wildlife and fisheries**	**Land grant- Industrial Engineering**
1	Basic concepts in ecological modeling	Beer Game	Systems approach to problem solving; Hwk 1	Course overview/system dynamics overview
2	Basic concepts/ Stella	Introduction and overview/tools to system approach	Conceptual model formulation; Hwk 2	Beer Game
3	Phase 1 concept model development	SD tool 1: reference mode; mapping	Hwk 3	Systems thinking/tools: references modes & building theory in CLD (project part 1)
4	Phase 1 concept model development	SD tool 2: building theory with CLD	HW 4	Mapping stock and flow structure/dynamics of stocks and flow
5	Phase 2 Quantative model formulation (Hwk 1)	SD tool 3: mapping stock and flow structure	Quantitattive model specification; Hwk 5	Linking feedback with stock and flow structure (project part 2)
6	Phase 2 Quantative model formulation	SD tool 4: dynamics of stocks and flow	Model evaluation & use, modular representation of structure and dynamics, iteration of modeling process	Material and information delays, co-flows, aging chains
7	Phase 3 Model evaluation (Midterm)	SD tool 5: linking feedback with stock and flow structure	Reporting the development/use of models; Midterm	Dynamics of growth, path dependence, (Midterm &project part 3)
8	Phase 3 Model evaluation / Phase 4 Model application	SD tool 6: linking feedback with stock and flow structure	Debrief/Exam due	Modeling decision making: formulating and testing models (Debrief midterm)
9	Generic modules for building dynamic models	Nonlinear systems and modeling growth processes	Project	Modeling process case study
10	Understanding math behind models	Modeling innovation diffusion/new product growth	Project	Managing instability: supply chains, forecasting and feedback (project part 4)
11	Numerical methods in simulation modeling (Hwk 2)	Positive feedbacks, path dependence, engines of growth	Project	Dynamics of projects, products, and processes
12	Modeling different ecological processes	Tools for modeling: delays	Project	Model analysis/ flight simulators
13	Modeling different ecological processes	Tools for modeling: co-flows and aging chains	Project	Dynamics of health care (final project report)
14	Modeling different ecological processes	Applying SD models and model evaluation		Applications in SD to Environmental and Public Policy Issues (exam assigned)
15	Modeling different ecological processes	Review of applied models		Building confidence in models (Exam due/ critiques due)
16	Final exam	Presentations	Final report due	
Modeling Platform	Stella	Vensim	Stella	Vensim

model description; 6) modeling problems with vivid, well known structure and dynamics; and 7) modeling personally chosen problems. In fact, sequences were quite variable in the number and nature of activities required for each class, but in general they all followed an "applied sequence" based on the number activities involved in model development of personally problems early and often in each course. Although it is unclear at this time why such an "applied sequence" would be emphasized, we hypothesize two potential reasons for this, one from a student's perspective and one from an instructor's.

First, graduate students in these programs are already required to take a core curriculum that is fairly rigid with only a few opportunities for electives. For those interested in SD and systems analysis, there is little to no room for additional courses above and beyond an introductory SD course. Due to this constraint, instructors were likely to prioritize creative exercises and projects rather than discussions of existing models, exploring, vetting, or copying models, or recreating and experimenting with "canned" model problems. By following a linear modeling process of problem definition, conceptual model development, quantitative model development, model evaluation, and then model testing, provides the instructor with a framework from which to follow (and which many SD books follow which they can reference and direct students to) and guide students in creating their own unique model relevant to their thesis topic.

Second, teachers teach the way they were taught (Dunn and Dunn, 1979), therefore the nature of educational experiences, regardless of the discipline, influence the preferred course design and delivery strategies. Education history as well as previous teaching experiences shape the instructors teacher efficacy. Teacher efficacy has been defined as "the teacher's belief in his or her capability to organize and execute courses of action required to successfully accomplish a specific teaching task in a particular context" (Tschannen-Moran et al., 1998). Given that the goal of SD is to use models to help solve a complex problem, the constraints of the students to be able to take an elective SD course, that most instructors (3 out of 4 of the sampled courses) were classically trained in another discipline that was supplemented with SD, and the rigor and effort that would be needed to cover the "canonical" sequence in one semester, it is likely that the instructors take the path of least resistance by focusing on student projects as a primary objective and using examples of SD applications as supplement.

In designing the first TAMUK SD course, a balance was sought between the "canonical" sequence and the "applied" sequence (Table 2; syllabus material, assignments, mid-term examples, and project prompts are provided in the Supplementary Material). In the applied sequence, the general phases of the modeling process were outlined during class lectures in a linear fashion, from conceptual model development to mathematical model formulation to model evaluation and testing. This format follows the text by Grant et al. (1997), which was chosen as the primary text due to its succinct, high level summaries of each task in the modeling process. When more in-depth of detailed descriptions were needed, Sterman (2000) was referenced. The primary delivery method for core course content was a standard lecture format. Original homework assignments began with reviewing basic terminology and constructing the first version of the student's dynamic hypothesis used for their future projects (hwk 1). The remaining homework assignments (hwk 2-5) attempted to mimic the canonical sequence described by Richardson 2014a. The mid-term exam consisted of developing a diffusion model (the students had already replicated a diffusion molecule) from a podcast series on diffusion of innovative ideas. Case studies for class discussion were saved for the second half of the semester after basic modeling content had been covered and students working on and looking for reference for their own projects. Student learner outcomes were measured by a brief course pre-test/post-test comparison and the quality of the completed semester projects.

Table 2. General outline of the TAMUK SD course for spring semester 2016.

	Applied Sequence	**Canonical Sequence**		
Week	**Course content and activities**	**Hwk/Quiz/Exam**	**Project**	**Readings (STC)**
1	Course overview (syllabus; pre-test); ch1 systems approach; ch2 basic concepts			
2	Phase 1: conceptual model development (reference modes, mapping)	Hwk: Systems mapping/CLD	Dynamic Hypothesis	
3	Phase 1: conceptual model development (building theory with CLD; mapping stock and flow structure)	Hwk: explore and copy model		
4	Phase 1 and 2: model formulation (mapping stock flow/dynamics; mathematics of models)	Hwk: add structure		
5	Phase 2: model formulation: (dynamics of stock flows; modular representation of system structure; molecules of structure)	Hwk: correct or improve structure	Project update 1	
6	Phase 2: model formulation: (dynamics of stock flows; material and information delays, co-flows, aging chains; path dependence)	Hwk: model problem with vivid well known structure and dynamics		
7	Phase 2: model evaluation/testing			
8	Phase 3: model evaluation/testing	Exam: model a "canned" problem description		
Spring Break				
9	**Project**			
10	Project update 2: Stock-and-flows; Data sources (mental models); Next steps			Turner et al. 2013 Diaz-Soliz et al. 2009 (ref. Diaz-Soliz 2003)
11	Project work			Beall and Zeoli 2008 DeMaso et al. 2011
12	Project work			Stave 2010 Stave 2003 Turner et al. 2016
13	Project work			Turner et al. 2016 Ford et al. 2012
14	Project update 3			
15	Project work			
16	Last class day	Final Report due / Presentation		

The first TAMUK SD course was taught during the spring semester 2016 with six graduate students participating. The students came from several different programs in animal, range, and wildlife sciences as well as ranch management. The class met once per week for 16 consecutive weeks (except for spring break week). After covering the majority of course content and completing the assignments, students focused on their projects, which ranged from land use issues, plant community state-and-transition factors, ranching profitability, and wildlife population management. After administering the course, student feedback provided in student rating of instruction surveys consisted of the following:

- “The instructor was nice. But I was not at all crazy about this class. Before it is taught again it needs to be seriously revamped and better organized. I know it’s a tough subject to teach but might want to reconsider your approach.”
- “Excellent professor, very professional and prepared for class. Very interesting and useful class.
- “The instructor clearly passionate about systems dynamics and modeling. He did a great job of expressing the value of modeling in natural resources management. I think we worked on good example models during the first half of the semester. But, I still feel weak on the nuts and bolts of modeling sometimes. Mostly, weak on the quantitative equations. It was a difficult subject to learn in a semester and I think the instructor did a good job answering our questions and definitely a good job encouraging us. Also, I think meeting more than once a week would help improve the class.”
- “The class was great however I think the slides were not very useful. I would have got more out of the class with more time being hands on, and duplicating models.”

Based on these comments (as well as those provided informally during and after completion of the class), it was clear that more in-class working on specific modeling issues rather than the modeling process itself. One instructor observation was that, although the homework activities were aimed at mimicking the canonical sequence, there was not enough demonstration or group work in the course content to facilitate students’ growth in confidence in modeling through such a sequence. Lastly, although the competence development framework developed by Schaffernicht and Groesser (2016) was published in early 2016, it was not early enough to influence the first course design (which occurred during fall 2015).

4. Course design and evaluation of student-learner outcomes following the competence development framework

In preparation for the second TAMUK SD course in spring 2017, comments from the previous course were considered in improving the course. However, the biggest influence on the course adjustments came from the competence development framework. The framework provides a progression of seven skills and 265 learning outcomes along four development stages from beginner to proficient (after Dreyfus and Dreyfus 1980). After reviewing the framework and how the previous course material aligned with the learning outcomes described therein, course adjustments were identified in the following areas to better align with framework and the “: a) course pre-test/post-test questions; b) focus on learning outcomes in the first 8 weeks and removing all project related work until the last 8 weeks; c) altering some content of the homework and restructuring the mid-term exam while leaving the sequence the same; and d) providing course materials (slides, reading list articles, example models, etc.) to student well before lecture periods (often 1 or 2 weeks) so as to direct students to helpful content and free up time during lectures for more hands-on exercises. Each of these will be discussed below, and an updated sequence of activities is shown in Table 3 (syllabus material, assignments, mid-term examples, and project prompts are provided in the Supplementary Material). Although the sequence did not change dramatically, the in-class activities and the nature of the assignments changed significantly.

Table 3. General outline of the second TAMUK SD course for spring semester 2017.

	Applied Sequence	**Canonical Sequence**		
Week	**Course content and activities**	**Hwk/Quiz/Exam**	**Project**	**Readings/Case studies (STC)**
1	Course overview (syllabus; pre-test); ch1 systems approach; ch2 basic concepts			
2	Phase 1: conceptual model development (reference modes, mapping)	Hwk: Exploring and existing model/Dynamic hypothesis formation		Turner et al. 2013 Diaz-Soliz et al. 2009 (ref. Diaz-Soliz 2003)
3	Phase 1: conceptual model development (building theory with CLD; mapping stock and flow structure)	Hwk: explore and copy model		Beall and Zeoli 2008 DeMaso et al. 2011
4	Phase 1 and 2: model formulation (mapping stock flow/dynamics; mathematics of models)	Hwk: add structure		Stave 2010 Stave 2003 Turner et al. 2016
5	Phase 2: model formulation: (dynamics of stock flows; modular representation of system structure; molecules of structure)	Hwk: correct or improve structure		Turner et al. 2016 Ford et al. 2012
6	Phase 2: model formulation: (dynamics of stock flows; material and information delays, co-flows, aging chains; path dependence)	Hwk: model problem with vivid well known structure and dynamics		
7	Phase 2: model evaluation/testing			
8	Phase 3: Model Evaluation/testing	Exam: model a "canned" problem description		
Spring Break				
9	**Project**			
10	Project update 1: Stock-and-flows; Data sources (mental models); Next steps			
11	Project update 2 Project work			
12	Project work			
13	Project update 3			
14	Project work			
15	Project work			
16	Last class day	Final Report due / Presentation		

First, it was clear that the original pre/post-test questionnaire was not nearly as comprehensive as it should have been, essentially put all of the weight of evaluation on the student projects. Having the majority of the learning outcomes reside in the semester projects made quantification of outcomes difficult. After examining the competence development framework, an abbreviated list of learning outcomes was extrapolated onto the existing outcomes of the course (i.e., it would be impossible to measure all 265 learning outcomes across competency levels from beginner to proficient). The implicit goal was to evaluate enough outcome in order to measure student development from beginner to the level of advanced beginner or competent (depending on the outcome). The abbreviated list of outcomes are shown in Table 4. The primary skills the learning outcomes focused on were: system dynamics language, dynamic reasoning, model analysis, and model creation, with fewer outcomes on project initialization, model validation, and policy evaluation and design (which generally require adequate data as well as interaction and input with key stakeholders). These outcomes were then synthesized down further into a revised pre/post-test questionnaire 2.5 times longer than the original, explicitly covering many of the refined learning objectives (see Supplementary Material for comparison).

Second, all project activities were removed from the first half of the course. Introducing individual project ideas or deliverables during the first half of the class distracted students from obtaining the critical modeling skills through homework and class activities. By moving all project activities to the second half of the class, this distraction was removed. Observations of both classes indicated this was a major benefit to focusing on class and homework activities, grabbling with common beginner modeling problems, and navigating the modeling software.

Table 4. Abbreviated list of learning outcome extrapolated from the competency development framework (Schaffernicht and Groesser 2016).

Skill	**Learning outcomes**
System dynamics language	Explains: model boundary, purpose, and reference modes; dynamic hypothesis; types of variables; units of measure; polarity; delays; linear, exponential, and goal seeking behavior; indicates polarity of loops; names variables as nouns; positive and negative feedback
Dynamic reasoning	Describes difference between a stock and a flow; Infers stock accumulation behavior given the in- and out-flows; Describes and infers a flows behavior given the stock accumulation behavior; Defines method of detecting loop polarity; Associates exponential and goal seeking behavior to positive and negative feedback (and vice versa)
Model analysis	Interprets structure of a CLD and SFD; Infers plausible behavior patterns from a SFD; Attributes which part of structure may be driving specific behaviors; Identifies relevant feedback loops in a quantitative model
System dynamics project initialization	Establishes the reference modes; Established preliminary model boundary; Establishes desirable and feared futures; Formulates a conceptual model
Model creation	Decides model boundary and time horizon; Classifies variables by type; classifies unit of measure; Develops representative casual relations in a SD model (diagram and equations); Uses simulation to reproduce reference modes and to formulate structure behavior hypotheses; Experiments and modifies simulation model; Starts the process with key stocks; infers key endogenous variables; Simplifies the model structure; Documents the modeling process
Model validation	Validates dimensional consistency; Tests and evaluates extreme conditions; Tests and evaluates model with respect to uncertain parameters
Policy evaluation and design	Explains how the problem is created by the model structure; Explains why one policy has high impact while others fail to do so

Third, several homework assignments were adjusted and the mid-term exam redesigned to reflect greater diversity of the learning outcomes while also incorporating those outcomes directly into Vensim modeling examples. Originally, the mid-term exam focused on replicating a Diffusion model based on a variety of cases (students were provided an hour long podcast describing a variety of diffusion examples in contemporary issues and had a choice of which one to construct a model). The year 1 students all successfully completed the exam but the narrow capacity to measure diverse learning outcomes was a key weakness to the exam in hindsight, especially given that so much time in the lecture period was devoted to elementary modeling concepts and examples. The revised mid-term became much longer and contained a wide array of activities to measure a broader set of learning outcomes identified in Table 4 (see Supplementary Material for comparisons).

Lastly, students were directed to course materials at least 1 week in advance and were instructed which parts to read prior to the next class. The year 1 students were given the same material as it was presented, which made it more difficult to follow and review outside of class and when working on example homework models or individual projects (see comments in Section 3 above and Table 4 below). By providing everything up front to the year 2 students and directing them where to go in the slides for different activities and for review (without going through everything sequentially) aided in student comprehension efficiency and opened up valuable class time to go through more hands-on examples.

With these adjustments, the second TAMUK SD course reached a more balanced approach between the applied and canonical sequences and was much more effective given the increased time in face to face class meetings to explore models and demonstrate applications together as a class. What was the cumulative effect of these changes on student achievement of learning outcomes?

5. Student experience, performance, and feedback from both courses

To try to understand how well the course adjustments based on the competence development framework could have contributed to both student performance and teacher efficacy, a number of data points were used for comparison (Table 5). Due to the year 2 class currently being in session, we only summarize the data currently at hand at the time of conference paper submission. The results will be expanded and Table 5 completed prior to the Cambridge meeting in July. Below is a bullet point summary of what is completed thus far (Note: results not well developed below are due to year 2 class being in session at time of conference submission. Prior to the conference these will be updated in time for the meeting):

- Cohorts of students from year 1 and year 2 differed in their experience and performance. The first SD course included three first year M.S. students (second semester), one second year M.S. student (fourth semester), and two doctoral students (4 semester). The second SD course included six M.S. students (four in their first semester, two in their second semester) and zero doctoral students. Overall grade point average (GPA) of students was compared to gauge past student success. The mean GPA between classes showed that the year 1 students were generally higher performers (mean 3.80/4.00; or higher tendency to score an A) than the year 2 students (mean 3.28/4.00; or higher tendency to score a B).
- Like other institutions of higher education, a requirement at TAMUK is to evaluate student learner outcomes (SLOs) for accreditation and reporting purposes. The SLO measurements

used in both classes were the pre-test and post-test as well as the individual student modeling projects (i.e., the working model, a written report, and a presentation). Pre-test averages were 33% (year 1 original pre-test questionnaire) compared to 44% (year 2 adjusted pre-test questionnaire). The improved performance on the pre-test was most likely due to: a) greater number of questions in which guesses could be correct; b) questions with greater specificity or detail were able to more accurately measure the students initial capabilities (e.g., inferring the dynamics of a stock based on the flows or vice versa).

- Intermediate feedback was sought from both cohorts during the semester to evaluate their comfort level with the course content, activities, and sequence. Prior to commencing with major project activities, the instructor asked students to write a reflection journal (1 entry for cohort 1, 3 entries for cohort 2). The responses from the journals were telling. Students in the first cohort were recognizing the value of the modeling process and concepts but had yet to begin internalizing them. They expressed some frustrations with their ability to operate Vensim programming and suggested that there should be more in-class modeling activities. Students in the second cohort expressed more enthusiasm that they were achieving (or progressing towards achieving) the course or assignment objectives. They expressed more satisfaction with their progress in Vensim and were internalizing course concepts (e.g., dynamic complexity) earlier.
- To measure students' self-perception of their achievement of SD learning outcomes, a post-course survey was developed (provided in Supplementary material) and provided to each cohort of students after completion of the class. Students were asked to self-assess their improvement in reasoning and capabilities in the synthesized list of learning outcomes (Table 4), including the modeling process, dynamic reasoning based on feedback loops, and ability to complete semester tasks. First year cohort respondents felt comfortable with the SD language, but were challenged in the area of applying the guidelines of good causal loop diagram development (e.g., indicates the polarity of causal links and feedback loops; names feedback loops; indicates time delays; names the variables as nouns; choses an appropriate level of aggregation). Scores on model analysis showed little deviation except for one participant who really struggled in this area. In relation to model creation, the scores were the same as the SD language. The two areas students felt they needed improvement in was the principles of developing the representation of variables (e.g., discovers the variables implied by spoken or written text; classifies the variables by type: stock, flows, or auxiliary), classifying units of measure, and formulating equations. Second year cohort students will conduct the same post-test and results will be provided when the course is completed before the conference.
- To complete the SLO measurements, the post-test (which was identical to the pre-test) was administered at the end of the semester prior to the student project presentations. Post-test questionnaire average of year 1 students was 66%, reflecting relatively poor improvement in proficiency of the learning outcomes. Second year cohort students will conduct the same post-test and results will be provided when the course is completed before the conference.
- Lastly, similar to other institutions, students provide evaluations of instructors via student ratings of instruction (SRI) instruments at the end of the semester. SRI metrics from year 1 students were fair but below the college and university means (not shown). Second year

cohort students will conduct the same post-test and results will be provided when the course is completed before the conference.

Table 5. Summary table of metric of student performance and feedback from students during and after completion of each class used to measure the improvements derived by the competence development framework.

Metric or Feedback	Year 1 (n=6 students)	Year 2 (n=6 students)
Mean GPA	3.80/4.00	3.28/4.00
Pre-test average	33%	44%
Reflection journal notes (1 journal per student for year 1; 3 journals per student for year 3)	• "The most productive part of the class so far has been working through models in class. It has been frustrating trying to work through them at home, I feel I lack the know-how about what options are in Vensim." • "To this point learning how to use the program and seeing how stocks and flows in action has generated ideas/questions for my research problems. I expect this will help my critical thinking." • "Now that I have a good understanding of mental models I find myself looking for ways to apply them to my research…Getting errors and not know how to fix or diagnose them has been most frustrating." • "The homework forced me to think and explore more options. The bath tub model really opened by eyes. Getting units right has been the worst." • "The Dynamic Hypothesis made the mapping less daunting…the most beneficial part of class is working on models, I find it frustrating trying to learn on my own." • "It's difficult to put all we see in class together on the homework, and how to find my mistakes in the models."	• "The Dynamic Hypothesis is critical in stock-flow modeling because it will enable me to focus solely on the problem, setting limits to my model." • "It has been a frustrating journey but I am much more proficient in Vensim…it takes time to learn the proper equations." • "Vensim has taught me to be patient but consistent and never give up, as my model problems were resolved with knowledge and patience." • "After homework 2 I can easily maneuver Vensim, I'm feeling more confident in my capabilities." • "Vensim improves my knowledge in equations and allows me to think more analytically." • "Vensim comes with a frustrating learning curve but improves my ability to think about complexity. I know see simple issues as complex." • "It's changed my thinking pattern by improving the way I reason." • "Modeling is about broadening your view of everything that directly or indirectly effects your stocks."
Comprehension of SD language and process	Summative mean of 23 out of 25	**Course in currently in progress; results to be presented at Cambridge meeting**
Dynamic reasoning and model analysis	Summative mean of 17 out of 20	↑
Task completion of model creations	Summative mean of 23 out of 25	↑
Complexity of semester projects (mean # of feedback loops)	11.8	↑
Post-test average	66%	73%
Student ratings of instruction (SRI)	(5 pt. scale)	(5 pt. scale)
• Value	4.4	4.2
• Enthusiasm	4.6	4.7
• Organization	4.2	3.8
• Group interaction	4.3	4.3
• Ind. rapport	3.6	3.6
• Breadth of coverage	4.6	3.7
• Exams/grades	4.0	4
• Assignments	4.4	4
Consensus comments on SRI evaluations	Structure needs to be revamped and reorganized; slides not helpful when working on own models; more hands on activities.	Course challenged my critical thinking; Broadened my thinking pattern; Extremely challenging since had to learn so much on our own.

6. Reflection on performance gains through the competence development framework and future directions for the course framework

> "This class has a reputation that I believe is reasonably well deserved for having a heavy workload. The reason for that is clear. I can't teach you anything. All that I can do-- all that we can do, is create an opportunity for you to learn for yourself. You have to do it, try it, practice it, if you're going to develop the capability." – John Sterman, Fall 2013, Introduction to System Dynamics: Overview (available on Youtube).

System dynamics (SD) is a rigorous scientific method that like many other fields of study requires discipline, attention, focus, skill, and patience. As most instructors that have not been formally trained in SD but were self-taught with the help of short-courses, workshops, or some other minimal training opportunities, initial course design mimicked the way they were taught, focusing on lectures that build up to students working on their own projects. This style of teaching is one based on teaching styles such as sensing or judging, where learning is centralized, students have a narrow range of choices, and the classroom is orderly and has a strict schedule (Lawrence 1993). On the other hand, the intuitive and feeling styles give students a wide range of choices, have students participate in groups, try to provide both praise and criticism, encourage independence, and will move around individual students in class to help them. As teachers recognize their own teaching and learning styles they are better equipped to address students through the students own learning style (Torres and Cano 1994).

Whether one instructor has been formally trained in SD or not, anyone who has practiced SD knows that it requires active learning, independence and creativity, and thoughtfulness to seek help when models get stuck. Acquiring SD skills is an act in active learning. A meta-analysis of STEM courses taught traditionally versus those based on principles of active learning showed that students performed better by 0.47 standard deviations, reduced failure rates by 12%, and that grade point averages were raised 0.3 points, helping students who are risk of leaving become persistent students (Freeman et al., 2014).

Each of the adjustments described in section 4 (Course design and evaluation of student-learner outcomes following the competence development framework) were important for both the students and instructor because they are helped move the course from a traditionally lecture taught course (emphasizing class material, concept inventories, and applications to student applied projects) to a course that emphasized active learning (emphasizing more in-class activities, modeling examples, and open discussions). Most importantly, the changes were implemented in the style and direction of the instructor, as very minimal course content actually changed. The delivery and sequence of objectives and activities, informed by the skills described in the competence development framework, provided the guideline for the instructor about what skills to show the students, what skills to ask the students to develop for themselves, and what order to have achieved these skills throughout the course.

Schaffernicht and Groesser (2016) outlined 6 future research avenues that could be traversed within the competence development framework: 1) corroborating and consolidating the framework; 2) defining issues of observation of learners' performances and interpretation of assessment; 3) developing learning activities and teaching sequences based upon the outcomes; 4) exploring possibilities for certification of SD experts; 5) investigating mutual links between research on dynamic decision making and teaching; and 6) adapting outcome to specific application fields. The course design, evaluation, and redesign described in this paper specifically falls under avenues 1 (consolidation of the framework shown in Table 4), 2 (defining observation and interpreting assessment through course pre/post-tests, homework, exam, project, in-class journals activities, and post-course questionnaire), and 3 (sequencing the course based on the learning outcomes and canonical sequence and applying it to a novel domain- agricultural and natural resources management in a diverse classroom context).

Lastly, the competence development framework suggests that the teaching sequence should allow learners to achieve a specified competence development stage with as little time and resources invested as possible. One key learning moment for this instructor was the way in which the time and effort was asked of by the students to achieve their objectives. In the first TAMUK course, where in-class modeling activities were more regulated from the instructor to the students, the core concepts were achieved rapidly but did not ‘stick’ (i.e., the same elementary points had to be reiterated multiple times during student projects that slowed progress down and weakened confidence in their own abilities). However, in the second TAMUK course, the instructor gave in-class activities that were introduced and worked on for a few minutes before proceeding to the next subject material. Any unfinished activity was due the next week of class in which the instructor would the complete the activity as demonstration. Although the students struggled and were more frustrated than may have needed to have been, once they achieved or saw the correct demonstration over the next few weeks, the learning points ‘stuck’ (e.g., after completed demonstrations many students acknowledged that they were close to the correct solution, had tried other unsuccessful solutions to clear model errors, or had recognized the correct solution but was unsure how to implement it. Confidence was built through these struggles as reflected in the journal comments shown in Table 5).

7. Conclusions

This paper presented the design, evaluation, and effectiveness of achieving student learner outcomes of a first- and second-time taught system dynamics (SD) modeling course to students at a minority serving institution focusing on agricultural and natural resource management disciplines. The first course design incorporated concepts from four other SD course examples in similar disciplinary environments (the “applied” sequence) as well as from expert SD educators (the “canonical” sequence; Richardson 2014a). The second course was revised with the goal of strengthening the content, assessment, and evaluation procedures based on the learning outcomes outlined in the SD competence development framework (Schaffernicht and Groesser, 2016). Adjustments to the second course struck a healthier balance between the applied and canonical sequences, supported a more active learning environment, and aided in stronger achievement levels in learning outcomes for the year 2 cohort despite them being slightly poorer performers compared to the year 1 cohort. Although no major adjustments in the course content were made between courses and only a few minor changes in the weekly course outline, future adjustments will be focused on strengthening course content through addition of modeling examples and case studies to widen the number of applications students are exposed to.

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