Introduction to Environmental Modeling: Results from a Three-Year Pilot

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Abstract

A redesigned course employing blended delivery, a flipped format, and modified mastery learning with a buffet approach to assign final grades was used to teach environmental modeling to classes containing approximately 15 dual-level (juniors, seniors, and first year graduate) students pursuing baccalaureate degrees in environmental, civil, or architectural engineering or a graduate degree in environmental engineering. The course introduced “systems engineering” as described by the International Council on Systems Engineering (INCOSE), and the course included explicit consideration of the 5-P’s, namely: 1) people; 2) planet; 3) prosperity; 4) partnership; and 5) peace as described by the United Nations Sustainable Development Goals (SDGs). During the semester, students developed five models, including: 1) a mass balance of the popular game, “Hay Day” by Supercell; 2) taste and odor removal from drinking water using activated carbon for the city of Chicago, Illinois; 3) transferable discharge permits to find the least cost solution for removal of biochemical oxygen demand in the Athabasca watershed of Western Canada; 4) tradeoffs to reduce air pollution and improve ground-level visibility in metro Beijing, China; and 5) improved access to water, sanitation and hygiene (WaSH) in developing communities. The construction of each model included ten steps, namely: 1) providing a narrative of the overall problem; 2) identifying important states and relationship with typical values and ranges of states; 3) developing a pictorial representation of the system; 4) listing critical assumptions; 5) using assumptions to reduce model complexity; 6) creating a mathematical representation; 7) implementing a computational solution; 8) interpreting the results of the computational solution; 9) conducting a sensitivity analysis; and 10) describing lessons learned from the modeling exercise. A unique aspect of this course was the integration of Diplomacy Lab from the US Department of State as the subject material for term-length projects, including: 1) using the internet of things to assess threats from dirty bombs; 2) using epidemiology to assess threats from outbreaks of communicable disease arising from populations of co-located prisoners; or 3) using actuarial science to assess climate threats to the fishing industry in the Caribbean.

Introduction

Modeling, as taught in the discipline of environmental engineering, may include any number of topics, such as: steady-state solutions to materials balance of unit operations with biological, chemical, and physical reactions; numeric solutions to ground water transport and reaction modeling; and regional air-shed modeling with cloud computing[1]. Courses may focus on teaching relevant software[2], and courses may leverage multidisciplinary approaches to introduce modeling as a foundational skill to student knowledge[3]. Faculty have explored the use of modeling to teach sustainability including life cycle assessment and carbon calculators[4]. The Body of Knowledge (BoK) for Environmental Engineering includes multiple opportunities to provide instruction in modeling[5], and concept inventories for core topics to be included in introduction to environmental engineering courses lend themselves to instruction using modeling as pedagogy[6].

Recently, environmental engineering has been challenged with considering broader "systems thinking" approaches while modeling community development projects, including: 1) population; 2) water; 3) food; 4) health; 5) housing; and 6) behavior change[7]. As explained by Professor Amadei, "A systems approach recognizes that, by definition, communities are complex adaptive systems consisting of multiple subsystems and parts (e.g., individuals, institutions, and infrastructure) that are interconnected, are driven by some purpose, follow certain rules, and interact with each other and with their surrounding environment." A more general "handbook" defining the discipline and practice of "systems engineering", available from the International Council on Systems Engineering[8], has been used to train engineers in a variety of topics, including: 1) technical processes (i.e., business mission, stakeholder needs, system requirements, design definition operation, maintenance, and disposal); 2) technical management processes (i.e., project planning, risk management, and quality assurance); 3) agreement processes (i.e., acquisition and supply); and 4) organizational project-enabling processes (i.e., life cycle management, human resource management, and knowledge management). These broader approaches to "environmental systems modeling" in the area of sustainability should aspire to achieve harmony among the 5-P's, namely: 1) people; 2) planet; 3) prosperity; 4) partnerships; and 5) peace, which form the basis of the United Nations Sustainable Development Goals[9], and align with, "The Grandest Challenge of All: The Role of Environmental Engineering to Achieve Sustainability in the World's Developing Regions," where Professor Mihelcic and co-workers call on environmental engineers to consider health, climate, water, energy, and food security; economic development; and reduction of social inequalities as part of education, practice, and research[10].

The purpose of this paper is to share the format and the experiences gained from three offerings of a pilot course entitled, "Environmental Modeling." This course leverages the "systems engineering" approach defined by INCOSE and specifically addresses the "five-Ps". A unique aspect of this course is the integration of Diplomacy Lab from the US Department of State as the subject material for term-length projects, and the course employs a unique format, including: 1) blended delivery; 2) flipped classroom; and 3) modified mastery learning with a buffet approach to assess final grades. Students provided demographic information, personality traits using an online Jung Typology test[11], and a Learning Styles Inventory[12]. Student satisfaction was collected using anonymous, online course evaluations administered using a campus-wide system after the fifteenth week of the course. Over the past three years, a semester-long offering has been delivered to a total of 43 dual-level students, including: 3 via asynchronous distance learning; 9 pursing a degree outside of environmental engineering; and 22 with graduate standing.

Methods

Course Catalog Description. Introductory course in modeling environmental systems. Course focuses on contaminant fate and transport in the environment. Models are developed that include physical, chemical and biological reactions and processes that impact this fate. Prerequisites include Fundamentals (Introduction) to Environmental Engineering and Science, Biological Fundamentals of Environmental Engineering, and Chemical Fundamentals of Environmental Engineering. The framework developed by the Internal Council on Systems Engineering is used throughout the course, and sustainable development reflected by a balanced appreciation for people, planet, and prosperity is utilized as a common theme.

Course Delivery. This course includes: a blended format; a flipped classroom; mastery learning; and a buffet of optional summative assessments used to assign a final grade[13]. Briefly, content delivery via both online digital media and via face-to-face lecture is known as a 'blended format', and some of the benefits include accommodating diverse learning styles (i.e., listening or reading) while improving student satisfaction with content delivery[14,15]. A 'flipped classroom' enhances the opportunity to use inductive learning strategies (i.e., think-pair-share) in the lecture because students preview course content before meeting face-to-face with the instructor[16,17]. As students struggle to 'grok' complex concepts, 'mastery learning' – where students demonstrate knowledge of a concept before moving on to the next concept – provides an opportunity for self-pacing to accommodate individual variation among students and among concepts[18]. And finally, offering a buffet of optional summative assessments – after minimum mastery has been achieved – provides a means of informal grade contracting where students opt to demonstrate their knowledge – and earn a grade – in a manner most consistent with their personal preferences (and likely their perception of the path of least resistance).

Course Content. The course consists of six required modules, including: 1) introduction to: blended, flipped, mastery learning, and buffet assessment; 2) introduction to systems science; 3) Langmuir isotherm and activated carbon for taste and odor removal; 4) Streeter-Phelps and transferrable discharge permits for river water quality; 5) Gaussian plumes and policy evaluation for air shed protection; and 6) application of systems science to sustainable development. An optional term project completes a Diplomacy Lab offering provided by the US Department of State[19].

Course Assessment. Student demographics were collected online, personality traits were measured using online Myers-Briggs testing, and each student completed and recorded a Learning Styles Inventory. Student satisfaction was collected using anonymous, online course evaluations administered through a campus-wide system after the fifteenth week of the course. Mastery learning was assessed using a mixture of instruments including multi-choice vocabulary quizzes, true/false statements from the online, required lectures, and true/false statements from the required readings. Students who demonstrated full mastery before the deadlines stated in the syllabus received a grade of 'C' for the course. To earn a higher grade, a buffet of optional summative assessments was utilized. The optional term project was assessed using rubric grading. Optional summative assessments for the five required units included the construction of models following a ten-step rubric. An optional, comprehensive, cumulative, written final examination was provided as an additional means of summative assessment. As discussed previously[13], the use of a modified, mastery learning approach allows the instructor to identify knowledge that 'must be learned', and to separate this required knowledge from the optional knowledge that 'can be learned'.

Results

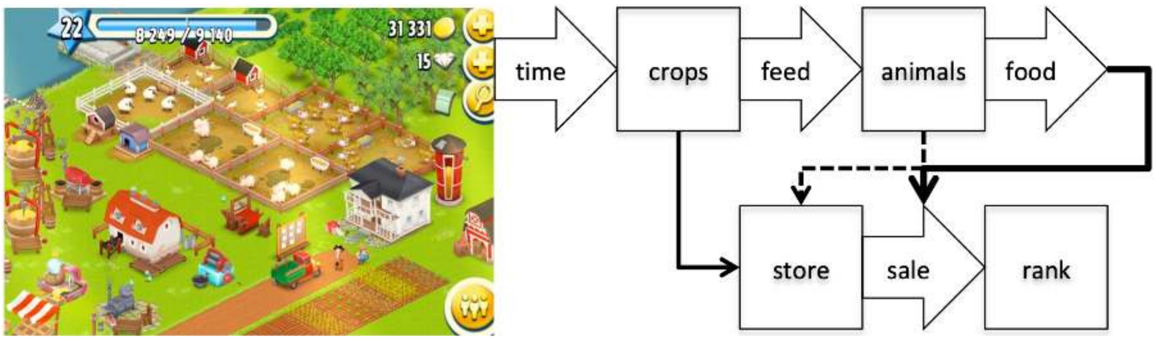
Details of Course Content. While a complete recapitulation of the entire content of "Environmental System Modeling" is beyond the scope of this paper (please contact the author for full course content), four critical elements of the course content are discussed below, in detail.

First, because many students are unfamiliar with a blended format, a flipped classroom, mastery learning, and a buffet of optional summative assessments used to assign a final grade, it is essential to include a course module to introduce these concepts[13]. The author prefers to introduce these concepts to students using "Happy Saint Syllabus Day" as the title for the inaugural course meeting. The author distributes a hard copy of the detailed syllabus to all of the students, and then proceeds to deliver a "traditional" didactic lecture introducing the details of the syllabus through a series of hand written notes on a white board. This in the one-and-only "traditional" lecture delivered during the entire semester. Between the first and second meetings of the course, students are instructed to complete a series of online activities delivered using a Learning Management System (i.e., Canvas or Blackboard or others). Appendix 1 includes the full instructions provided for students to complete before the second face-to-face meeting of the course, and Appendix 2 includes representative questions included in the online student assessment of mastery learning – students may take the online quiz as many times as needed to earn a score of 100% before the class meeting (i.e., to demonstrate complete mastery).

Second, to provide a common frame of reference for students to understand the link between conceptual understanding and computer simulation, each student is instructed to acquire a copy of Hay Day by Supercell[20], and to play the game for a minimum of 15-minutes per session for at least four days in a row. As part of the optional homework assignment, students are invited to construct a model that includes six components, namely: 1) providing a narrative of the overall problem; 2) identifying important states and relationship with typical values and ranges of states; 3) developing a pictorial representation of the system; 4) listing critical assumptions; 5) using assumptions to reduce model complexity; and 6) describing lessons learned from the modeling exercise.

The HayDay game allows students to operate a virtual "farm", including: clearing land and removing hazards to farming; preparing land for planting; selecting crops and sowing seed; waiting for crops to grow; harvesting crops; choosing to store crops in a barn or process crops into animal feed; feeding animals; choosing to store animals in a barn or process animals into human food (i.e., bacon from pigs added to eggs from chickens to create a "breakfast meal"); and selling stores to collect coins that are used to purchase infrastructure (i.e., a larger barn for storage) as well as serving as a means of increasing the rank of the player (i.e., higher rank = more successful virtual farmer). The various steps require different amounts of time (i.e., wheat grows faster than corn), and the value of the various products reflects typical market values (i.e., one piece of bacon is worth more than one egg and the creation of a "breakfast meal" requires four eggs and two pieces of bacon). Through playing the game and developing a mass balance model of the game – considering people, planet, and prosperity – students gain a common frame of reference for class discussion – basic concepts of stocks and flows are explored conceptually and in simulation where time and spatial scales have been modified (i.e., wheat grows in two minutes while corn requires five minutes).

Figure 1. Screen capture from Hay Day by Supercell (left, from Google) and an example of a pictorial representation of the system showing stocks and flows provided as an example to students during active learning sessions (right).



Third, the "majority" of the course is spent exploring three modeling examples, namely:

- module 3) Langmuir isotherm and activated carbon for taste and odor removal;
- module 4) Streeter-Phelps and transferrable discharge permits for river water quality; and
- module 5) Gaussian plumes and policy evaluation for air shed protection.

As provided in Table 1, each of these modules includes list of learning outcomes, a list of required vocabulary terms, a required reading from a textbook, as well as a recorded lecture from the course instructor. Students are required to complete two online quizzes as evidence of mastery of learning outcomes. One quiz includes multi-choice based upon the vocabulary terms found in the required reading. And a second quiz includes multi-choice based upon the learning outcomes and the content of the recorded lecture. Each of these two quizzes is required, and to complete the quiz, a student must repeat the quiz until a grade of 100% (i.e., mastery) is achieved. In this manner, the approach used in this course – blended, flipped, modified mastery – ensures that the learning objectives are fully met for every student. Each module also includes an optional exercise to construct a model. Supplementary references discussed with the students as part of the construction of the optional model are also included in Table 1.

And finally, because many students are unfamiliar with applying course material from the classroom to the workplace environment, the author has found it is helpful to include a hands-on, experiential learning opportunity as part of every course. For "environmental modeling", Diplomacy Lab from the US Department of State is used as the subject material for term-length projects, including: 1) using the internet of things to assess threats from dirty bombs; 2) using epidemiology to assess threats from outbreaks of communicable disease arising from populations of co-located prisoners; or 3) using actuarial science to assess climate threats to the fishing industry in the Caribbean. For example, in the Caribbean there are approximately 200,000 subsistence (artisan) working in two-dozen countries. Each year, during hurricane season, these fisherfolk face increased risk due to intense storms, including tropical cyclones (hurricanes). To

Table 1. Learning outcomes, vocabulary terms, required reading, and optional supplementary references used during model construction are included for modules 3, 4, and 5.

Mod	Learning outcomes	Example vocabulary terms	Required reading	Optional reading
3	1) recognize the relationship between isotherms and chemistry 2) define important physical characteristics for activated carbon adsorption 3) describe the use of activated carbon in drinking water treatment 4) appreciate the application of systems thinking to the design of activated carbon drinking water treatment systems	Ad/absoption Langmuir Freundlich Empty bed contact time (EBCT) Particle size distribution (PSD)	Chapter 15, Adsoprtion, MWH Water Treatment Principles and Design [22]	[23, 24, 25, 26, 27,28]
4	1) describe the derivation of the Streeter-Phelps dissolved oxygen sag equations 2) define important physical and biological characteristics impacting dissolved oxygen levels in streams and rivers 3) recognize the use of optimization routines to identify best possible scenarios among alternative options 4) appreciate the application of systems thinking to the evaluation of tradeoffs between treatment and economics to protect water quality	Assimilative capacity Non-point sources (NPS) Biochemical oxygen demand (BOD) 7Q10	Chapter 4, Water Quality Management, Introduction to Environmental Engineering [29]	[30, 31, 32, 33]
5	1) describe the derivation of the Gaussian Dispersion model for point source air pollution 2) define important meteorological characteristics impacting pollution in air sheds 3) recognize the use of optimization routines to identify best possible scenarios among alternative options 4) appreciate the application of systems thinking to the evaluation of tradeoffs between treatment and economics to protect air quality	Anthropogenic sources Micro/Meso/Macro-scale Coriolis effect Lapse rate Electrostatic precipitator (ESP)	Chapter 6, Air Pollution, Introduction to Environmental Engineering [29]	[34, 35, 36, 37]

provide fisherfolk with insurance for loss of income, gear, vessels, and shore-based infrastructure due to severe weather, the US Government, in partnership with the World Bank and the United Nations Food and Agriculture Organization, created COAST – the Caribbean Ocean Assets Sustainability faciliTy – as the first-ever global example of parametric insurance in the fisheries sector[21]. COAST insurance is designed to incentivize fisherfolk to reduce their exposure to extreme weather – taking preventative action before a storm – and to build back better – using insurance funds to make purchases that will survive future storms. The optional term-length modeling assignment undertaken in "environmental modeling," allows students to explore the relationship between risk assessment (i.e., estimating potential losses due to storms) and risk management (i.e., preventing losses due to storms) using finance as a tool (i.e., assigning a monetary value to goods and actions). Students construct a ten-step model that includes the 5-P's, namely: people, planet, prosperity, partnership, and peace, and rubric grading is used to assign a grade.

Details of Pilot Results. A new course, "Environmental Systems Modeling" was offered in the Autumn of 2016, 2017, and 2018 to a total of 43 students. Table 2 presents a summary of course demographics. As part of the Required, online lecture for Unit 0, students were directed to complete an online Learning Styles Inventory and a Myers-Briggs Personality Test. The results of these assessments were captured in questions included in the Unit 0 Required lecture quiz (see Appendix 1, below). Additional student demographics including gender and enrollment status (i.e., distance student or face to face student; Graduate student, Senior, or Junior standing; and degree program) were collected from information provided by each student and cross referenced with the database maintained by the Registrar.

Of the 43 total students who participated in the three course offerings, the classes approximately doubled with each offering (from 7 to 14 to 20 students). Each class was between 30 and 60% female. Visual and Auditory were the preferred, single strongest Learning Styles, but a consistent minority of students documented a preference for two or more styles. Among the results of the Myers-Briggs Personality Test, the Jung Typology for "source of energy" indicates a near equal balance for Introversion and Extroversion, which may be considered somewhat surprising for a class predominantly of engineering students who are often stereotyped as "shy". The results for how students "gather information" indicates a near equal balance for Intuition and Sensing, which indicates an approximately equal number of students who use "gut feelings" and "tradition". The results for how students "make decisions" indicate a preference for Thinking over Feeling (i.e., 26 individuals versus 17), which may indicate a preference for "logic" and "rules". And finally, the most significant difference for Jung Personality Type was observed in a strong preference for Judging over Perceiving (i.e., 33 individuals versus 10), which likely indicates a strong preference for "order" and "instructions". These trends have been reported previously for students in our department[38], and based upon these trends in Jung Personality Type, the use of clear instructions (i.e., For Your Information, FYI.doc file) has been included as part of each course unit (i.e., Exhibit 1, above).

In the Autumn 2016 offering, no students were enrolled via distance. In Autumn 2017, 1 student was enrolled via distance, and in Autumn 2018, 2 students were enrolled via distance. This modest increase in distance enrollment is consistent with the enrollment trends observed in other classes in our department, and reflects an increase in the number of total students enrolled via distance.

The majority of students in the class held Graduate status, while students with Senior status were enrolled in "Environmental Systems Modeling" during their penultimate semester before graduation. Given the maturity of the student population, it was somewhat surprising and disappointing that the results from course evaluations, discussed below, represented limited participation.

Table 2. Demographics of a total of 43 students enrolled in three course offerings of "Environmental Systems Modeling" in the Autumn semester of 2016, 2017, and 2018.

	Autumn 2016	**Autumn 2017**	**Autumn 2018**
	N = 9	N = 14	N = 20
Gender			
Male	6	6	12
Female	3	8	8
Learning Styles Inventory			
Visual	3	5	6
Auditory	3	7	5
Kinesthetic	1	1	3
V, A, K all equal	0	1	4
Two higher than third	2	0	2
Jung Typology			
Extrovert (E)	5	8	9
Introvert (I)	4	6	11
Sensing (S)	4	7	10
Intuition (N)	5	7	10
Thinking (T)	6	8	12
Feeling (F)	3	6	8
Judging (J)	7	9	17
Perceiving (P)	2	5	3
Enrollment status			
Distance	0	1	2
Face to face	9	13	18
Graduate student	4	7	11
Senior standing	5	5	8
Junior standing	0	2	1
Civil Engineering	1	1	4
Environmental Engineering	7	12	15
Other	1	1	1

And finally, the majority of the students were enrolled in the Environmental Engineering degree programs, a smaller number were enrolled in the Civil Engineering degree programs, and a few students enrolled in other programs also completed the course. Therefore, the student responses to course evaluations conducted at the end of the semester should be interpreted as including primarily students who have a “vested interest” in the course content.

A summary of final grades for “Environmental Systems Engineering,” is presented in Table 3. In the first offering of the course, an overwhelming majority of the students elected to complete optional assignments to earn a grade of “A”. Interestingly, in subsequent offerings of the course, the number of students completing the optional assignments to earn a grade of “A” appeared to diminish. The instructor noted that class attendance was lower on optional days, and fewer students opted to complete the optional homework assignments. There is no immediate explanation for this change in behavior of the students through the three course offerings. Future studies should attempt to ascertain if there is a “reason” for students electing to ignore or not-complete optional assignments to earn a higher grade.

Figure 2 presents a summary of student satisfaction for Autumn 2016, Autumn 2017, and Autumn 2018 collected using an anonymous, online course evaluation administered by the institution during the fifteenth week of the course. For Autumn 2016, the rate of response (N=4) was less than half of the full course enrollment (N=9). This result – a lack of students completing the online, anonymous course evaluation – is consistent with the overall low level of participation in most end-of-semester evaluations conducted at our campus – and calls into question the value of these data for interpreting teaching effectiveness. Five questions were included in the assessments. The first three questions – assessing the quality of the course independent of the instructor; the instructor’s concern for students; and the overall teaching effectiveness of the instructor – are required by the institution. The fourth and fifth questions – tell other students about the instructor’s communication skills; and recommends the instructor to other students – are required by State law.

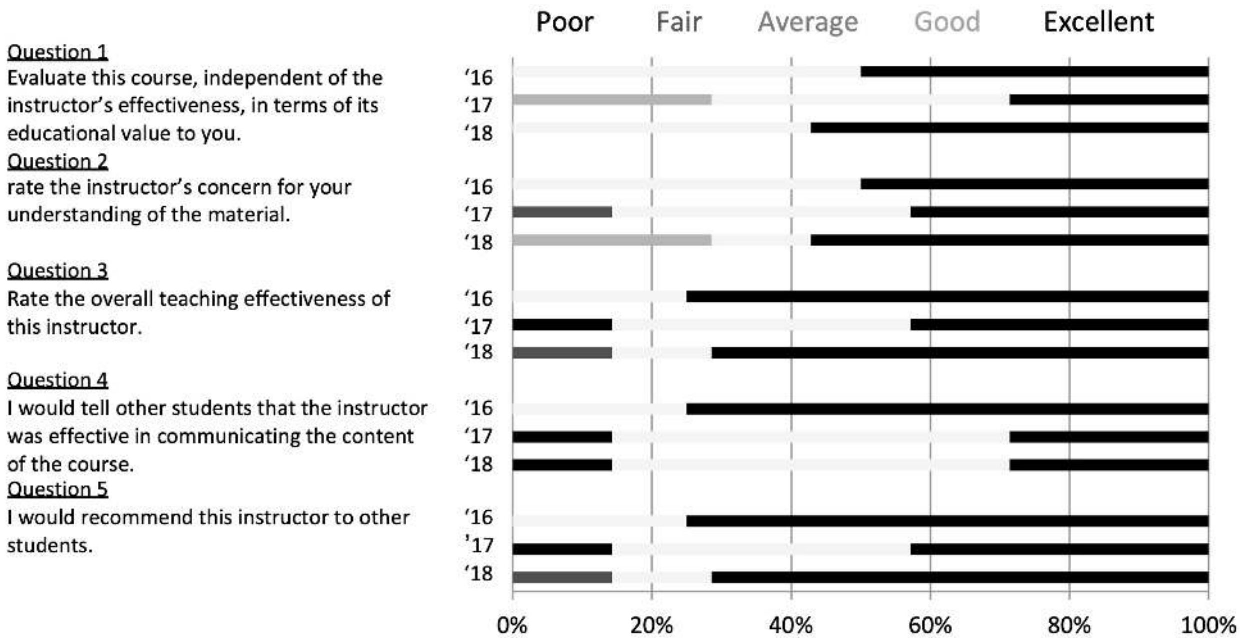
Table 3. Summary of final course grades for “Environmental Systems Modeling” for the Autumn 2016, 2017, and 2018 semesters.

Final grade	Autumn 2016 (N=9)	Autumn 2017 (N=14)	Autumn 2018 (N=20)
A	8	11	9
B	1	3	9
C	0	0	2
F	0	0	0

For the fifteenth week of Spring 2016, the results for all five questions demonstrate a strong positive response. Although a limited sample size, the results from the first offering of this course indicate that at least some students were satisfied – perhaps even a majority when considering the final course grades (Table 3, above).

For Spring 2017, the same five questions were administered during the fifteenth week of the course. The response rate (N=7) was equal to one-half of the full course enrollment (N=14), and again reflects the poor rate of response typically observed on our campus. The majority of responses were either “excellent” or “good”; although the number of “excellent” responses in the second offering of the course was less than the number during the first offering of the course – perhaps suggesting a different perception of the course and the instructor, or perhaps simply due to the small sample size. For Spring 2018, again the same five questions were administered during the fifteenth week of the course, and the response rate (N=7) represented a minority of the enrollment (N=20). While the overall response was generally positive, it is interesting to note that at least one student expressed significant concerns – an assessment of "poor" or "fair" in both the second and the third offering of the course.

Figure 2. Results of student assessments conducted after the fifteenth week of the semester in Autumn 2016, Autumn 2017, and Autumn 2018. Responses are reported normalized to one hundred percent.



To supplement the numeric scores reported in Figure 2, representative "additional comments", edited to increase readability, have been provided in Appendix 3 for all three semesters. These comments are provided as representative of the "free responses" received from students. To aid in evaluation of the comments, the similar comments have been grouped into three categories, namely: 1) about the instructor; 2) about the course format; and 3) about the course content. Comments A and B reflect a strong reaction by the students to overt attempts by the instructor to leverage the flipped classroom to include active learning as part of face-to-face lectures. This type of response is consistent with other courses offered by the instructor[13], and suggests a general discomfort with active learning in the classroom. Comment C reflects annoyance by some students when the instructor explains and re-explains classroom rules included in the syllabus. To address this issue, the instructor includes a comprehensive unit 0 as part of every class, and reviews the syllabus during the first class meeting. Because the format is significantly different from prior courses, and because many of the students are of the "Judging" personality type, it is not uncommon for the instructor to witness exasperation by some students, as other students need time to "grok" the course format. Nonetheless, a number of students express great satisfaction with the blended, flipped, mastery format as reflected in Comments D, E, and F. The ability to secure a minimum passing grade of "C" by completing required assignments, allows students maximum flexibility to demonstrate additional competence with the material to earn a higher grade of “B” or “A”. Finally, Comments G, H, I and J reflect the diversity of students in the class and the differences in expectations of students who are completing their baccalaureate degree as compared to full-time graduate students (i.e., Comment J). Future work by the course instructor will continue to address the apparent disconnect in offering a dual-level course with both undergraduate and graduate students; perhaps some additional modifications to the required and optional exercises will result in an improvement when dual-level students occupy the same classroom?

As outlined in the introduction of this paper, the instructor made a conscious choice to introduce “systems engineering” and to explore the 5-P’s as part of this course, “environmental modeling.” Therefore, although some students expressed concern with the need to teach “specific software,” a number of students appreciated the flexibility of mastery learning and specifically highlighted the benefits of “big picture” learning.

Discussion

Recently, there has emerged a call to include “systems engineering” or “systems thinking” as part of “environmental modeling,”[7]. To address this need, a new course was created entitled, “Environmental Modeling.” This article summarizes the course description, delivery, and content. The results of assessment of three offerings to a total of 43 students are presented. The course included a blended format, a flipped classroom, mastery learning, and a buffet of optional summative assessments used to assign a final grade. The course content utilizes available resources from INCOSE as well as includes the 5-P’s approach advocated by the SDGs. While some students resisted the emphasis on active learning (i.e., “… shy students may feel intimidated by the discussion format”), other students expressed satisfaction with mastery learning (i.e., “… the grading system encourages students to take risks … without worry about math mistakes”), and other students expressed satisfaction with the course content (i.e., “… I like the triple bottom line – including people and prosperity in addition to planet”).

The instructor learned: (1) a substantial investment of time is needed to create a course using blended, flipped, and mastery pedagogy; (2) a buffet approach to summative assessment to assign a final grade creates both new opportunities and new challenges as compared to a more “traditional” grading scheme; and (3) hands-on term-length projects focused on the practice of learned skills significantly stimulated discussion and created tension among undergraduate and graduate students in a dual-level course (i.e., “make this a graduate only course so that we could have a higher-level discussion without undergraduates…”).

Future work should: 1) follow-up with students to identify the value of the course in their professional practice; 2) assess changes in student attitudes and beliefs from before and after the course; and 3) replicate the course at other institutions to demonstrate effectiveness independent of the personality of the instructor and with a variety of student types.

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Appendix 1. The instructions provided to students to complete their first, online, blended, flipped, mastery exercise in "Environmental Modeling."

Course:	Environmental Modeling
Unit:	0 Introduction to Blended, Flipped, Mastery Learning
Document:	FYI

The objective of this unit is to familiarize students with the technologies used in this course, to aid students in creating a personal plan for success in this course, and to begin to establish peer-peer interaction among students.

By the end of this module, students should:

1) be able to access Canvas for course materials
2) be familiar with the vocabulary and concepts that differentiate classroom and online education
3) understand the concepts of ‘adult learning’ and ‘mastery learning’
4) have, in mind, a plan for successfully completing this course
5) complete at least one discussion board assignment
6) OPTIONAL complete a discussion board assignment to evaluate the pro’s and con’s of MOOCs

Detailed instructions of REQUIRED exercises (NOTE: All required exercises must be completed before the deadline stated in the syllabus. The completion of all required exercises is necessary to earn a grade of ‘C’. If you do not complete all required exercises before the deadline stated in the syllabus, you earn a grade of ‘F’ for the entire course.)

1) download the file entitled, ‘vocabulary.doc’
2) read the following blog entries making notes about the vocabulary terms:
    a. Making the transition from classroom to online education
    b. The difference between online and on campus courses
    c. How to ace your online class
    d. NOTE: these three blog entries are available for download as PDF files from the folder entitled, ‘copies of blog entries’
3) using your notes, complete the online vocabulary quiz entitled, ‘Unit 0 REQUIRED vocab quiz’ (NOTE: You may retake this quiz as many times as you wish before the deadline stated in the syllabus. You must achieve a 100% to complete the quiz and to earn a grade of ‘C’ for this exercise. If you do not achieve a 100% before the deadline stated in the syllabus, you earn a grade of ‘F’ for the entire course.)
7) open the folder entitled, ‘REQUIRED lecture’
8) listen to the MP3 files and review the accompanying Power Point slides available in PDF format. Each MP3 file is approximately 15 minutes in length. (NOTE: you may wish to listen to the audio at an accelerated speed. ALSO NOTE: URLs are provided in the accompanying Power Point slides for you to access online tools to complete your Learning Styles Inventory and your Myers-Briggs Personality Test)
9) complete the online quiz for the required lecture entitled, ‘Unit 0 REQUIRED lecture quiz’ (note: You should take this quiz ONE time. You will need to complete the required lecture BEFORE you take this quiz so that you have the information necessary to document your Learning Styles Inventory and your Myers-Briggs Personality Test.)
10) complete the required discussion board activity entitled, ‘Unit 0 REQUIRED online introductions’
    a. you are required to complete TWO separate posts, which include the following:
    b. Post One: a brief introduction of yourself suitable for reading by the entire class that includes:
        i. (1 pt) your complete name and what you liked to be called;
        ii. (1 pt) your student status (i.e., full/part time, and field/major);
        iii. (1 pt) brief expectations for the course (i.e., I’d like to learn a lot, I’d like to earn an ‘A’, I’m taking this course because it’s a requirement, etc);
        iv. (1 pt) what you'd like to learn from the course (i.e., the practice of environmental health, environmental regulations, etc);
        v. (1 pt) your plans for how to tackle a course that uses a blended format, a flipped classroom, and mastery learning plus a buffet of summative assessment opportunities for assigning a final grade; and
        vi. (1 pt) how you like to communicate online (i.e., email, Twitter, etc).
    c. Post Two: (1 point) at least one professional and encouraging comment in response to an introduction posted by someone else in the class.

Detailed instructions of OPTIONAL exercise:

1) complete the optional discussion board exercise entitled, ‘Unit 0 optional MOOC article’
a. search the popular press (The Chronicle of Higher Education is one good source) for a news story discussing the 'pros' and ‘cons’ associated with MOOCs (i.e., read about edX or Coursera or Udacity or others).
b. You need to make TWO separate posts, which include the following:

c. Post One: (10 points total) a brief summary of the article that includes:
   i. (1 point) article citation (publication name, article name, author, date of publication, page numbers, URL, etc)
   ii. (1 point) what is a MOOC
   iii. (1 point) what is one 'pro' of a MOOC
   iv. (1 point) what is one 'con' of a MOOC
   v. (6 points) a concluding statement that supports or refutes the statement, "I believe (or do not believe) that MOOCs will revolutionize learning in higher education because…" Cite specific examples from the story and reference any external citations employed in your summary (your statement should be less than 250 words).
d. Post Two: (10 points total) at least one professional and thought provoking criticism of someone else's concluding statement (i.e., While I agree with your assessment, I believe you missed this important point… etc)

Appendix 2. Representative questions used in the online assessment of student mastery learning. Note, students were required to repeat a quiz until a score of 100% was obtained.

Online instructions for the quiz, "You may retake this quiz as many times as you wish before the deadline. You must achieve a 100% to complete the quiz and earn a grade of 'C' for this exercise. If you do not achieve a 100% before the deadline, you earn a grade of 'F' for the entire course."

Select the correct answer:

1) course content is:
a) information relayed by the professor
b) the online equivalent to "class participation"
c) an important means of opening up the lines of communication between a student and the professor
d) designed by instructors to allow students to work at their own pace
e) a student in an online course
f) other students enrolled in the course

2) message board is:
a) the online equivalent to "class participation"
b) an important means of opening up the lines of communication between a student and the professor
c) designed by instructors to allow students to work at their own pace
d) a student in an online course
e) other students enrolled in the course
f) information relayed by the professor

3) email is:
a) an important means of opening up the lines of communication between a student and the professor
b) designed by instructors to allow students to work at their own pace
c) a student in an online course
d) other students enrolled in the course
e) information relayed by the professor
f) the online equivalent to "class participation"

4) according to lecture, a scientist climbs a mountain to:
a) because its there
b) I don't know why
c) to test a new piece of equipment
d) to place a weather station

5) according to the reading, "science is the systematized knowledge derived from and tested by observing nature without the need to perform experiments such as the empirical studies of engineers."

a) false
b) true

6) the "oldest" cycle question is, "which came first, the chicken or the egg?" What's the correct answer:
a) we don't know
b) the chicken
c) the egg

Appendix 3. Representative students comments provided during assessment in all three offerings.

About the instructor:

A. Although it is very clear that the professor cares about student learning, shy students may feel intimidated by the discussion format.
B. Very passionate professor.

About the course format:

C. Please spend less time going over the 'rules'. Yes, the class has a unique structure, but students should read the syllabus.
D. A major strength in this class is the grading system - any student who doesn't earn an 'A' is either lazy or stupid or both.
E. The grading system encourages students to take 'risks' and explore the assignments without worry about 'math mistakes'.
F. Great homework that promoted and rewarded freethinking and 'crazy' answers to challenging problems.

About the course content:

G. The professor talks a lot about less important things, and needs to spend more time teaching us specific software.
H. I enjoyed the focus on the 'big picture' and less emphasis on 'just doing the math' for the models; great discussion!
I. I like the triple bottom line - including people and prosperity in addition to planet (environment).
J. Make this a graduate only course so that we could have higher-level discussions without undergraduates always asking questions.