Innovative Model, Tools, and Learning Environments to Promote Active Learning for Undergraduates in Computational Science & Engineering

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ABSTRACT
This paper presents an innovative hybrid learning model as well as the tools, resources, and learning environment to promote active learning for both face-to-face students and online students. Most small universities in the United States lack adequate resources and cost justifiable enrollments to offer Computational Science and Engineering (CSE) courses. The goal of the project was to find an effective and affordable model for small universities to prepare underserved students with marketable analytical skills in CSE. As the primary outcome, the project created a cluster of collaborating institutions that combined students into common classes and used cyberlearning learning tools to deliver and manage instruction. The instrumental tools for educational technologies included Smart Podium, digital projector, teleconference systems such as AdobeConnect, auto tracking camera and high quality audio in both local and remote classrooms. As an innovative active learning environment, an R&D process was used to provide a coherent framework for designing instruction and assessing learning. Course design centered on model-based learning which proposes that students learn complex content by elaborating on their mental model, developing a conceptual model, refining a mathematical model, and conducting experiments to validate and revise their conceptual and mathematical models. A wave lab and underwater robotics lab were used to facilitate the experimental components of hands-on research projects. Course delivery included interactive live online help sessions, immediate feedback to students, peer support, and teamwork which were crucial for student success. Another key feature of instruction of the project was using emerging technologies such as HIMATT (Highly integrated model assessment technology and tools) [11] to evaluate how students think through and model complex, ill-defined and ill-structured realistic problems.

Categories and Subject Descriptors
K.3.1 [**Computer Uses in Education**]: *Collaborative learning, Distance learning.* K.3.2 [Computer and Information Science Education]: *Computer science education, Curriculum.*

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Experimentation, Verification.

Keywords
Hybrid Learning, Cyberlearning, Educational Technology, MOOC, Model-based Learning, and Computational Science & Engineering Education.

1. INTRODUCTION
The digital technology in the 21st century is characterized by omnipresent smart devices and ubiquitous computing that enables computing to occur anytime and anywhere. This contributes to big data challenges, increasing complexity and rapid changes in technologies. Consequently, marketable skills for technical careers emerge and rapidly change. To harness complex technologies and make sense of the big data, undergraduate students majoring in STEM (Science, Technology, Engineering, and Mathematics) need to learn how to model the associated problems in mathematical formalisms and leverage the computing resources to simulate the problems. In [18], Levy summarized one of three major educational initiatives of a SIAM (Society for Industrial and Applied Mathematics) as follows:

"The Modeling Across the Curriculum, was built around the idea that modeling can build many job skills students need and can be an important educational tool at not only the secondary and undergraduate levels, but throughout the educational experience".

The SIAM-NSF-ASA Workshop on Modeling Cross the Curriculum II [13, 14, and 20] made the following two recommendations to math teachers and STEM education policy makers: Building a pipeline for K16 education in mathematical modeling and connecting math to reality. Computational Science and Engineering (CSE) is an emerging multidisciplinary field of study that incorporates both endeavors recommended above. CSE focuses on the integration of knowledge and methodologies from computer science, applied mathematics, engineering, and science to solve real-world problems. CSE provides the critical mathematical modeling skills and data analytical skills that apply to all STEM fields. Therefore, it is critical that CSE courses and curricula are a viable option for every undergraduate STEM major. [19]. Based on the literature above, the authors of this project identified the following two courses as the corner stones of a CSE curriculum: Mathematical Modeling and Simulation (MMS) and Data Mining and Visualization (DMV).

Many non-research focused higher-education institutions, including most minority-serving and small institutions that the authors of this paper are affiliated, lack the necessary resources and minimal enrollments to justify offering such CSE courses. To help provide CSE educational opportunities for students at small institutions, a proof-of-concept project was funded by National Science Foundation (NSF). The project created a cluster of collaborating institutions that combined students into common classes and used cyberlearning technologies [1] to deliver and manage instruction. The primary goal of the project was to offer three cyberlearning courses in CSE through a coalition of three small universities by sharing resources and pooling students. Another goal was to use short-term summer projects to reinforce student learning and assess student ability to solve real-world problems. The following three key activities were implemented: (a) establish a multi-institution coalition that collaboratively provides CSE courses and projects by combining students from different colleges into a single class and leveraging each college's capabilities, (b) provide general CSE courses organized by computational methods (e.g. mathematical modeling and simulation) rather than domain specific courses such as computational biology; and (c) use cyberlearning technologies to deliver courses. This project provided a feasible model and innovative configuration of educational technology to significantly increase student participation in CSE and a cost effective method to renew courses and curricula.

2. STRATEGY AND IMPLEMENTATION

This section presents the implementation details of the hybrid learning model, innovative educational toolset, new MOOCs (Massive Open Online Course) in CSE, and the active learning environment for both face-to-face and online students.

2.1 Infrastructure of Coalition of Universities and Hybrid Cyberlearning Model

The infrastructure of the coalition was built on the contract that all participating institutions share the workload, resources, and benefits equally through faculty partnership over a period of two years. The Coalition of Universities includes two campuses of Embry-Riddle Aeronautical University (ERAU) - Daytona Beach (DB) Campus in Florida and Prescott Campus in Arizona, and Adams State University (ASU) in Colorado. The authors of this paper who are associated with the coalition of universities took turns developing, reviewing and teaching the three courses in Mathematical Modeling (I and II) and Data Mining. In particularly, Liu at ERAU developed the first draft of MMS course, Ikle at ASU reviewed, revised and adapted Liu's course for ASU one year later. Meanwhile, Ikle developed the first draft of DMV, then, Liu reviewed, revised and adapted the course for ERAU. While Liu offered the first course in MMS in spring 2014, Ikle sat with his ASU students and monitored the course delivery online. Reciprocally, when Ikle at ASU offered the DMV courses in fall 2014, Liu sat with his student at DB Campus of ERAU online. Moreover, Liu and Ikle exchanged courses to teach in the next round (e.g. Ikle taught MMS in ASU in spring 2015 and Liu taught DMV in fall 2015). Therefore, Liu and Ikle both served as the co-developers and co-teachers of each other's course. Consequently, both universities gained a new course in their curricula that were originally developed by a peer university in the coalition. This model not only provided students access to new CSE courses in each year but also provide a cost-effective method for faculty development and curriculum enrichment.

2.2 Cyberlearning Technology to Facilitate Tri-located Course Deliverance

Each of the three courses was taught by a professor in the classroom at one location with physically present students while a small number of students in the other two universities attended the same class in remote classrooms using live two-way communications. The approach of this project is actually a hybrid learning environment that combines traditional classroom and cyberlearning with live interactions between the classmates as well as students and instructors.

The courses at ERAU were delivered at a state-of-art Teleconference Classroom. The major hardware devices are: (1) HD voice audio system with one microphone sitting in front of the podium and two mics hanging on the ceiling of the classroom and multiple well positioned speakers, (2) an auto video tracking camera that was installed on the back of the classroom to video the instructor, (3) a SmartPodium, which integrated the whiteboard with the computer screen by SmartTechnology (home.smarttech.com) on the front podium, and a digital projector installed in the ceiling of the classroom. Besides standard software settings, the computer in this classroom installed the AdobeConnect teleconferencing system to support two-way live communications to the students in the remote classroom. Among all the devices mentioned above, the most important one is the reliable teleconference system that makes the two-way communication possible. The second most critical instrumental factor is the quality of the audio system. Poor quality mics and speakers can be very annoying to the students in remote campuses. Before a new semester starts, a new instructor for such a synchronous online learning course should practice setting up and testing all relevant systems under the supervision of an experienced member of the IT staff.

In our tri-located class, we have a local class and two remote classes. Two modes of the teleconference features most frequently used were the video mode that uses the full screen to show the videos of local and all remote classes and the presentation mode that use the whole screen to show the lecture notes or other software documents of the presenter. The instructor has the ability to promote a participant in a remote campus as the presenter. In presentation mode, about three quarters of the screen of the remote classes shares the screen of the presenter and the right panel of the other quarter screen shows the small size videos of the instructors and other classes. The CSE courses require the instructors to use the presentation mode most of the time. In this case, students in remote campuses are invisible to the instructor unless they ask questions. Because the online students do not have the physical presence in the classroom, students are reluctant to ask questions and consequently can be easily neglected by the inexperienced online teacher. Therefore, instructors of such a hybrid synchronous learning course need to learn how to periodically query the online students in remote campuses. An effective technique we learned was to set a laptop near our SmartPodium which in effect turns the local class into an additional virtual class. The laptop is used to connect the second video camera shooting towards to physical present students so that it enables students in the remote classes to see the students in the local classroom. While the main computer connected with Smart Podium is set in presentation mode, we can set the laptop in video mode to monitor the facial expressions of the remote students. In this mode, the screen of our virtual classroom is equally divided into four sections, one for the instructor shot by the auto tracking camera, the second one is the students in local classroom shot by the second camera, and the other two display the two classes of remote students.

2.3 Innovative Learning Environment

An R&D process was used to provide a coherent framework for designing instruction and assessing learning in which the instructional and assessment methods were aligned with a common idea: Model-based learning and reasoning. Besides traditional grading, the project used emerging technologies such as HIMATT to evaluate how students think through and model complex, ill-defined and ill-structured realistic problems [16].

All courses employed model-based learning and reasoning from first principles and were aligned with SIAM's CSE educational goals [19]:

1. Students can construct qualitative models using first principles of the domain.
2. Students can translate their qualitative models to mathematical models which require them to understand the underlying equations governing first principles.
3. Students can use mathematical modeling and computational software tools to create their mathematical models, design data collection systems, and interpret experimental data.

The three cyberlearning courses were: (1) Mathematical Modeling and Simulation-1 (MMS-I). This course was often titled Introduction to Computational Science and is included in most CSE curricula. It was first taught at ERAU-Daytona Beach. (2) Mathematical Modeling and Simulation-2 (MMS-II). This course was a revised version of the computational physics course and was first taught at ERAU-Prescott. This course provided a test case of modifying a domain-specific CSE course and making it non-domain specific: structuring the course by computational method methods rather than by types of physics problems. (3) Data Mining and Visualization (DMV). This course reflected a change in CSE degree programs [2]. Data explosion is a major trend and the resulting challenges have created tremendous employment opportunities in data-driven business, scientific research, and counterterrorism. All courses consisted of modules organized by computational method rather than organized by applications. When the organizational unit was based on the method of computation rather than the domain of application, it made the development of course modules for distributed teaching much easier. Also, modularization provided the flexibility needed to adapt courses to the particular interests and needs of students. Each module included a recorded demonstration and lecture and interactive instructional activities.

The project has been committed to course-based research experiences (CURE) which connect math with reality [14]. The primary instructional strategy of the project was for students to work in study teams solving problems using online resources created or selected for the particular topic. Since students represented multiple academic disciplines, each module included problem sets and supporting materials for the different domains. Each module consists of instruction on (1) a prototype problem, (2) tools for creating a conceptual model, (3) mathematical modeling tools, and (4) resources for each of the various academic disciplines. Each module was designed by clarifying and defining objectives and selecting or developing problems and examples. After completing the team course projects the students in remote campuses had the opportunities to participate in a two-week long summer research workshop. The purposes of the workshop were to reinforce learning and assess the students' problem-solving ability. The workshops were based on the ACE program: Analysis, Computation, and Experiment [5].

We will use a couple of examples from the MMS to illustrate how the course objectives were implemented and accomplished. MMS (http://modelsim.wordpress.com) was designed for college sophomore and junior students who have taken multivariate Calculus and are familiar with at least one programming language. The goal of the course was to learn how to use the advanced mathematics language such as matrix algebra and calculus as well as software tools to solve real-world problems. The topics of the course covered broad interdisciplinary problems whose solutions heavily depended on mathematical modeling and simulation. More specifically, objectives were to

1. Introduce the major categories of mathematical models as well as their modeling languages and tools
2. Expose students to a broad variety of real-world applications of computational mathematics
3. Train students how to follow mathematical modeling process to conceptualize problems, validate their models and verify their solutions
4. Improve students' capability to make judicious tradeoffs in their modeling assumptions to abstract complex problems
5. Provide students with hands-on experience in the use of computational software tools such as MATLAB, NetLogo, STELLA, etc. to model and simulate mathematical problems, and present visual representations of the problem space as well as alternative solutions.
6. Provide students with teamwork experience to solve problems beyond the scope of textbook exercises and typically beyond the scope of effort for one person.

The course includes five modules: 1: Model Classification and Modeling Methodology, 2, Matrix Algebra, 3: Data and Error Models, 4: Agent-based Modeling, and 5: Modeling System Dynamics. The system engineering modeling methodology in module 1 ([7]) emphasizes (1) building of conceptual models before the mathematical models to increase traceability of model assumptions and first principles, (2) separating concerns and refining models iteratively to divide and conquer complexity, and (3) verification and validation (V&V) based on empirical data and mathematical analysis. The other four modules were divided into three units and each unit starts with an interesting application and develops a core concept to model. For example, to illustrate how we designed the course to develop deep learning, but starting at low thresholds, the concept of Eigenvectors was revisited four times with increasing depths at each time. In the first unit, we adapted a module about the Leslie transition matrix and its applications to Biology from a paper by A. Shiflet and G. Shiflet [12]. The Eigenvector was informally and intuitively introduced as the stable population distributions of the Leslie population model. In the second unit, we inspected the direction changes of the vectors under geometric transformations such as mirror reflection and projection. The students found that most transformations have some invariant directions except rotational matrices. Therefore, the concept of Eigenvectors was identified informally again. We provided its formal definition in the third unit and adapted an example of its application to the Google page ranking problem from a popular paper [3] by Bryan and Leise. In the fifth module, the Eigenvectors and their geometric interpretations were identified again from the solutions of the initial value problem of a linear ODE system.

The third module demonstrates the uncertainty and inevitable errors for modeling real world applications. Instead of seeking exact solutions, the students learned that when dealing with real world applications it is more practical to search for optimal solutions that minimize the estimated errors based on observable data. Random variables, Monte Carlo methods, Markov chain were introduced in the first unit. Students learned how to use the stochastic transition matrices to model and simulate the uncertainty of outcomes for real-world financial and business problems. Students also discovered that great differences of outcomes can be significantly mitigated after the corresponding model was simulated thousands of times. The second unit focused on multivariate data fitting techniques and applications of data-driven prediction models. The third unit presented the concepts of error models, linear and nonlinear Kalman filters, and their applications to GPS. MATLAB was used to simulate how the Kalman filters could help to pinpoint our positions in feet range error by using the signals from 4-6 semi-geosynchronous GPS satellites that were 25,000 km above the earth. Liu learned about this application at a conference in 2005 which was the major inspiration to initiate the MMS course [10]. It takes 27 class hours to cover all lessons of the first three modules. The course included a mid-term test and an individual conceptual modeling project was due two weeks later. In the last month of the course, the focus was shifted to team projects and the instructor met each team separately at least once a week to check their progress and answer questions. The instructor only gave lectures once a week to give an overview to both agent-based modeling and system dynamical modeling. The students were encouraged, but not mandated to learn the last two modules online based on the needs of their team projects.

2.4 Learning Assessment

Our summative learning assessments included: (1) student feedbacks and survey data, (2) peer reviews of the online published course materials and student paper work samples by external experts such as the external evaluator Dr. Michael Spector and instructional designer Dr. Jerry Klein, and (3) student research outcomes from coauthored publications and presentations. We used traditional assessment instruments to measure student learning including tests that required students to explain and predict events as well as rubrics to grade student conceptual and mathematical models. However, knowledge-based tests are not sufficient. These instruments do not measure how an individual thinks or might approach other projects and problems [4]. We created assessment instruments using the HIMATT learning assessment methods and tools [11] and 16]. HIMATT is a validated technology that essentially captures the student's conceptualization or model of a complex situation and compares it with a reference model that could be an expert's model, to assess progress towards expertise, or models of that student at an earlier time to assess progress from previous states of complex thinking. In order to implement this technology, the project faculty created problem scenarios that were open-ended and not fully specified so as to require students to think about the nature of the problem and possible alternative solution approaches but not so detailed that students could actually provide concrete solutions. Four questions were then asked of students and experts: (1) what are the key factors influencing this problem situation, (2) describe the nature of each factor, (3) how are the factors related, (4) describe the nature of each relationship among the factors. HIMATT uses analyzing pairs of resulting conceptualizations with regard to surface, structural and semantic similarity. In general terms, experts tend to see more relationships among factors and tend to identify key nodes or concepts that influence the situation in comparison with fewer experienced persons, and that pattern held up in this study.

Student feedback included one survey in the beginning and two evaluations in the middle and the end of the semester. The survey had 21 questions about the students' academic and demographic background as well as their beliefs about CSE courses, cyberlearning vs face-to-face learning, and team work. The two evaluations consisted of four items focusing on assessing the students learning outcomes and the need for improvement: (1) List the primary ways your learning has been enhanced in this course, (2) List the primary ways that your learning has been hindered in the course, (3) List the primary ways you could enhance your own learning in the course, and (4) Some recommendations. An independent evaluator conducted the evaluations, summarized the data, and then, reported to both the instructor and the external evaluator. The summary report included the samples and frequencies of positive and negative feedbacks as well as recommendations. It is difficult to quantify the success of this type of data and summarize the feedback of all 8 classes. It is obvious, however, that positive feedback comments were dominant, and constructive criticism was evident; in addition, there was a very low drop/fail rates (0 to 10%) of all classes comparing with other math courses at ERAU (10%-30%). Indeed, the evaluations and formative assessments were more helpful in making timely instructional adjustments than measuring success. For example, in the middle term evaluation of MMS I in the spring of 2014, the remote students complained that the poor audio quality hindered their learning. To respond to this issue, the instructor obtained advice from IT experts and purchased three sets of the high-end quality audio and mic systems called Konftel. In two weeks, the desktop computer based audio systems in all three classrooms were all replaced with the Konftel systems. As another example, we observed that students paid little attention to the lectures that seemed irrelevant to their own team projects, which were assigned in the last month of the course. Therefore, we changed the course delivery method for the last month accordingly in next term: Instead of lecturing to the whole class three hours per week, the class met once a week to address logistics and common issues and an hour mandatory meeting with the instructor was scheduled with each team to report on progress, obstacles, and work plans for the next week. Consequently, the students were more engaged and prepared for their meetings with the teacher.

Team projects assigned for the MMS and DMV courses are presented here to illustrate how course objectives were met. In the last month of a semester, the emphasis shifted to team projects. The intention of projects was to cultivate students' ability to solve real-world problems. Project problems and grading rubrics are similar to those of the Mathematical Contest in Modeling (MCM, https://www.comap.com/) sponsored by COMAP (Consortium for Mathematics and its Applications). After the 10th week of the semester, the instructor provided two or more open-ended problems for their team projects. One is a continuous modeling problem and the other is a discrete modeling problem. In particular, the rubrics of the project grading included: 20% paper presentation, 10% for oral presentation, 20% for conceptual and math modeling, 10% for simulation, 20% for mathematical analysis, and 20% for verification and validation of the model.

One MMS problem was to model and simulate a safe landing gear for aero robots. Students had two weeks to build conceptual models that captured the major factors and their qualitative relationships. The conceptual model required students to answer the four questions mentioned listed above. A month before the end of the course, teams of 4 students were assigned to build the mathematical model and simulate for the problem using Stella. The won team of students had the opportunity to participate in a paid summer research workshop and conduct the experiments in ERAU's Wave Lab (see Figure 1, safe landing gear for weather balloon problem). An example of discrete modeling is students in MMS were asked to model and simulate the emergent evacuation of the vulnerable residents in a coastal city when a tsunami hits the city. The basic geographic information such as the elevation and the population density of each city district were given in a data sheet. The territories of the districts are approximated as grids of uniform sizes and the streets are horizontal and vertically lined up to separate districts. The students were given 40 school buses and asked to select only one exclusively used street from east to west to evacuate the vulnerable residents who could not drive or had no cars. Two teams chose this project and both used the agent-based modeling approach for the problem. One team wrote their own Java program, and the other team chose to use NetLogo to model and simulate their solutions. While EXCELL, MATLAB, Stella and NetLogo were frequently used in case studies and students learned how to read the programs and diagrams, the instructor did not teach students how to program in those languages and tools. Instead, free online tutorials were provided to students so they could learn as needed. Teams were assigned based on complementary knowledge and skills so that each team had at least one student proficient in programming. An observable outcome was that students often demonstrated their ability of learning-on-demand when inspired by interesting problems ([6]). For example, one student who used NetLogo to program their evacuation model learned how to use NetLogo from scratch and did an excellent job in less than a month. He is continuing his project and intends to submit a paper for publication.

The DMV (http://dataminedvis.wordpress.com/) instructional design and course delivery strategy are similar to that of the MMS. Since DMV is a course that is offered by most universities, the content selection was less challenging than the MMS course. Two aspects that made our DMV course differently were the team projects: (1) The teams sometimes had to collaborate with students in a remote campus and (2) some projects have an industrial co-mentor in addition to the instructor. We also allocated the last month of the course for the team projects. The instructor selected the won team project and encouraged the students to continue the project in order to earn internship or job opportunities. Of particular interests are two projects that were successfully completed in spring 2015 and spring 2016. The first project involved data mining for profiling incoming students and predicting student retention rate based on the authentic training dataset provided by the Office of Student Success and Retention at ERAU. A team of four students from ERAU Prescott selected the project and did an excellent job when they took the course offered at the Daytona Beach campus in spring term 2015. In middle May of 2015, the four students were invited to Daytona Beach in the summer research workshop and they were co-mentored by Liu and Mr. Steven Lehr who had over 15 years of industrial data analytics experiences. After the research outcomes were presented to administrators at Office of Student Success and Retention, they organized a committee to investigate the impact of gateway courses such as pre-calculus or calculus to the student retentions in 2016. The research results [14] was published in an IEEE conference proceeding in 2016. The second project was assigned to two students as a team project in spring 2016. The project was to use the biomass data collected around the artificial reefs provided by the Beach Safety Office of Volusia County to predict the healthiness and effectiveness of the artificial reefs towards to marine ecosystem preservation. The team continued to improve the data mining results in the summer with support from the Prepare Industrial Career Math mini-grant. The project was co-mentored by Liu and a staff member at the Beach Safety Office. The Project was presented as a poster at the SIAM Annual Conference in 2016. Because of this project, one student found an internship opportunity and part time job in Volusia County government. In summary, the strategies we used to engage student learning were (1) teach mathematical concepts using relevant application contexts and (2) provide team research projects that will facilitate the development of marketable problem-solving skills.

3. OUTCOMES

As the project progressed, the following new educational resources were created: (1) Multimedia MOOC materials for three courses in Mathematical Modeling and Data Mining, (2) Documents for formative and summative learning assessments; and (3) Five peer-reviewed research papers coauthored by the undergraduate participants of three summer research workshops from 2013-2015.

Each college contributed one faculty member and one course resulting in each university in the coalition having three new courses. All courses were thoroughly reviewed by peer instructors and upgraded multiple times providing each university three high quality innovative cyberlearning courses. The students in each campus have more course choices while the campuses save costs by not having faculty members teaching extra courses: We simply shared resources and pooled students to make the class size reach the ideal number of students. The feedback collected formally and informally from students indicated that they benefited from the multimedia course website, which allowed them to learn the material at their own pace. They read textual materials for the theory and concepts and watched the videos for the examples. Three course websites were built using WordPress technology and contributed to the MOOC.

Three two weeks workshops were offered for a total of 18 students from three universities in summer 2013-2015. Five students in ASU and Prescott campus were funded by the NSF grant to participate in the summer workshops at Daytona Beach. All students started their mandatory team projects six weeks before they completed their CSE courses in spring semesters. The focus of course-based research experiences (CURE) is on the modeling, computation, simulation and analysis of open-ended application problems. All 18 students chose to continue their research projects in their CSE courses but shifted their focus towards model validation based on authentic data. The three teams of students used the ACE methodology [5] to model and analyze physics applications such as safe landing gears of weather balloon payload, buoy motions and underwater light scattering patterns in a Wave Tank. They obtained their data from hands-on experiments in the Wave Lab and the Leverage Robotics Lab. A team of five students from the DMV course used data from the ERAU admission and registration office to predict student retention and attrition. The course-based researcher and summer research workshops resulted in four student co-authored papers [6, 8, 9, and 17], three conference presentations, and two conference presentations. Figures 1-4 shows the five student coauthors of [9] from ASU designing and testing a safe landing system for weather balloon payload in summer 2015.

Because students of the cyberlearning courses represented more diverse STEM majors than the typical students at any single campus and course assessment approaches were quite different, there was not a proper control group to compare learning outcomes quantitatively. In addition, class sizes were between 12-20 students from three campuses and consequently sample sizes were too small to draw statistically significant conclusions. Suggested by our external evaluator Spector, we compared the learning outcomes of MMS with an Ordinary Differential Equation Course (ODE, MA345 in ERAU), which was one of most similar courses taught by the same instructor of the MMS course at the same time. The two courses were similar in these aspects, (1) same prerequisite, (2) similar contents, matrices algebra and system ODE, (3) similar small class sizes (17 vs 29 students). Besides the delivery method (MMS used cyberlearning & blended learning, ODE used traditional face-to-face lectures), the other major differences between MMS and ODE are: (1) ODE students were more homogeneously from physics and engineering majors and the students in MMS came from more diversified STEM majors including biology and meteorology majors, (2) MMS is a problem-based learning course with model-based instructional design and assessments, query guided learning, teamwork, etc., the ODE course was taught and tested in conventional methods, and (3) the focus of the MMS course was on the depth of their understanding of the key concepts and problem solving ability with the use of computational tools while students in ODE course covered a broad range of content and solved several types of ODEs by hand. Comparing the student evaluations of the two courses showed that the students in MMS were much more motivated. They gained more confidence from the MMS course to solve relevant problems to their careers by using system engineering methodology and computational tools. Grades of ODE in spring 2014, 7 A's, 7 B's, 10 C's. 2 F's, and 3 W's, which is a typical grade distribution at ERAU. The grades awarded for MMS in the same semester were 6 A's, 6 B's and 4 C's, and 1 W. Though the grades of the courses might not tell how much the students really learned, we believe that low attrition and failure rate of the classes is a good indicator of the course success. We offered DMV three times, the first time by IKle, the second time by Liu, and third time by Liu and Lehr. Not a single student did withdraw from the class. This is very rare for any other mathematics course: The typical withdrawal rate of similar level mathematics courses are 10-20% at ERAU. Our student feedback showed that most of them loved the courses because of the relevant and marketable skills they gained for industrial careers. The withdrawal (W) or failure (D or F) rates of the three MMS courses were very low: one to two students in each course.

Spector examined all the student evaluations reports presented in section 2.4 and also evaluated online course materials, sample student test papers, project reports, etc. for each course. He communicated with the instructors frequently so that the student concerns were addressed timely and the project efforts were aligned with the major goal of these courses: fostering student problem-solving ability and promoting deep learning. As a result, the students in MMS courses learned how to use the system engineering modeling methodology and procedures to translate real-world problems into mathematical models. Students also gained hands-on experience in using software tools such as MATLAB and STELLA to model and simulate real-world projects. A set of sample projects of the MMV-II indicates that students developed deep learning including: (1) A Model of the Rings of Saturn illustrating the appearance of the Cassini Division for certain parameters of the shepherd moon(s) and (2) Writing a game of "Tanks" in MATLAB. The students especially enjoyed the team projects on the application of authentic weather data, genetic data, public health data, real-estate data, and student retention data.

Although the student evaluation metadata in section 2.4 had limited value in helping us to accurately measure our success, the numerous positive feedbacks including the constructive criticisms clearly indicated that all three courses were effectively delivered and improved in the second and third round of offerings. Many of these student comments were included in the final project evaluation reported by the external evaluator to NSF. In the final project evaluation to NSF, Spector presented the following evaluation summary:

"In terms of the three primary goals of this project (establish an initial cluster of three collaborating colleges; create and offer a computational science and engineering program at collaborating colleges; create the infrastructure and processes to extend the collaboration cluster), this program has been successful and all three goals have been achieved. …… Problems encountered have been addressed and refinements made. Students taking the collaboration courses at a distance are performing as well as students in comparable classes as indicated by the grades awarded. Understanding of complex computational engineering problems is occurring as shown by an analysis of problem conceptualizations and solutions previously reported. Interest is especially high as shown by voluntary participation in the two summer workshops, which should be better funded if such non-formal but highly productive efforts are to be continued."

Figure 1. Students are preparing the safe landing system

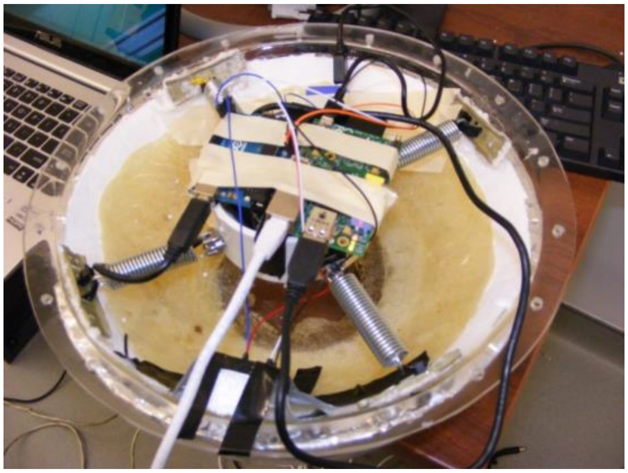

Figure 2. Sensor and Arduino board of the safe landing gear

Figure 3. Prepare test for landing on grasses

Figure 4. Captured the moment for landing on water

4. BROADER IMPACT AND FUTURE WORK

This project provided a feasible model to significantly increase student participation in CSE. Few small colleges have the resources to provide CSE courses and programs for undergraduate students. The project also demonstrated a viable method for scaling up: Adding more colleges to a cluster and then creating a network of clusters. Our strategies to advance CSE education can be straightforwardly extended to other disciplinary domains and other small universities.

In addition to the MOOC websites, this project resulted in the five publications [6, 8, 9, 15, and 17] (undergraduate coauthors are marked by asterisks). PIs conducted the following personal dissemination events: Liu and A. Shiflet co-chaired a miniSymposium on Educational Innovations in CSE Education in the SIAM Annual Conference, July 2014 in Chicago. Liu and Ludu Co-Chaired a miniSymposium in SIAM SEA Conference 2014 in Melbourne, FL, 2014. Spector and Liu Co-Chaired a miniSymposium on Cyberlearning Technology and Deep Learning in a CSE Conference in March 2015 in Salt Lake City, Utah. In addition, three students gave a presentation at the 2015 Kappa Mu Epsilon National Convention.

The social benefit to students included providing equal learning opportunities to under-represented students: Adams State University is a federally designated Hispanic Serving Institution (HSI). The summer research workshops brought minority students from Adams State and students from the Prescott campus in Arizona to meet the students from the Daytona Beach campus. These events not only facilitated student collaboration on research, but also helped them build friendships and develop the mutual understanding of other students from different cultural and socioeconomic backgrounds. In summary, the project is sustainable and scalable because it benefits small universities and provides a cost effective solution to advance CSE education.

As a continuation of this project, we have undertaken a new project that included more institutions, more STEM disciplines, and more students. In addition to ASU and ERAU, the newly funded IUSE project created a coalition that included two more institutional partners—Hampden-Sydney College (HSC) in Virginia and Bethune-Cookman University (BCU), a Historic Black University (HBCU) in Florida. The four small universities are collaborating to integrate CDSE (Computational Data-enabled Sciences and Engineering) coursework into the undergraduate curriculum and embed authentic research experiences based on a CURE pedagogical model. Four new courses were added: (a) Database Design, (b) Genomics and Bioinformatics, (c) Problems in Atmosphere and Hydrosphere, and (d) Advanced Computing Resources in Biology. Except for the Database course, the other three new courses were organized by applications instead of computational methods. We are also creating of a virtual educational observatory to ensure that the effort will be ongoing after project funding ends and consequently have an even broader impact, especially on small, regional, and minority-serving institutions. The continuous project will help us collect adequate survey data so that we can draw statistically significant conclusions using evidence based and data driven evaluations. For example, we have added more questions in the end of term evaluation so that we can compare changes in student beliefs about CSE and team work after they have completed the course. The end of term evaluation will also ask each student to rank his or her perceived importance and difficulty level of the course contents. In addition, the new project will adopt new technologies (e.g. educational data mining, learning analytics), use proven instructional approaches (e.g., experiential, problem-centered, collaborative learning), and integrate them into a flexible curriculum involving the co-creation of resources and activities by participating partners.

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