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ACE - A Model Centered REU Program Standing on the Three Legs of CSE: Analysis, Computation and Experiment

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Abstract

Enhancing REU (research experience for undergraduates) has become a popular strategy for many selective universities to enhance quality of undergraduate education and recruit gifted new students. The university that the authors are affiliated has set REU as one of the major outcomes for our QEP (quality enhancement program) for next 5 years. This paper presents a model centered REU program entitled as ACE standing for Analysis, Computation and Experiment. As a work in progress, the program is planned to run for the next 5 years and to serve for 20-30 undergraduate students who are gifted in mathematics and computing annually. ACE is to use interdisciplinary research projects, the guided exploration based on sound pedagogical practice and the top niche analogical and virtual dual lab facility bring measurable impacts to over a hundred of gifted undergraduates.

Keywords: CSE Education, REU, Project-Oriented Pedagogy

1. Introduction

This paper introduces the ACE program at the Embry-Riddle Aeronautical University (ERAU). ACE stands for Analysis, Computation and Experiment, which are the three legs of CSE. It is an interdisciplinary REU program facilitated by analogical and virtual research labs. We identifies the three obstacles that all REU programs encounter: most undergraduate students are immature of critical thinking, inexperienced of handling the complexity of research level real-world application, and lacking of domain knowledge to validate their research results. Our approach illustrates the three folds of strength to overcome the obstacles: interdisciplinary topics, guided exploration, and hand-on lab facilities. The three folds of strength of the ACE program synergize to a pivot to leverage the challenges of the REU program.

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ERAU has set REU as one of the major outcomes for our QEP (quality enhancement program) for next 5 years. ACE also provides a prototype of mathematics education reform that is customized to the QEP need of ERAU. Nearly one third of the students at ERAU are in Aerospace Engineering (AE) major and most advanced mathematics courses are taken by the students from all sorts of engineering programs. Modelling and observing kinematics and fluid dynamics poses great challenges to our engineering students. Lacking sufficient mathematics preparation significantly limits their potential. Hence, the gateway to the success of our QEP program is to reform mathematics education so that it is more connected to the engineering applications. The ACE program starts the reform at a relatively small number of selected students and offer an interdisciplinary REU program to the students who are gifted in mathematics and computing. As a work in progress, the project to prepare the facilities and teaching material for the ACE program has been primarily supported by internal grants. The annually budget to run the program depends on a pool of internal and external recourses. Depending on the sponsoring strength, which is beyond of our control, the program will potentially bring measurable impacts to over a hundred of gifted undergraduates and 30 graduate research assistants in next 5 years.

The paper is organized as follows. Section 2 describes the background, rationale and design of our ACE program. Section 3 explains our pedagogical approach. Section 4 describes the lab resources that facilitate the experimentation and computation of the program. Section 5 demonstrates how coherently a couple of sample projects stand on the three legs of sciences: theory, computation and experimentation. Section 6 presents the outcome and evaluation plans.

2. Background, Rationale and Design of ACE Program

The three categories of academic programs that inspired our ACE program are: firstly the newly established Computational Mathematics (CM) programs at ERAU, secondly numerous successful REU programs across the United States, thirdly the Non-Linear Wave Lab, (NLWL 2, see picture 5 and 6) that the second co-author led to build recently. Six faculty members including the first co-author at the mathematics department were introduced to the CSE education research in the three summer workshops offered by Shodor in 2003 and 2004 [1]. Led by Charles Martin, we started preparing our first proposal for our CM program in 2004. Besides the training that we got from Shodor, the links and survey provided by Swanson in [15] helped us tracing and learning from many successful CSE degree programs. Our CM program was first launched in 2009 and enrolled about 40 students up to date. Several successful undergraduate CSE programs can be found in [10], a well circulated article published on SIAM Review recently. While reviewing of REU program is beyond of the scope of this paper, readers can find many successful REU program sponsored by NSF at http://www.nsf.gov/crssprgm/reu/reu_search.cfm. Both authors have been actively involving REU program over past 10 years and run some funded REU projected before. However, it is too early to put an external proposal for the ACE program or to compare it with other successful REU programs due to its immaturity as a work in progress. Before we start the ACE program, our undergraduate research projects at ERAU were limited to theory and/or computation. With the establishment of dual lab facilities, we added the experiment component to our program as the third leg and initiated the ACE program recently (see figure 1).

2.1. Three major challenges that hinder the success of the REU

1. Critical thinking: Most undergraduates only got trained to plug in data to formulas and demonstrate little ability to extend mathematics concepts beyond an algorithmic level. Hence, most research topics suitable for graduate students are not proper for REU because the problems with scientific significance rarely fit the scope of one to two courses for undergraduate students.

2. Complexity: Undergraduates lack experience to divide complex problems into multiple comprehensible small problems. However, the complexity of valuable scientific research is typically beyond the comprehensibility of undergraduates.

3. Applicability: Undergraduates have limited domain knowledge to their applications. Therefore, they cannot connect the domain knowledge to validate their mathematical models. They are even more intermediated to open ended problems.

2.2. The three folds of unique strengths of ACE Program

The ACE program provide sound, original, and QEP designed solutions to the three above challenges of REU:

1. Interdisciplinary Topics and Teamwork: The ACE program provides at present three specific interdisciplinary topics whose individual components fit the disciplinary boundary and size limitation of individual team projects for undergraduates yet those small components can be assembled to significant scientific endeavour. In order to address the first of the three major challenges the ACE program offers in addition a list of open end problems where formulating the model, choosing the tools, validating and justifying the results are more essential than knowing the algorithms and the recipes. Based on the solid procedure of inquiring of faculty and their collaborators' research goals and current problems, on the front of the wave of the scientific priorities in the world and nation, and on the concrete objectives to be solved the authors' affiliated university, the ACE team continuously improves its list of precise problems to be solved by the student teams. For each new recruited student we will choose an individual specific stream of problems associated to students' abilities, skills, options and potential.

Interdisciplinary topic 1: This is a fluid dynamics topic related to the interaction between ocean waves, wind, a FMO (floating moored objects) buoy network, and a fleet of AUV (autonomous underwater vehicle) devices. ACE addresses several fundamental physical science and engineering problems in this oceanography area. We study the interaction between buoys, ocean waves and wind; also the study of stability and maneuverability of small scale AUV against internal gravitational waves, rip currents, and tsunamis; and finally building and maintaining a C-Man (coastal-marine autonomous network) between the buoy fleet equipped with integrated ocean observers (IOOS) which will act as data acquisition environment and ARES/GPS system for the AUV submarine fleet, in order to direct and position them [13, 14]. This topic is important also from the economical point of view: the expensive ARES systems get usually lost in the ocean, or they are damaged strong waves and currents. Another direct application of this topic of ACE refers to the recent invitation to contribute to NASA's research on the splashdown of the Orion capsule in the Pacific Ocean, and the possibility of predicting weather patterns through an AWIPS (weather interactive system) buoys system in the area. Students from three different pools are participating: computing mathematicians/CFD (computer fluid dynamics) students, system engineering students, and mechanical engineering students. They direct their efforts in 6 different fields: design the devices using state of the art computing programs, design the AWIS/GPS network of computers and buoys and their role of floating GPS system for the AUVs, experiment the models in our NLWL 2 (nonlinear wave lab), build the buoys and submarines, compare the tank tests results with their CFD simulations, and test them in the ocean.

Interdisciplinary topic 2: The second topic refers to the study of nonlinear water waves, like Rogue waves and/or tsunamis. In order to generate a tsunami-like wave in the tank NLWL 2, a certain team of students will need to find out how the wave-maker should move. This motion, governed by Newton's laws and hydrodynamic conservation laws, it is controlled by a computer-operated electromagnetic ball-actuator. The team members will also investigate the possibility of using a compressed-air rail pneumatic actuator placed at the bottom of the tank. Such actuator can generate almost shock waves along the vertical direction which can initiate a tsunami-like wave. The members of the team will divide the whole tsunami experiment in sub-systems: the water surface, influence of boundaries, onset of turbulence, the paddle mechanics, the engineering of the rods, the actuator computer control and feed-back, the power suppliers, the computer signal generator, and the lasers measurement system. Students will tackle a certain sub-topic accordingly to one's abilities and motivation. Then they study as a team what is the influence of the computer signal to the power amplifier, how this energy transfers to the motion of the paddle, and how this motion generates the desired waves under the imposed boundary conditions, and how one proves and measures it. The next step is team global and consists in modeling this chain in systems of dynamic equations. Then, again individually, students will adjust parameters in order to optimize the desired results. The last level is to understand how these sub-systems interact with each other and the corresponding feed-backs, which is again team work.

2. Guided Exploration: The ACE program can provide undergraduate researchers the required *guided exploration* to the problems under concern. A model centered methodology and system engineering procedure will be used to guide them to take small steps, analyze the problems incrementally and refine the results iteratively. For example, at the Nonlinear Wave Lab one problem is related to measurement of surface waves in fluids by using laser beams, reflective systems and computerized sensors. The students already designed a model system by using geometry (ray propagation) and analytic geometry (placement of components). They will test it experimentally on

known wave profiles. In order to use the system for predictions, the students will solve its inverse problems, which request differential geometry and finally computation geometry. Based on these procedures, students optimize measurement system's parameters in order to build the most efficient, accurate and competitive wave measurement system.

3. Lab Facility for Hand-on Model Validation: The ACE program is facilitated by the analogical and virtual dual labs (see figure 2). The facilities provide students the immediate visual and hand-on feedback to their queries. The computing software tools offers the students the opportunities to visual platform to build and simulate their mathematical and computing models. The Nonlinear Wave lab facilities (NLWL2 and 3) and a fleet of (AUVs will provide students the unique hand-on experience to measure and validate their models.

The ACE program is expected to launch in the spring of 2014 just after the 5 year QEP program of ERAU starts. The preparing and testing to a small number of students has started and are expected to be completed in fall 2013. The following components have been initiated.

- a. Upgrading the analogical and virtual facility of the Nonlinear Wave Lab NLWL2 to meet the need of the ACE program.
- b. Building a fleet of AUVs as an instrument and test bed for the ACE program.
- c. Developing and testing the instruction modules and tutorials for computational tools for the full scope seminar courses and summer REU workshops.

The following components are expected to deliver in fall 2013 or spring 2014 provided they are fully sponsored:

- a. Offer an honors-designated seminar course each year to 20 - 30 students who are selected primarily from the Honors Program, Computational Mathematics program and SIAM/MAA student chapters.
- b. Organize a rewarding research workshop in each summer to about one third of the top students of the research seminars. These students are expected to publish their results in proceedings or journals.
- c. Train the top students to contend in the national competition of student research projects.

2.3. The role of the faculty mentors of the ACE program

At the current phase, the first co-author is preparing the teaching material based on the previous developed education modules and developing a fleet of AUV (see Eco-Dolphin project below) with helps from the second co-author and a team of research assistants. Besides the topics enlisted in this paper, both authors will work together to cumulate more research topics for the seminars and summer workshops so that the research problems will be modified each year. The second co-author will design and prepare the required experiments at NLWL. Besides the co-authors who are playing major role to co-teach the seminars and workshops, other faculty members will be invited to give presentations and mentor students. The co-authors and other invited mentors will provide research topics to the participants. For example, each of the two interdisciplinary topics mentioned in section 2 are too big to fit to the scope of an individual team project. The mentors will split each of them to multiple related projects. As our primary advising role, we will also help student teams to divide their individual projects to a few subprojects of the sizes that most undergraduates can handle. The student will elect their team leaders to manage their projects and the mentors will play the roles of moderators and advisors. The grades of the students mostly depend on the quality and merits of their projects and research papers. The mentors only provide the rubrics for evaluate their projects. In general, the role of the co-authors and colleagues at our mathematics department is assigned according to our own interest and expertise. These roles are flexible and subject to change as the program advances.

3. The Pedagogical Approach

The pedagogical approach of ACE is a *Guided Exploration* through system engineering approach (see figure 3). Some of ideas can be traced back the work of the authors in [2, 9]. The first co-author was inspired from a couple of summer workshops offered by Shodor [1] in 2003-2004 and has been practicing in his teaching and mentoring student research projects since then [6 - 8]. Figure 1 shows the system engineering approach based on the Model Centered Methodology in [1, 3, and 10] and figure 3 demonstrates the Incremental and Iterative Dual Loop Process in [6], the previous work of a co-author.

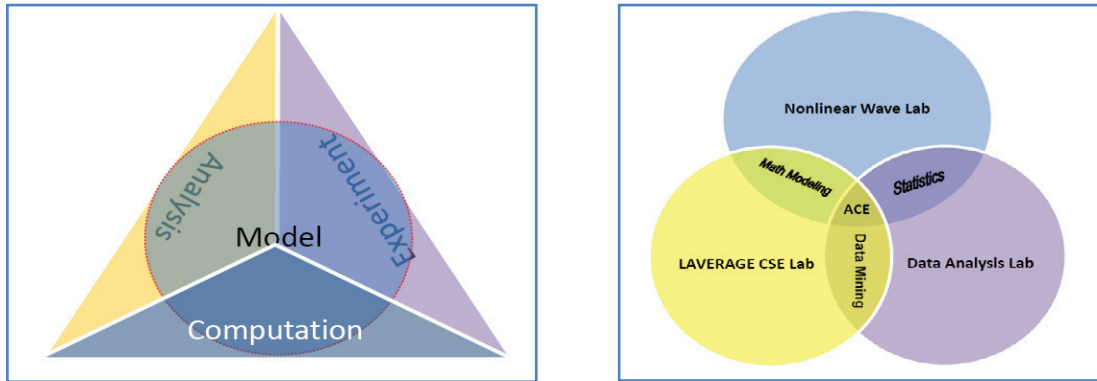


Figure 1, left: Model Centered ACE Program; Figure 2, right: Trans-disciplinary Synergy

Analysis, Computation and Experiment are the three support legs of our *Model-Centered Methodology*. Meta-model and discipline based ontology is used to divide and conquer the problems that are far beyond the research capability of undergraduates. For example, a top level problem in nonlinear wave application is specified by a nexus of hybrid models, including continuous models for wave dynamics, discrete models for instrumental control and data acquisition, and stochastic models for the non-deterministic events and chaotic behavior. The mentors start to divide the problem into small projects to fit the research scope of the teams and help them to assemble the projects and demonstrate them the discovery in the end.

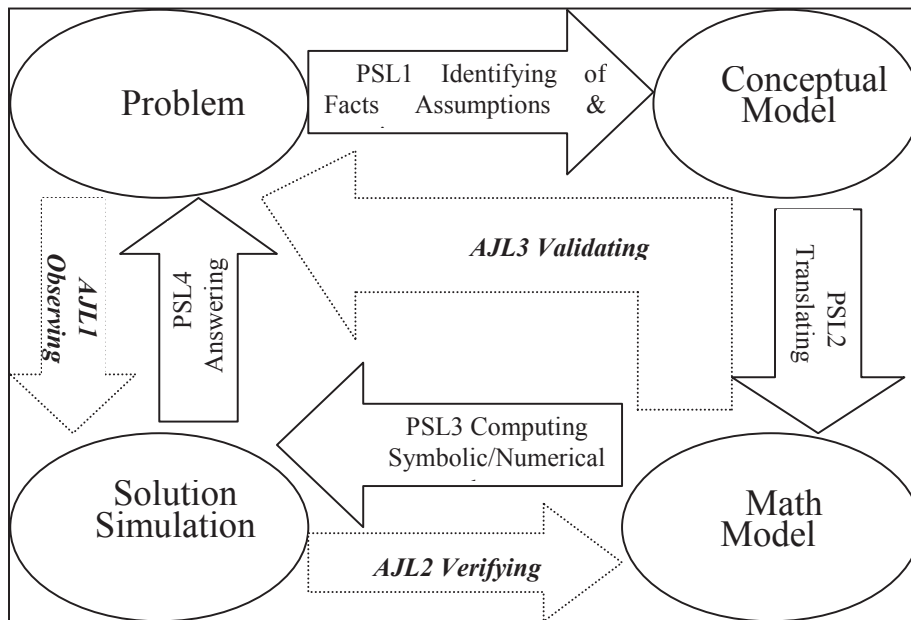


Figure 3: System Engineering Approach from [6], the previous work of one co-author

The real-world applications only bring open-ended problems that are unlikely well-posed and usually have no close form correct solutions. The process shown in Figure 3 can help them to trace their intermediate research artifacts and evaluate their own solutions. The process consists of two loops, the Problem Solving Loop (PSL) and the Answer justifying loop (AJL). The steps in the both loops are to be iterated until a satisfactory answer to the problem has been reached. A guideline to each step is a list of questions or tasks. The *guided exploration* to the new participants starts by feeding them the project with such a guideline. But, they will learn how to follow the guideline and solicit the questions.

4. Lab Facilities and Instrument

The Nonlinear Wave Lab (NLWL 2) can produce the desired fluid dynamics to test the vehicle design under different categories of currents such as *laminar* or *turbulent* flow. A significant component of the ACE project is to prepare the NLWL 2 facility and build the fleet of AUVs that are called Eco-Dolphins as the instrument and test bed for the ACE program. As a project oriented REU program, we choose our projects that connect mathematics to the applications in aviation and aerospace industry. The Eco-Dolphins are particularly built for the ACE program at first place and expected to serve for surveillance and environmental monitoring in future. We observe that the difference between hydrodynamics and aerodynamics is the former has 80 times of the density of the latter. The slow voyage of an AUV in the wave water tank and the fast flight of an airplane in aerospace share almost the same fluid dynamical and kinematical models. But, the former is much easier for students to measure and test since it can be confined in a wave water tank facilitating interferometers. UAVs (unmanned aerial vehicles) are commonly used to simulate the kinematics of airplanes. But, measuring and observing the aerodynamics of UAVs can be difficult for it is hard to confine UAV flights in a lab space.

4.1. Nonlinear Wave Lab

The analogical component of the ACE consists in a series of hands-on research projects in applied mathematics, fluid dynamics engineering, physics, etc. in which our faculty and the students are interested. Each of these projects is composed of three intertwined streams: (1) experimental research and data collection in the NLWL-2 16 feet long lab (see picture 4-5) and the double large NLWL-3 lab to be constructed starting with 2014; (2) analog data investigation, correlation and statistics processing, conversion to digital, and dynamical storage; and (3) numerical modeling of the physical processes investigated in these labs. The research NLWL 2 consist in a closed circuit 2,000 gal flowing water tank with electronic wave makers and laser data collecting instrumentation. The NLWL 3 Lab (32 feet long) will be built at industrial scale. The present and proposed nonlinear wave tanks are designed with maximum flexibility in mind. These two labs will experiment phenomena from applied mathematics and engineering of fluids with demonstrated accuracy as never before. The labs are constructed by having in mind wide undergraduates impact and top applied research novelties. The experiments will be design in order to be performed by undergraduate teams with faculty supervision, and on the other hand to answer to some of the industry or national agencies open questions and demands for innovations.

NLWL 2 performed the following tasks:

1. Provided a full computer assisted autonomous system for the wave tank. This system was entirely built by the 10 students from Computer Engineering department under a dedicated contract between us and their Real Analysis Computer Lab. Their work was wrapped into the “Specs & design of Real-Time Systems (CEC-5231 at the ECSSE Dept.) This system controls the water filling, dumping and level stability in tank, and also controls the recirculating pumps.
2. The Capstone project students of our CM program performed already fluid mechanics research in the NLWL 2 tank and studied two fluid mixing, wave generation with paddles, and acoustic waves at the water surface. Their results were edited as science research and there were already presented at the Industrial Advising Board meeting in our department this January.
3. A grant project is already drafted by our graduating seniors, and it is now in the NASA Orion team’s hands for review.
4. There is already a network of collaboration between our team of 18 students: 4 seniors graduating for our math Dept, 10 from the Computer Engineering Dept, 2 from mechanical engineering, 1 alumni working as lab technician, and 1 from aeronautical engineering. To this we added a team of 6 freshman in AE who shown a great interest and excitement in collaborating with us. These freshmen are distributed among different groups of older students, who will train and tutor them. In this way we will forward the NLWL 2 to students only, while we will move our research at the new NLWL 3.

NLWL 2-3 can commit to do the following

1. Test the fluid dynamic of the AUV hulls designed by student teams.

2. Test the mission control and routing algorithm for AUVs designed by student teams.
3. Design, build and study land loss, erosion, sediments and pollutant agents transport experiments. Given the unique capabilities of NLW of generating any desired type of waves, we will experiment novel ideas to control the motion and accumulation of third phases in water by surface resonance.
4. Study the following space science open problems: gas-free propellant to spacecraft thrusters, directly through capillary vanes, significantly reducing cost and weight, while improving reliability. Also, transport, transfer and storage of fluids in absence of gravity, by capillary processes.
5. Investigate prevention of occurrence of large scale waves: tsunami, rogue, and clear air turbulence.
6. Study and experiment re-firing of reaction engine at water impact.

The flexibility of the tasks of the new NLW Lab is designed so that each of its modules can serve a different purpose, as well as allowing simultaneous experiments to take place in the different sections. Close integration of experimental and mathematical modeling is another special feature of the labs. The visual appeal of fluid motion and the challenge of its mathematical modeling will further extend the proposed instrumentation into a primary educational tool able to attract bright undergraduate students to careers in the sciences, thereby increasing the competency of our workforce in these fields of national interest.

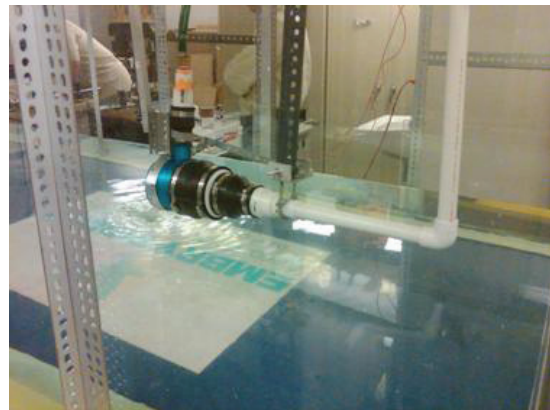
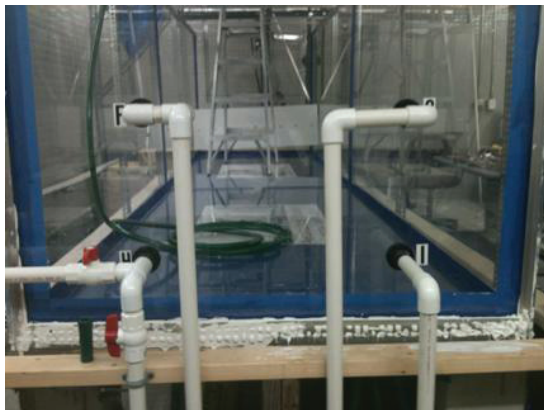


Figure 4, Left: longitudinal view in the 16' long tank showing the "soliton boulevard"; Figure 5, Right: compressed air disperser/mixer experiment for the "green" engine industry.

4.2. LEVERAGE Lab

The LEVERAGE (Learning Enhancement Via Education Research And Guided Exploration) Lab is a Virtual Lab to support Computational Science Education. Based on the Mathematical Modeling Modules (MMM [6, 7, 8]) and supporting software tools, one of the co-authors taught students how to use Stella, MATLAB, UPPAAL, and NuSMV for modelling and simulation, OpenGL, ParaView, perfuse and Tableau for Visualization, WEKA and GATE for data Mining in recently years.

LEVERAGE lab can commit to do the following in next 5 years:

- Build a fleet of three AUVs named as Eco-Dolphins and its communication buoy network.
- Two proposals from our student teams have been submitted to internal research grants.
- Identify more application research problems to expand the MMM assets.
- Install, customize and develop the software tools to satisfy the future need of ACE program.
- Develop software to serve the need for upgrading the Nonlinear Wave Lab to a Smart Lab.

4.3. Eco-Dolphins

Eco-Dolphin is the name of a fleet of adaptive and cooperative AUVs that we are currently building. We are currently building the prototype. It is named after its vehicle shape that looks like dolphins. Its functionality will be

similar the AUV in [12] but in different size. It will be designed to support future environmental science research and surveillance services in littoral water. The next section will demonstrate how the Eco-Dolphins and the Nonlinear Wave Labs complement each other to serve as an instrument and test bed for the ACE program. The associated REU projects will involve 6-12 students who are talented in computing, mathematics and engineering in each semester.

The prototype includes the following features and will be tested in the Nonlinear Wave Lab NLWL2.

1. A WIFI receiver for Eco-Dolphin to communicate with the ground station when it surfaces
2. Three servers for underwater communication / positioning by relaying WIFI and acoustic signals, control and monitor the Eco-Dolphin remotely from ground station while it submerges.
3. Measure the velocity of current by comparing the absolute velocity obtained from the acoustic positioning system and the relative velocity obtained from the IMU.

Because we have to use acoustic signals for the communications under water and its bandwidth/speed are 5 magnitudes smaller than the wireless communication in air, building buoyant servers to relay the communication signals among AUVs and ground station is challenging and expensive. Although the acoustic network can only exchange small message under water in slow pace, with this feature, the ground station can control and monitor Eco-Dolphins under water and Eco-Dolphins can communicate with the ground station while it is submerged. One of the related research topics for REU is to find the optimal geometric layout of the buoys and AUV routing so that the system can cover the maximal surveillance area under its limited battery power. Many interesting research topics about UAVs can be found in [11].

5. Example of ACE Program

We present four sample projects in table 1 to demonstrate how our model-centered program can coherently take advantages of the three legs of computational sciences. The GUI interface for ground station, the microcomputer controllers, all expensive devices such as IMU and propellers of the Eco-Dolphins will be shared among the REU teams. To complete the experiments, the student teams need to write their own codes for the mission controlling and routing programs, install on the user GUI interface of ground station before tests start. In the second and third sample projects, the student teams need to build their own AUV hulls and ballasts which are relatively inexpensive. But, they have to share the three sets of micro-controller boxes and propellers of the Eco-Dolphins. In each year, 20 – 30 students are enrolled and divided as 6-8 teams to the research seminars. Only about 2-3 of the winning teams are selected for summer researching workshops. The last project is designed only for the summer workshops. The project needs full features of Eco-Dolphins, including the underwater communication and positioning buoys. The student teams will design and write codes for testing the mission efficiency for multitasks and multi-agents. The student teams of the summer workshops can identify their own environmental research topics and use the Eco-Dolphins to facilitate the data collection and environmental monitoring missions under shallow waters near coastline or fresh water lakes. The teams of the seminars are expected to give presentations in local REU conferences and the teams of the summer workshops are expected to coauthor with the mentors and publish the researching results in conference proceedings and/or journals.

Table 1, Sample Projects

Example	Analysis	Computation	Experiment at NLWL2
Optical weight of ballast & size of compressed air tank	Hydrostatics Archimedean theory Newton's law	Simulation the system ODE by Stella	Speed of sinking and surfacing measured by interferometers
Optical vehicle configuration (such as shape of hulls)	Fluid dynamics governed by Navier-Stokes theorem	Solve by FEMLAB CFD simulation	Test the hull design by using Eco-Dolphin's devices, controllers
Optimal routing	Path and surface integrals and potential Theory	Simulate algorithm in MATLAB or Java	Test AUVs programmed by the routing algorithms
Safety and efficiency of mission control for multitasks and agents	Graph theory, multitask optimization such as Hungary algorithm	Simulate the mission control algorithm in Java or C programs	Test the mission efficiency of the fleet of Eco-Dolphin controlled by the algorithm designed by the team

As shown in figure 1, each project contains a model that is shared by the analysis, computation and experimentation aspects of the project. Hence, the ACE program is entitled model-centered systemic approach. Currently, several teams of research assistants are recruited to test the feasibility and prepare the tutorials for the programming and experimentation components. To test the first and second sample projects, several students in computational mathematics majors were assigned to design the hull of AUVs based on the hydrostatics conservation law and fluid dynamics, then, use FEMLAB to find numerical solutions and MATLAB for visualization, finally test the performance of the design at the NLWL 2 lab.

A little more details for the second project in table 1 demonstrate how the CSE leverages the challenges of advanced concepts such as nonlinear PDE. The project needs knowledge of CFD which is typically taught after junior years when students have completed PDE and Numerical Analysis. However, our targeted students for the research seminar are mostly sophomores. The selective students may have completed multivariable calculus, but, none of them are expected to take the PDE by then. The teachers may introduce the basic of ODE and PDE on the fly based on their understanding the derivative concepts. However, lecturing theory alone, it would very hard if not impossible for the students to comprehend nonlinear PDE. This is how our ACE approach works. To help student understand the role of the Reynolds number on either causing laminar or turbulent flow, our approach guide them to jump back and forth from the analysis to computer simulation, from simulation to experiments by following the incremental and iterative system engineering process. As shown in figure 1, the shared models produce a synergy of the three legs of CSE and help students to connect the Navier-Stokes equations, the visual perception in simulation and the real laminar or turbulent current in the water tank at NLWL 2.

6. Outcome and Assessment Plans

The outcomes of the ACE program are as follows:

- Enroll about 20-30 gifted freshmen or sophomores in mathematics and computing for a research oriented seminar course and 6 – 10 students for the summer research workshops in next 5 years.
- Enhance critical and system thinking skills, mathematics and computing skills, collaborative learning across the curriculum, data processing and analysis skills in first two years.
- Promote REU through mentored research and coauthored publications with undergraduates.
- Improve lab facilities supporting student learning for students to build, validate, verify and simulate mathematical models, collect and analyze data, and visualize the research discovery.
- Build up and collect course materials for model-centered REU programs.
- Attract bright undergraduate students to careers in the sciences, thereby increasing the competency of our workforce in these fields of national interest.

ACE uses data driven formative and summative assessments to evaluate the performance. Before a project is assigned to the participants of the ACE program, we will test it to the research assistants teamed with both graduate and undergraduate students. The feedback from them are collected and analyzed. Then, we create the rubrics serving as the grading standard to the undergraduate projects. We collect feedback from our students regularly for formative assessments and measure our progress from the baseline. We also collect data from internet and publications to emulate other REU in peer universities. We will adapt some the course materials and trace the progress of the computational science programs mentioned in [3, 4, 5 and 10]. Our summative assessment is based on two benchmarks, one is quality and quantity of student publications and the other is the competitiveness of our participants to national competitions.

This paper introduces the ACE program at ERAU. We identified the three obstacles that all REU programs encounter and demonstrated our three folds of strength to overcome the obstacles. We present a couple of sample projects to demonstrate that our model-centered approach is capable of synergizing the three legs of sciences: Theory, computation and experiment to leverage the challenges of REU programs. Even though the program itself is at its preparation phase, the ideas of the program and relevant work have been evolved over years. The associated projects to prepare the lab facilities, instruments such as the fleet of AUV and course material are both time consuming and expensive. The scope and quality of program depend on the resource that the co-authors may obtain internally and externally. Regardless the annual budget in next 5 years, the ACE program is committed to bring measurable impacts to over a hundred of gifted undergraduates and 30 graduate research assistants.

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