SYSTEM ENGINEERING IN SENIOR-DESIGN CAPSTONE PROJECTS

Kevin W. Rudd, Jennifer K. Waters, Duncan O'Mara, Christoph J. Flaherty, and Michael Janssen

United States Naval Academy

ABSTRACT

The United States Naval Academy (USNA) is an undergraduate-only institution whose mission is to educate future officers in the United States Navy and Marine Corps. The Naval Academy has participated in a number of project based learning efforts both in engineering classes (Design–Build–Fly) as well as in focused projects (e.g. SAE Formula-1 race car, Cockpit of the Future, and the Sailbot). We are currently participating in the Systems Engineering Research Center research topic "RT-19: Research on Building Education & Workforce Capacity in Systems Engineering" (RT-19) for the 2010–2011 academic year. Research topic RT-19 is to develop Systems Engineering talent in the workforce through projects developing working solutions to real-world problems. USNA RT-19 participation includes sixteen students from four majors and three departments working on four independent senior-design capstone projects:

- Improving Surge Power Capabilities.
- Personnel Tracking.
- Portable Low-power Water Purification (interdisciplinary project).
- Portable Renewable Sea-based Power Generation, Storage, and Distribution (interdisciplinary project).

Each team is developing a functioning artifact that could be delivered to the RT-19 sponsor as a prototype implementation. The projects were conceived to solve a specific problem, designed to be viable within senior-design course limitations, and implemented by the students. They will be demonstrated as part of capstone presentations in April.

We have faced two challenges so far. The first challenge has been interdisciplinary project coordination in the presence of different senior-design sequences with different schedules, course content, and course requirements. The second challenge has been providing systems-engineering content without a common senior-design sequence for interdisciplinary project teams.

In this paper, we provide a full accounting of our experiences to date including accomplishments, lessons learned, and our plans to improve the senior-design process to support both well-defined as well as quick-reaction project opportunities.

KEYWORDS

Systems Engineering, interdisciplinary team, capstone project.

INTRODUCTION TO THE USNA RT-19 EFFORT

The United States Naval Academy (USNA) is an undergraduate-only institution whose mission is to educate future officers in the United States Navy and Marine Corps. There has been a significant increase in recent years in the emphasis on laboratory and project-based-learning in many science and engineering courses for majors and non-majors alike. The Naval Academy has participated in a number of project based learning efforts both in engineering classes (Design–Build–Fly) as well as in focused projects (e.g. SAE Formula-1 race car, Cockpit of the Future, and the Sailbot). At the Naval Academy, student time is a scarce resource with many academic, military, and physical requirements competing for a share; unlike most academic institutions, student time is even committed during Summer. Project work, as important as it clearly is, must be bounded in both time and complexity so that it can be completed successfully by students in light of the many competing requirements for their time. We always strive to find and support projects that can develop and lead students into new opportunities in both their military and eventual civilian careers.

The Naval Academy is currently participating in the Systems Engineering Research Center research topic "RT-19: Research on Building Education & Workforce Capacity in Systems Engineering" (RT-19) for the 2010–2011 academic year. RT-19 enables participating institutions to develop programs that educate students in a technical area that has significant growth and opportunity both within the military and in industry. The purpose of research topic RT-19 is "to pilot innovative strategies to increase learning and career awareness of systems engineering through capstone courses during the 2010-11 academic year.... A 45% growth is expected in SE jobs in the next decade and there have been numerous studies and workshops that have highlighted the shortfalls in both the number and capability of the SE workforce" [1]. It is a step toward addressing this problem through development of project-based learning curricula and the integration of Systems Engineering coursework for senior-design capstone courses. At the end of the academic year, all participants in research topic RT-19 will be meeting to share the lessons learned so that they can be incorporated in future senior-design capstone courses. We also plan on feeding these various learnings back into our senior-design capstone courses over the summer so that improvements based on this year's experiences are in place for senior-design projects next academic year.

Key to RT-19 is the application of Systems Engineering to senior-design capstone courses. In RT-19, as in our current courses, the senior-design capstone courses involve significant projects that are focused on developing solutions to real-world problems; what is added with RT-19 is an emphasis on the development and application of Systems Engineering skills and methods. For the 2010–2011 academic year, USNA RT-19 participation includes sixteen students from four majors and three departments working on four independent design projects. The students involved in these projects have already gone through the first three CDIO phases: they first conceived solutions to specific problems (selected and specified by them from a set of basic problem and project areas provided by the RT-19 sponsor), then they designed and implemented systems based on their solutions. Each of these design projects is developing a functioning artifact that could be delivered to the RT-19 sponsor as a functioning prototype. The students have finished their implementations and have presented their efforts and demonstrated their operation them to their departments as well RT-19 program sponsors and staff; they all successfully demonstrated their efforts in as the finale of their senior-design capstone experience.

The four RT-19 senior-design capstone projects that students worked on are as follows:

- Improving Surge Power Capabilities: develop a means to scale power-generation capacity dynamically consistent with power demand.
- Personnel Tracking: develop a distributed and portable system to track personnel and to produce status reports on demand in both routine and emergency situations.

- Portable Low-power Water Purification (interdisciplinary project): develop a water-purification system to produce pure water in stand-alone applications supporting up to 150 personnel.
- Portable Renewable Sea-based Power Generation, Storage, and Distribution (interdisciplinary project): develop a wave-power generation system that is highly portable and easily deployed to provide power in stand-alone applications supporting up to 150 personnel.

We have faced two significant challenges so far. The first challenge has been interdisciplinary project coordination. This challenge has been difficult because each department has its own senior-design sequence with different schedules, different course content, and different course requirements. The second challenge has been systems engineering curriculum integration for the students participating in research topic RT-19. We have had mixed results in developing workarounds to these challenges. However, we are working on adjusting departmental senior-design project calendars to enable better support for interdisciplinary projects and will provide feedback to the RT-19 sponsor on how to better match their research programs with academic schedules. Solving the timeline mismatch between funding-agency and academic-year schedules is a more general and difficult problem that is beyond the scope of what we are discussing in this paper.

In the rest of the paper, we describe our RT-19 effort. First, we describe how we integrated Systems Engineering content into the senior-design capstone process; then we introduce how we managed interdisciplinary projects. Next, we cover the four projects and evaluate how well they achieved the main research topic RT-19 and CDIO Standard aspects. Finally, we discuss the key lessons learned from our participation in RT-19 and how we are using these learnings to improve our senior-design capstone courses—both from the perspective of participating in an externally-driven senior-design project with its own requirements as well as from the perspective of delivering a successful senior-design capstone program.

SYSTEMS ENGINEERING INTEGRATION

Research topic RT-19 is focused on improving the Systems Engineering capabilities of students in engineering programs, especially in those schools like the Naval Academy which do not have traditional Systems Engineering majors. The International Council on Systems Engineering (INCOSE) describes Systems Engineering as “an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem” [2]. In contrast, at the Naval Academy the Systems Engineering major “prepares students to integrate mechanical, electrical and computer systems in an effort to automate different processes. Some of our main applications include Robotics, Unmanned Vehicles, Computer Vision, Guidance Systems and Sensor Technology. At other schools we would be called Mechatronics or perhaps Feedback Control Systems” [3]. The Department of Weapons and Systems Engineering, like all of the engineering departments, includes some Systems Engineering concepts as part of the senior-design capstone courses but they are not presented as part of a complete process for managing and realizing complex systems.

There were two basic requirements in this area: first, to integrate Systems Engineering coursework into the curriculum; second, to include Systems Engineering processes into senior-design capstone projects. In this case, because of our registration and scheduling timeline at the Naval Academy, class selections and student schedules were fixed before research topic RT-19 was announced; an added problem was that projects and teams were not organized until well into the fall semester shortening the time available for delivering the Systems Engineering content. As a result of these schedule-related issues, we decided to take advantage of existing web-based course delivery from the United States Defense Acquisition University to deliver a combination of acquisition and systems engineering coursework on an independent-study basis. In addition to making course delivery as flexible as possible (having a recommended module completion schedule but no specific work schedule and only a few hard course completion deadlines), an added benefit was requiring specific courses that would enable future certification as a Systems Engineering acquisition professional (in accordance with the United States Defense Acquisition Workforce Improvement Act).

This choice proved to be unsatisfactory in an undergraduate environment due to both course content (the courses were overly focused on bureaucratic aspects of acquisition and systems engineering) and policy (the courses followed a “three-strikes and you're out” policy that had students restart the course if they failed to get a perfect score on a subject-area exam three times). An additional complication was that the courses were not organized for group delivery and progress tracking with the consequence that many students were caught well behind at scheduled completion deadlines and a number of them rushed through the courses, failing a subject-area exam three times, and were then forced to do a complete restart on the course with all of their successfully-completed material discarded. The end result is that all but one of the students completed the required courses successfully, but they focused more on completion than comprehension and thus, unfortunately, failed to learn the relevant Systems Engineering content to a sufficient degree that they could apply it significantly in their projects. However, although the specific web-based courses that we used were problematic in content, policy, and delivery, we believe that there is a strong potential to migrate some course material into web-based courseware to complement in-class delivery of related material and intend to investigate this solution in the future.

In spite of the difficulty with focused delivery of Systems Engineering coursework, all of the project teams were encouraged by their mentors to apply Systems Engineering processes to their projects. In particular, students were encouraged to define requirements and to design their systems to meet those requirements. Where possible (especially in the two interdisciplinary projects), the students were encouraged to design modular systems both to make the designs more flexible as well as to distribute the load across different subgroups of students during the project.

INTERDISCIPLINARY PROJECTS

The problem areas specified by research topic RT-19 were diverse; our projects were selected from these project areas and two of them, unsurprisingly the larger two projects, were also interdisciplinary—this aspect of the projects was one of the main reasons that participating in RT-19 was compelling. In particular, coordinating the interdisciplinary projects has been particularly difficult because students on the project were on different schedules and in different senior-design capstone classes. Unfortunately, the late start for research topic RT-19 resulted in such a late timeline that it limited our ability to organize to support interdisciplinary projects. Because of the nature of the Naval Academy, student schedules are very full and fairly rigid once they are defined—class preparations were complete and student class assignments and schedules already fixed, both were accomplished without consideration of research topic RT-19 requirements as the details on RT-19 were not available until just before the fall semester began. In addition, project selections did not occur until the semester was well underway making schedule revisions (including the likelihood of multiple class or section changes) unreasonable. Thus, the students who ultimately chose to perform senior-design capstone projects under research topic RT-19 were already distributed across multiple classes in the three departments and chose to do these projects knowing the difficulty that they would likely face.

Starting up the interdisciplinary projects proved to be the most difficult aspect of our RT-19 effort because it was particularly arduous to get the students on these projects to coalesce into a team and to define their project direction to the point that the different student groups (in different classes) could break off and make forward progress independently. This problem was exacerbated by the fact that each department had different class schedules and assignments which meant that even when the students could get together, they were often working on different aspects of the problem to meet their own course content and assignment deadlines. However, once the students were able to reach the point of basic project definition and partitioning, they were able to distribute the work among subgroups and made solid forward progress—unfortunately delayed from what might have been, but more than reasonable given the coordination difficulties from having different subgroups working on the same project.

CAPSTONE PROJECTS

The USNA RT-19 effort comprises four independent projects undertaken by sixteen students from four majors and three departments; there were six civilian and military faculty mentors supporting these projects. This section summarizes the projects and reports on student successes and failures as they went through the RT-19 effort.

Improving Surge Power Capabilities

The Surge Power Capabilities project comprised one Electrical Engineering student; the project was originally a two-student project but one student changed projects at the last minute which proved to be the limiting factor for what the remaining student could accomplish during the project. The fundamental problem that this project was intended to address was the dynamic nature of expeditionary power grids and its impact on fuel consumption in expeditionary or humanitarian-relief camps of approximately 150 people. For this project the student selected a primary and alternate power source as well as a dynamic load to research the feasibility of dynamic load balancing between two power sources. Testing of this concept required the student to integrate the two sources so that the load could be transfer alternately from one source to the other and some method of measure the current transients.

The student that selected this project conceived of using a bank of four car batteries connected together to create a 24 VDC alternate energy source; the intent was to model the HMMWV vehicle batteries that are in common use in camps. The student used a standard 120 VAC gasoline generator to model the primary power source and used large residential HVAC units to represent the dynamic loads. Although the student initially expected to use a simplistic circuit for connecting the sources two sources to the load, the student soon realized the complexity of a realistic high power component interconnection. Ultimately, the student designed a 24 VDC bus that both power sources could be individually connected to and disconnected from; 120 VAC power to power the dynamic loads is produced using power inverter off of the 24 VDC bus. To be able to connect the generator to the 24 VDC bus the student designed a high voltage rectifier to convert the voltage from 120 VAC to 120 DC and buck chopper to drop the voltage to 24 VDC. Both circuits are common and frequently used but not commonly in 5000 W power range. This project required the student to conduct an in-depth study of power electronics and heat dissipation in order to specify the necessary components as well as to consider the mechanical aspects of circuit design to provide sufficient thermal dissipation when the circuit was under load.

The completed system will be able to serve as a test bed for further research on providing power to dynamic power grids from multiple sources. It also has great potential for future student projects in control automation and algorithms to improve efficiency.

Personnel Tracking

The Personnel Tracking project comprised two Computer Engineering students who developed a Personnel Tracking system that replaces paper logs and reports with mobile devices connected to a dedicated server system. In addition to using a dedicated base station, the system is designed to be able to use ad hoc communications to enable continued operation during power losses or emergencies requiring facility evacuation.

Following the initial conception of their project, the students defined the project in terms of required capabilities. They then designed the overall system architecture and selected the hardware to meet those requirements. Next they built paper versions of the software interface to enter, search, and view personnel status. In parallel with basic system and software architecture, the students also ramped up on wireless propagation models.

The students have implemented a basic application on a mobile device (Apple iPod Touch) that is able to scan the barcode on student IDs (using the Infinite Peripherals Linea-pro barcode scanner/magnetic stripe reader); the application on the mobile device combines the barcode information with manually-entered status information and wirelessly updates the personnel-status database on a remote server. They have also performed a characterization wireless signal study within the main student dormitory complex and produced a propagation-loss model for mobile devices connecting to the fixed wireless network; they are also working on an outdoor propagation-loss model assuming mobile devices only. They are using this information to determine how many access points are required within the building as well as suitability of outdoor ad-hoc wireless networks to achieve the connectivity to support the necessary connectivity. The product from this effort is the fixed-location server system and access points as well as the software and mobile devices to allow basic use.

Due to problems obtaining a development license required to program the mobile devices, the project was delayed significantly and the students were only able to complete part of the actual system implementation as a proof of concept. In particular, software development is not where they had originally planned it to be and does not include full flexibility on status input or the end-user application to produce the reports. However, the current proof-of-concept application and wireless propagation model demonstrates that their system architecture and basic implementation are reasonable for the dormitory complex and the outside emergency assembly points.

Portable Low-Power Water Purification

The Portable Low-Power Water Purification project team comprised three Systems (Controls) Engineers and one Electrical Engineer. The goal was to provide water in expeditionary or humanitarian-relief camps of approximately 150 people. During the fall semester, the team conducted extensive research to try to determine the best approach for making potable water with the least power consumption. Two key areas emerged for study: “what is potable water?” and “how is potable water made?”. The team researched current systems being used in expeditionary camps as well as other potential implementation options.

Analysis of requirements included project break down into three key functional areas as shown in Figure 1. The team then analyzed the project break down using a free mind chart to delineate what was needed as seen in Figure 2.

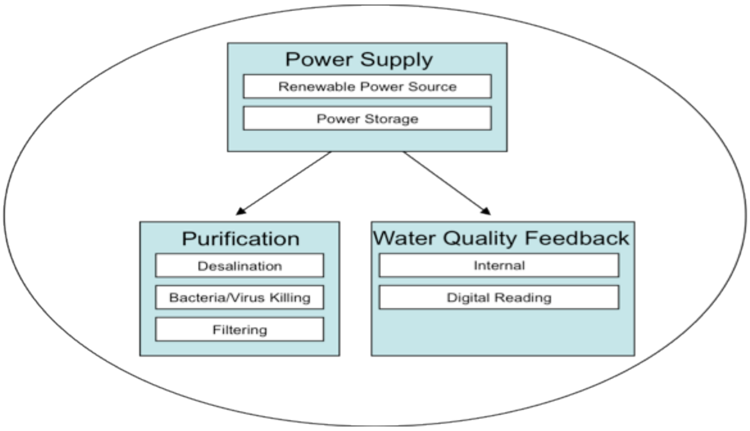

Figure 1: Low-Power Water Purification system structure

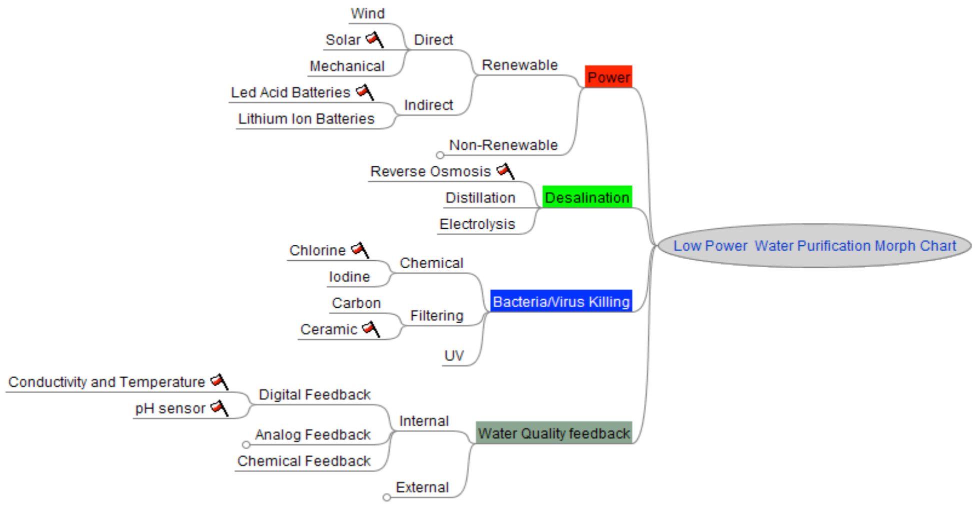

Figure 2: Low-Power Water Purification system Mind Map

The initial concept was refined during the fall semester with a design concept revolving around the use of reverse-osmosis units. Once that key design decision was made, further work went into energy generation and storage methods to include solar panels and NiMH batteries. Lead acid batteries have been used in the shop for routine testing and power applications to minimize costs as the design was being built and to keep the build process constant as acquisition of NiMH batteries, charger, solar panels was in process.

A key design and acquisition component of the project, aside from the reverse osmosis unit and the power generation and storage system, has been a sensor suite to enable the Low-Power Water Purification project to determine what exactly is needed to take source water and turn it into potable water. The team decided that the best way to make potable water with low power consumption was to first determine the initial water quality level and then determine what level of purification is required to make the water potable. Previous to this design approach, all water, independent of its initial quality, was being put through the entire purification process in a given water-purification system. To reduce power consumption without adversely reducing safety or quality of the potable water, the students decided to use a laptop computer interfaced to a water-quality sensor system; the computer then controls a set of valves which direct the feed water supply through only those purification stages determined necessary to produce potable water. By bypassing unneeded systems, there would be a power savings while continuing to produce the desired quality of potable water.

Obtaining the required parts has been difficult due to cost limits and processing delays. These delays have not only delayed initial project setup but also limited the possible system improvements of the design as it has matured from a paper concept to a functional system.

At the time of this writing, the Low-Power Water Purification system is being assembled after testing each individual component. The team has put the system together without the sensors to test for pressure drops and valve operation. Using salt water as the initial water source, the system works without incident. But the freshwater side has some pump pressure issues, probably due to the pump itself; the students continue to work on identifying and resolving this problem. The students have produced a graphical interface on the laptop computer which works well displaying status and controlling valve operations. The overall system is working as expected despite a few minor problems along the way.

Power measurements are not complete and it is currently unknown how effectively the system produces potable water at low power; this work is underway and the students expect to be able to discuss the power breakdown of their purification process in their final project reports. One goal is to determine how to optimize the process better using control algorithms (consuming the sensor data) on the laptop computer. If the project receives continued funding for next year, further work would refine the original design for further power consumption declines based on both improving the control algorithms as well as refining the system and components to overcome both efficiency and quality issues. One avenue not fully explored this year is optimizing motor selection for this application; the students identified other motors that are available but could not be purchased in time for the project due to cost (which exceeded direct purchasing limits) but which have low power consumption. Other work will improve solar panel utilization and efficiency when charging batteries, especially during cloudy conditions; this issue has proven difficult and the only current off the shelf system to offer any promise in efficiently storing energy under these conditions seems to be a fly-wheel storage system which would be way too large and way too expensive to use in this small prototype development.

Portable Renewable Sea-Based Power Generation, Storage, and Distribution

The Portable Renewable Sea-Based Power Generation, Storage and Distribution project comprised six Ocean Engineering students and three Electrical Engineering students who designed and built a linearly-moving wave-action electrical power generator. Initial design challenges included resolving the competing requirements regarding power generation and portability. Specifically, the students determined that they would not be able to build a power system that is backpack portable for expeditionary or humanitarian-relief camps of approximately 150 people. The team decided to focus on achieving a desired power generation capacity of 4,000 to 6,000 watts per unit and to keep the system portable by small military vehicles (zodiac boats or HMMWV vehicles). In order to more accurately determine the required size of a 4,000 to 6,000 watt wave-action generator, the students decided to build a smaller, approximately quarter-scale prototype model first. The Electrical Engineering students focused on designing and building a permanent magnet generator with the magnets on a moving member vertically translating up and down through the center of a set of cylindrically wound stator windings; designing and building rectification and battery charge control systems; and putting together the battery storage bank itself. The Ocean Engineering students focused on designing and building waterproof enclosures for the stator windings and the permanent magnet moving member; designing and building an anchoring system that would keep the positively buoyant stator assembly near the seabed; and designing and building a buoy system that would provide the motive force necessary to move the permanent magnet assembly up and down through the stator assembly.

The development of good inter-disciplinary communication skills was essential to this project in that members of each discipline had to be able to articulate design constraints to members of the other discipline. As an example, the Ocean Engineering students did not fully appreciate the size and weight of electrical components necessary to generate the desired electrical power and the Electrical Engineering students did not fully appreciate the challenges associated with waterproofing a moving (i.e., variable geometry) device. By being able to communicate, understand, and resolve these challenges, the students were able to complete the construction of a working prototype generator.

The team succeeded in the design and construction of the smaller, operational, prototype generator to include final assembly and testing with various wave periods in the Naval Academy's 380 foot tow tank. Due to initial purchasing delays and the long lead time associated with certain components of a full-sized system (the larger magnets require custom fabrication), the students were not able to complete the larger, full-scale design within the time period of the project (approximately seven months). Their continuing analysis of the prototype's operation and their lessons learned, however, will enable a follow-on project team to undertake the scaled design and construction of a larger system.

LESSONS LEARNED FROM THE USNA RT-19 EFFORT

As with any program, the authors along with the student teams learned many lessons as we participated in research topic RT-19. The most obvious lesson learned (again) is that it is undesirable to create project teams that are unable to work closely together. Other lessons learned are incidental (and, to a degree, consequential) from this issue: having separate classes drove the move toward web-based learning which proved to be very ineffective and frustrating for the students; having separate course requirements made interdisciplinary planning difficult as the students in different classes (and departments) learned different design processes and thus students affected by this situation had to plan and prepare different assignments on the same project as a consequence of these different classes.

Because of the nature of the Naval Academy, student schedules are very full and fairly rigid once they are defined. Ideally, research topic RT-19 requirements would have been available early enough in the Spring that we could have attracted interested students, selected projects, and assigned students on these projects them into common senior-design classes. In our case, although the goal of having interdisciplinary projects hosted by the participating departments was laudable, hindsight shows that we should have backed off on that goal and created (or partitioned) projects so that students participated within their scheduled class, not across classes. With this solution, we would have lost the interdisciplinary nature of the projects but could have focused much better on both the Systems Engineering coursework (as available within each class) and the projects. One of our recommendations back to the RT-19 sponsor will be to ensure that for future projects they engage with schools early enough that the schools can plan to support the effort and engage students early enough that they select projects and are assigned into common senior-design classes for each project.

One recurring problem that we faced on all projects related to purchasing required materials for the projects. We started off behind because access to the funds were delayed for several months; we were finally able to start purchasing about half way through the project window and the students still had to learn how to work effectively within the purchasing system which took additional precious time to navigate. The late start meant that we no longer had time to use the regular contracting process so the project teams had to redesign their systems to use low-cost items that could be purchased directly without requiring contracting. There were only a few items that ended up posing problems with this process, but eventually the students found ways to engineer the system in spite of these non-technical challenges. In addition, even with the use of direct purchasing, getting through the purchase process took longer than the students expected, even when they had all of the paperwork in order when submitted. Going into future projects, although funds availability and purchase-request processing are beyond our direct control, we will ensure that students learn the general purchasing requirements early on to avoid unnecessary delays that are within our control.

There are several alternatives that could be explored to avoid the need to back off of the interdisciplinary aspects. One alternative would be to have separate classes targeting interdisciplinary projects and to have students from participating departments register for these classes with the expectation of being on a to-be-determined interdisciplinary project. Not only would this approach enable students to develop interdisciplinary projects, but it would also enable last-minute project sources such as arose with research topic RT-19. These classes could be taught by any of the participating departments but would allow students from each of the participating departments to enroll and still meet the senior-design capstone class requirements of their own department.

Another alternative would be for all departments to schedule all senior-design classes during the same times. Although each class would be taught by different departments, they would have similar schedule, content, and requirements to facilitate students moving between classes or sections as projects are selected. This approach is more difficult to achieve than having a few specified interdisciplinary-project classes due to space and resource constraints.

On the integration of Systems Engineering coursework, we would not repeat our choice of web-based learning to deliver the Systems Engineering course content. Although web-based learning can be effective, it must be well targeted to the goals of the project (these courses were not) and it must be supplemented with coordinated classroom learning (which was not possible in our circumstance). There is clearly value in researching (or developing) suitable web-based learning to augment classroom learning. However, even if well suited to the subject matter and audience, web-based courses should not be the cornerstone delivery method used to incorporate Systems Engineering coverage into classes; instead web-based courses should supplement and integrate material introduced and discussed in class.

The authors plan on conducting more interdisciplinary projects in the future and will leverage the experiences from participation in research topic RT-19 to make these projects more effective learning experiences. There are several other current interdisciplinary projects at the Naval Academy (e.g. SAE Formula-1 race car, Cockpit of the Future, and the Sailbot) but these are generally large-scale multi-year projects with faculty and staff supporting the projects for multiple years. There is a significant opportunity to have more flexibility in interdisciplinary senior-design projects beyond these large-scale dedicated projects. And, as illustrated in these examples, smaller-scale projects such as the RT-19 projects described in this paper may have immediate relevance and applicability in solving urgent problems that are currently faced around the world. We intend to pursue these kinds of smaller-scale interdisciplinary projects in the future to complement the large-scale multi-year projects and provide design experiences that are responsive to real-world needs.

ACKNOWLEDGEMENTS

We would like to thank the Systems Engineering Research Center (SERC) for funding us through research topic RT-19, Research on Building Education & Workforce Capacity in Systems Engineering. We would also like to thank Professor Clifford Whitcomb and the Naval Postgraduate School for their coordination and help with program review and funding assistance. And, last but not least, we would like to thank our sixteen students who, although certainly the direct beneficiaries of RT-19 support, were also saddled with additional

coursework and project requirements that their colleagues in projects not supported through RT-19 did not have to complete.

REFERENCES

[1] Systems Engineering Research Center, "Invitation to SERC Collaborators, RT-19 Research on Building Education & Workforce Capacity in Systems Engineering", April 2010.

[2] International Council on Systems Engineering (INCOSE), "What is Systems Engineering" web page, http://www.incose.org/practice/whatissystemseng.aspx.

Biographical Information

Kevin W. Rudd is an Assistant Professor in the Department of Electrical and Computer Engineering and is the Director of General Engineering (Interim). He has a range of experience in the military, industry, and academia. He teaches in a wide area of Computer Architecture and basic Electrical Engineering. His current research and educational interests include computer architecture, performance measurement and modelling, and applications; he is also a strong proponent of interdisciplinary student projects, youth robotics programs, and science fairs. He has a B.S., M.S., and Ph.D. in Electrical Engineering.

Jennifer K. Waters is the Department Chair of the Department of Naval Architecture and Ocean Engineering. She teaches and conducts research in the area of Ocean Engineering with an interest in wave kinematics and nearshore dynamics, especially related to marine vessel dynamics in the littoral zone. She is an ardent supporter of interdisciplinary projects and program efforts by students as well as faculty. She has a B.S. in Naval Architecture and Marine Engineering and M.S. and Ph.D. degrees in Ocean Engineering.

Duncan O'Mara is the PEO IWS Chair in the Department of Weapons and Systems Engineering and is a Master Instructor. He teaches in the areas of Systems and Linear Controls and has mentored a number of interdisciplinary student projects. He has experience in a wide range of engineering positions including management, coordination, logistics, and safety during operations and overhaul of large Naval ships. He has also worked in the area of test and evaluation logistics. He has a B.S. in Biology & Chemistry and an M.S. in Mechanical Engineering.

Christoph J. Flaherty is a Master Instructor in the Department of Electrical and Computer Engineering. He teaches basic Electrical Engineering, Signals and Systems, and Fiber Optical Communications. He also has served as an expert consultant in electrical accident investigations. He has a B.S. in Physics and a M.S. in Electrical Engineering.

Michael Janssen is an Instructor in the Department of Electrical and Computer Engineering. He teaches basic Electrical Engineering. He has experience in expeditionary environments constructing communication networks and power grids. He has as B.S. in Electrical Engineering and an M.S. in Acoustics Engineering.

Corresponding author
Dr. Kevin W. Rudd
Department of Electrical and Computer Engineering
Mail Stop 14b
105 Maryland Avenue
Annapolis, Maryland, USA 21402
+1 410 293 6155
rudd@usna.edu