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Active Learning and Assessment within the NASA Robotics Alliance Cadets Program*

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In response to the 2006 National Defense Education and Innovation Initiative, NASA and DAVANNE LLC have collaborated to create the NASA Robotics Alliance Cadets Program to develop a highly integrated and interactive STEM (Science, Technology, Engineering, and Mathematics) undergraduate curriculum. This paper investigates the NASA Cadets' use of Active Learning to not only meet the nationally recognized need for a formal assessment standard, but also to ensure the sustainability of the program. To demonstrate the program's Active Learning tools wide accessibility and their integration with the program's methodologies, this paper examines the NASA Cadets' robotics platform and its use within an educational experiment co-developed by Cornell University.

Keywords: education; active learning; assessment; STEM; undergraduate; engineering; robotics; NASA; competition

INTRODUCTION

ACTIVE LEARNING is well established as an excellent method for increasing academic achievement, promoting the higher levels of Bloom's Taxonomy [1], developing supportive relationships among students and between students and teachers, and even improving students' attitudes towards STEM (Science, Technology, Engineering, and Mathematics) fields [2, 3]. These benefits, combined with the motivation provided by ABET's Engineering Criteria 2000, have inspired the development of numerous specialized programs that incorporate Active Learning at several US top colleges [4–8]. In fact, several top research groups, such as Dr. Felder's team at North Carolina State, have gone as far as to provide the research equivalent of 'how to' guides for incorporating Active Learning [8]. Despite these efforts, however, the need to extend these programs to more curriculums and more colleges continues to be voiced at a national level in high profile documents such as the 2003 *NASA Education Enterprise Strategy* and, more recently and quite strongly, in the 2006 *National Defense Education and Innovation Initiative* report [9,10].

A significant reason that this continues to be a key issue is that although the energy and talent dedicated to creating existing programs has been in some cases remarkable, propagation of these developed programs is severely hindered by four main factors. First, many programs are too specific to a particular school's resources to be transferable. Second, the developed Active Learning tools often lack the flexibility to be used in other similar educational situations. Third, these programs do not include adequate partnered assessment strategies to ensure that the intended goals are being met, and, fourth, these programs commonly do not include plans for sustaining the program or adapting it to future student and teacher needs. Both the NASA Education Enterprise Strategy and the *National Defense Education and Innovation Initiative* offer evidence of these factors and emphasize in particular the need to do more to aid the frequently untargeted 'Underrepresented and Underserved' student populations [9, 10].

As a result, a significant duplication of efforts has occurred across many institutions, with each developing their own innovative programs, Active Learning exercises, and even entire methodologies to teach the same material, but without having any method of objectively comparing their effectiveness. Although the current efforts should continue, they would be far more productive, effective and able to advance the overall community's program

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quality if a standard for assessing the learning outcomes was established to highlight the strengths of each program This concept is echoed by several bodies of research that state that if methodologies are to be created by any organization, there must be assessment methods in place to determine the methodologies' effectiveness [10–14].

In response to this need, the NASA Robotics Alliance Cadets Program was designed around the concept of developing and incorporating assessment techniques that could be easily used not only to assess its own program effectiveness but also could be easily incorporated into outside agencies' programs. This in turn can then provide a fair and balanced measure of assessing any program's ability to meet a similar set of learning objectives [15]. The development of the NASA Cadets Program's assessment suite also has the support of ASEE's Educational Research and Methods (ERM) Division; ASEE Executive Director Frank Huband has expressed his support of this program in 'enhancing the effectiveness of other programs' [16]. This collection of assessment tools also fulfills the ABET recognized need to enable less experienced instructors to perform accurate measures of the quality of their own programs and Active Learning exercises. As ABET acknowledged in a similar discussion in 2006 regarding the use of outcomes-based methodologies, 'It is apparent that while the new, outcomes-based criteria finally provide the opportunity for innovation and program individuality, they also appear to leave much interpretation open to program evaluators and faculty, many of whom, the constituents believe, have varying levels of sophistication and training in outcomes assessment' [17].

Once a program's strengths are identified, the NASA Cadets Program is dedicated to providing fellow colleagues and developers with detailed implementation procedures that can be used to ensure that the results can be reproduced across a variety of institutions. Moreover, NASA Cadets Program asserts that this is a necessary step that all leading educational facilities should follow in order to allow other institutions quickly to take advantage of these efforts and rapidly improve upon the educational quality of their own programs. Given the benefits of Active Learning stated earlier, the NASA Cadets Program holds this as a key practice in Active Learning and overall program development that must be adopted on a larger scale to meet the National Defense Education and Innovation Initiative's core goal to: 'identify and promote best practices and programs in undergraduate STEM education, especially those that address college freshman attrition and under-representation of minorities and women in STEM fields' [9, 10, 15].

This paper offers an introduction to the new assessment standardization work being conducted by the NASA Cadets Program as part of a formal educational report currently being developed. This paper also examines the significant role that Active Learning plays in providing both in-class assessment to instructors and students as well as in aiding instructors in conducting post-session assessment within this new standard. Finally, this paper discusses the educational capability of Active Learning tools within the program to demonstrate the utilization and wide applicability of this new assessment standard.

In order to provide the reader with background on the NASA Cadets Program, the paper begins with a condensed description of the program's methodologies for reaching its goals with particular attention given to provide an overview of the new assessment suite. This then motivates the next section to discuss the role of Active Learning as an assessment tool as well as some of the additional educational benefits that can be achieved simultaneously. For completeness, the paper then provides a further description of the assessment suite with regards to methods by which the Learning Objectives of the Active Learning tools are themselves assessed. This section and the next section also describe the attention given to the targeted evaluation areas of critical thinking, innovation, troubleshooting and community. These are areas that extend beyond the traditional ABET focus of breadth, depth, and professionalism but have been identified as highly important if not crucial areas by the educational research community [18–20].

After establishing the assessment suite concepts, the next section addresses accessibility and cross-institution applicability with regards to the incorporation of Active Learning into more equipment intensive settings such as labs and design projects. This section also focuses on the NASA Cadets' robotic platform as a key element to achieving this goal and the platform's role in aiding in the new assessment standard. The last section discusses a module developed for Cornell University in order to demonstrate the integration of many of the program aspects that have been emphasized throughout the paper.

THE NASA ROBOTICS ALLIANCE CADETS PROGRAM

The NASA Robotics Alliance Cadets Program was created in September 2005 to develop a nationwide initiative to re-design the first two years of Mechanical Engineering, Electrical Engineering, and Computer Science as highly interactive and integrated curriculums. Furthermore, through these curriculums NASA would not only combat STEM attrition trends and diversity issues but ultimately inspire more students to pursue STEM careers while guaranteeing improved academic performance and knowledge retention [9, 10, 15].

At the heart of the NASA Cadets Program's core deliverables in realizing this goal is the *NASA Cadets Instructor's Manual*. The *Instructor's*

Manual is a collection of detailed lesson plans that, in addition to outlining the core concepts and equations that are traditionally taught, includes detailed implementation procedures for Active and Cooperative Learning techniques, planned discussions on evaluation methodologies and applications, and real world motivations. Combined with carefully constructed homework and labs, together these lesson plans ultimately move engineering education beyond merely the Knowledge and Comprehension levels of Bloom's Learning Taxonomy to which most current first and second year courses are limited, into the higher levels of Analysis, Synthesis and Evaluation [1].

In order to make this leap possible, coupled with the *NASA Cadets Instructor's Manual* is a newly designed robotic platform. This platform was specifically created to allow a variety of Active Learning and other educational activities to be easily realizable across numerous institutions of varied resources. In fact, this platform is designed to be a highly robust yet modifiable testbed that is cheap enough to allow every student to own their own robot. Given the robot's modular nature, the students are then able to employ their courses' material in a very hands-on, results-oriented setting and they are even encouraged to devise their own experiments to answer design problems. As the field of robotics requires expertise in all three target fields (Mechanical Engineering, Electrical Engineering, and Computer Science), required weekly interaction with the robotic platform will re-enforce the cross-course connections and will continually review older concepts while relating them to new material. A summary on the details of the robotic platform as and its use as an Active Learning and overall educational tool is provided in the section *Program accessibility: the robotics program*, below.

The design aim of creating the entire program to be as inexpensive as possible is actually crucial for the program to obtain its higher goals. Although it is certainly a requirement that the educational components developed be at, if not above, the standards of the country's highest regarded institutions, it is equally important that the program and the implementation procedures be as accessible and realizable as possible to even junior colleges nationwide. This objective relates back to the NASA Education Enterprise Strategy identification of the commonly untargeted Underrepresented and Underserved student populations within STEM fields [9]. Since the NASA Cadets Program is centered on the first two years, it also offers the opportunity to develop student transfer programs from 2 year to 4 year schools that would have a better chance of reaching these populations. However, in order for these programs to be successful, the 2 year schools must first be able to afford to incorporate the NASA Cadets Program into their programs. Steps have already been taken to ensure that the *NASA Cadets Instructor's Manual* can be easily obtainable through the NASA Robotics Curriculum Clearinghouse (RCC) a currently well-established, NASA administered on-line service that provides robotics related curriculum materials to educator members at little or no cost. Furthermore, the DAVANNE LLC, is dedicated to providing the program with a fully autonomous base robot at a cost of approximately \$450, a price that equates to less than a textbook per course in a projected base 6-course program.

As part of integrating the Active Learning and robotics platform components into the lesson plan curriculum, the program is also designed around the need to incorporate effective assessment strategies from the beginning. The assessment methodology is detailed further in the next section but is overviewed briefly here. In addition to following the accreditation rules and guidelines set out by ABET, the educational model of Learning Objectives was chosen to aid in both the efficient design of NASA Cadets Program courses as well as their assessment and comparison with current undergraduate courses. In short, the Learning Objective model states that all instructional goals will be phrased in the form 'Given X, students will be able to perform Y, whose quality will be determined based on rubric Z'. By providing both the students involved with the NASA Robotics Alliance courses and those students who are instructed via more common methods with the same problems and information, i.e. 'X', the students can then be asked to perform 'Y' and can be measured and compared by the same standard 'Z'.

This in effect builds into the system a direct measure of student performance and can be easily incorporated into knowledge gain tests. Indirect measures such as student/faculty surveys and feedback interviews as well as student employment/further education trends will also be used to judge the quality of the program. Just as importantly, the program will also include newly developed tools for 'intangible' student assessment in vital engineering skill areas, such as troubleshooting, innovation, design, community, and project management, which have been traditionally overlooked.

As it is unrealistic to assume that the entire program would be instantly welcomed and adopted by every institution, the lesson plans developed by the NASA Cadets Program are developed to be highly modular in nature. This allows instructors the flexibility to integrate elements at a pace they deem reasonable. Furthermore, the NASA Cadets Program is designed to allow participating instructors the opportunity to contribute to the program at large through a formal process of documenting new modular components that can be used in addition to or to replace current components. This process relies heavily on the assessment suite as a way to verify the educational value of proposed components and therefore necessitates that the assessment suite is used not only for single component evaluation but for a standard in comparing components.

This NASA Robotics Alliance Cadets Program is named an alliance as it does more than just bringing together the skills and resources of government agencies such as NASA and higher level academic institutions such as Cornell University. This program also aims to incorporate the experience and support of industry and professional organizations. There has been well documented evidence that many companies strongly believe that graduating college students lack many of the key skills necessary for them to succeed in the workplace [10, 18–20]. This position was perhaps best brought out most recently in the 2006 higher education report *A Test of Leadership: Charting the Future of U.S. Higher Education,* which states 'Employers report that many new graduates they hire are not prepared to work, lacking the critical thinking, writing and problem-solving skills needed in today's workplaces' [18].

The role of industry's and professional organizations' support is not merely financial, but as the program is developed, NASA Robotics Alliance members can be asked to provide reviews on or concepts for various course components. Aside from the altruistic benefit of aiding the education field, the benefit in return for these members is a unique and potentially highly widespread promotional opportunity. Also for those groups whose products are applicable and can be donated or offered through special discounts, there is the opportunity to build their market by making their products more familiar and relied upon by Alliance students. However, the most important target benefit is having access to significantly better potential employees and professional members.

Potential expansion into additional disciplines and higher level course development is certainly a possible extension of this project. Likewise, there is also a great opportunity to spread the program down into secondary schools, potentially allowing high school students the chance to earn transferable college credit through methods already in development at Cornell. The success of the project at this stage, however, is defined as the creation of at least two courses for each of the three areas: Mechanical Engineering, Electrical Engineering, and Computer Science. These courses are significantly integrated and build upon one another's content while utilizing the robotics platform above and discussed in the section *Program accessiblity: the robotics program*, as well as and the assessment suite discussed further in the section below.

These courses will cover at least the accreditation requirements of the first two years of the current courses in these three areas, and will then be evaluated using the Learning Objectives educational model and the other assessment methods mentioned above. The results of this evaluation will then be published and released to the public. Based upon the highly anticipated success of the NASA Cadets Program, the developed curriculum will be made available via the NASA Robotics Curriculum Clearinghouse as well as through limited but direct contact with schools and universities, particularly to those of significant Underrepresented/Underserved student populations. Continued support by NASA Robotics Alliance members is highly encouraged and, as mentioned above, is potentially very rewarding for all those involved. For more information on the NASA Cadets Program, please contact co-founders David Schneider or Mark León.

IN CLASS ASSESSMENT THROUGH ACTIVE LEARNING

The key to verifying that the NASA Cadets Program's goals are being met is through the development of a variety of assessment methods that can be used to establish the program's benefit to students, faculty and potential employers, to validate the credibility of the educational methods employed; and to provide a means of comparison with current and additional future methods. This section provides an overview of how the NASA Cadets Program uses Active Learning techniques to provide in-class feedback for both instructors and students while creating a positive impact on student learning. This section also provides an overview of how the Active Learning techniques themselves are assessed through the use of Learning Objective rubrics and how these rubrics are in turn used to establish the assessment suite as a standard. The next section will use this discussion as a foundation to describe how these rubrics are used in the program to ensure accessibility and reproducible results.

The prevalent incorporation of Active Learning within the NASA Cadets Program Lesson Plans helps to enforce the value in using assessment tools not only for post-reviews of a program but for providing useful indicators to the current progress of a class. T. A. Angelo perhaps states it most succinctly as 'Classroom Assessment is a simple method faculty can use to collect feedback, early and often, on how well their students are learning what they are being taught. The purpose of classroom assessment is to provide faculty and students with information and insights needed to improve teaching effectiveness and learning quality' [21]. This view is shared by the NASA Cadets Program. Indeed for the proven capabilities of their methods, the book *Classroom Assessment Techniques* by Angelo and Cross is identified as one of the major sources for developing the Active Learning components of the assessment suite [13, 22].

One of the aspects that is most attractive in using the methods of *Classroom Assessment Techniques* (CATs) is the seamless nature by which they can be integrated into lesson plans while jointly improving the learning experience. This view is already well supported as Schwarm and VanDe-

Grift noted in 2002: 'By using CATs, instructors can monitor students' learning while engaging students in reflective evaluation of course concepts' [22].

Many of the CATs tools, which also include active learning and self-assessment techniques, have been shown to encourage critical thinking skills in students [21, 23]. In fact, many of the NASA Cadets Program's Active Learning methods include a student self-assessment component as an integral way of building skills that are important to engineering education, such as problem-solving and lifelong learning skills [21, 24, 25]. Active Learning techniques have also been shown to assess and improve student learning in such targeted areas as innovation and troubleshooting [19, 20]. Although the areas of innovation and troubleshooting are relatively new, many of the concepts that these areas encompass are often grouped in the better known, better analyzed areas of problem-solving or critical thinking skills.The incorporation of these skills is particularly important as has been well voiced in numerous educational reports such as Ref. [26], which states, 'As is the case for many professionals, graduates of engineering education need strong critical thinking skills in a fast-changing world of increasing complexity. Critical thinking skills can be applied in professional and personal life, and are especially important to engineering education and engineers in solving problems, and designing products systems, or processes.'

The variety of Active Learning exercises that can provide these multiple benefits is also substantial and hence the Lesson Plans repeatedly vary the method employed to provide presentation diversity to meet different learning styles and increase class attention. Some researchers have commented that this allows an instructor to vary the stimulus enough, much in the same way that movie special effect artists vary their tricks so that the audience accepts the method as a part of the larger presentation then recognizing it as merely an attempt to win them over. Nevertheless, the NASA Cadets Program, CAT and others have identified numerous techniques as having a particular strength in assessing knowledge of core concepts and design. These include knowledge gain tests (knowledge probes), various misconception/preconception checks, the muddiest point method, in-class or online minute papers, punctuated lectures, process analysis and analysis of performance exercises as well as CAT's Methods that are intended for use assessing lab activities and problem solving skills to name a few. [13, 22, 27–30] A more detailed description of the NASA Cadets Program's assessment strategies, particularly with regard to critical thinking, teamwork, communication and learning skills, can be found in Ref. [31].

For the purposes of this paper, this section highlights the use of the Active Learning 'polling exercise' to demonstrate how the exercise's implementation is designed, how the method's assessment benefits are matched to desired Learning Objectives, how the method itself is assessed, and how the procedure is documented to allow other institutions to reproduce the results effectively.

The process begins by establishing Learning Objectives (as mentioned in the section above, *The NASA robotics alliance cadets program*) and then matching these Learning Objectives with an effective teaching strategy such as polling. Polling, also known as a finger signals or clickers exercise [32], consists of the instructor providing the class with a multiple-choice question and in response students or groups of students raise an appropriate index card or click a button from a wireless device to indicate to the instructor their own separate answer. The students' answers are visible only to the instructor, but the instructor can visually or electronically confirm that each student has answered. Some versions also allow the instructor to record student responses as a history of individual performance or at least a general distribution of answers across a class.

One of the largest benefits of this teaching strategy is that all students are forced to think about the problem and commit to an answer as the instructor is easily able to confirm answers from all students. The time required for reaching every student is equivalent to the traditional method of having a single student voice their answer. However, because they all commit to an answer, they all receive personal feedback on their performance. This in turn offers every student either validation in having achieved some level of mastery of the subject or it has forced them to realize that this area may be a source of confusion and hence they will need to focus further on or ask their own follow-up question.

In addition, this Active Learning exercise provides a lower pressure environment for the students as only the instructor and not their peers are aware of their specific answer. This also provides the instructor with feedback as to the entire class' understanding as a whole and should a significant percentage of the class provide the same wrong answer this offers the instructor a chance to respond to this trend immediately before attempting to build upon this material. For these reasons, this Active Learning activity is excellent to match with Learning Objectives that have been identified as commonly being associated with misconceptions. As Ref. [32] states 'Although multiple-choice questions may seem limiting, they can be surprisingly good at generating the desired student engagement and guiding student thinking'.

Variations on this activity include having groups of students offer a single answer. This in turn creates discussion among students and requires students to critique each other's ideas and develop conflict resolution skills in trying to achieve a consensus. There is also great opportunity for discussion afterward. If the instructor also shares the distribution of class answers with the students, particularly when a large portion of the students answered incorrectly, the students will be more comfortable asking clarification questions, as they can see that others also had uncertainty on this point. This kind of exercise can also be repeated before and after an instruction section of the class in order to provide an even stronger measure of the effectiveness of the instruction section as well as hopefully to help students realize that learning has indeed occurred.

LEARNING OBJECTIVE RUBRICS

Once the entire instruction and the Active Learning exercise are complete it is crucial to perform a separate assessment of their effectiveness as well. Despite the number and validity of the methods already in existence, a significant 2006 report [33] still called for the need of an assessment suite that could be used as a standard of comparison by stating 'These standards also should establish some requirements for valid and reliable assessments so that accrediting organizations can provide the public some assurance that students receiving degrees or other types of credentials have the skills that institutions and programs claim' [33]. This report is not alone however as Refs [10–12, 34] state similar requests of the community calling for the development of ' . . . a structured, documented system for continuous improvement' [12] in which comparison assessment methods can also be used to show developmental progress.

The cornerstone of creating such a standard assessment suite within the NASA Cadets Program is the development of Learning Objective rubrics. These rubrics are designed to be quick to implement and conduct and are independent of the students' specific assignments or activities. Hence they can be applied as an assessment tool for any exercise that targets the same individual abilities that the students are expected to master.

For each learning objective or desired learning outcome identified within a course, an individual rubric is constructed that is separate from grade evaluations. While an assignment or activity may touch upon many different concepts, and hence many different learning objectives, and a grade would summarize a student's mastery of these concepts combined, the rubrics summarize the students' mastery of a particular learning objective and show trends across several assignments or activities. Correlations between rubric scores and traditional course grades are typically strong, however the rubrics help to separate out which concepts a student may be struggling with or what the entire educational program is particularly effective in achieving. These rubrics also address what are traditionally deemed in engineering as 'softer skills', such as the application of communication, teamwork and problem solving skills during the assignment [19, 20].

The Learning Objective rubrics are incorporated directly into the Instructor's Manual to help ensure their proper use. The rubrics are also meant to be shared with the students, both before and after the instruction to provide students with weighted criteria for assignments and the aforementioned softer skills. In this way, the rubrics provide the entire class with a clear outline of the learning objectives for each part of the classes and the assignments. This also aids the instructors in tying the assignments to the concepts being taught in class while providing students with descriptions of the expected skill levels. The same Learning Objective rubrics may appear in several different assignments or class sessions, enabling students and instructors to observe their progress throughout the semester.

Although in this section only one sample Active Learning method has been discussed, it demonstrates how these methods can be incorporated in the lesson plans to provide in-class assessment and to assess the methods themselves. Because the process is formalized and quick to implement, it is also easy to sustain or adapt to changing needs. A report on all of the assessment methods being analyzed collectively by such processes as those outlined in *Assessing Student Performance on EC2000 Criterion* [35] will be made available by NASA through the RCC with special attention given to the methods' consistency and ease of use by faculty. This assessment suite will ultimately provide the key mechanism for enabling other institutions to validate and submit their own program modules as official components to the NASA Cadets Program. Thus, the program will be able to incorporate not only the ingenuity of fellow educators, but also ensure its own continual growth and longevity.

PROGRAM ACCESSIBILITY: THE ROBOTICS PROGRAM

Active Learning tools can also be highly effective when extended to labs and more involved design projects. However the requirement to make the program as accessible and sustainable as possible, with widely realistic implementation procedures and equipment needs, can create substantial challenges. For this reason, the NASA Cadets Program heavily supports the incorporation of the low cost, highly modular robotic platform being developed by the DAVANNE LLC. Every robotic tool in the platform is designed to meet as many learning objectives as possible using as few specialized equipment pieces as possible. Hence considerable effort is spent on flexibility in the tools to allow quicker adaptation and faster learning curves for using these materials in other institutions courses as well as the NASA Cadets Lesson Plans.

As stated in the section above, *The NASA Robotics Alliance Cadets Program,* working with robotic systems will require students to gain a proficiency in integrating the three target areas of

Mechanical Engineering, Electrical Engineering and Computer Science. More than this, using robots in an educational environment has been shown to help develop the program targets skills as identified in the last two sections. Many research studies have demonstrated the immediate value of robots as tools for students in engineering courses to relate classroom theory to its applications, and to develop their skills in problem solving and critical thinking [19, 20, 36–50]. Furthermore, research has also shown the long-term benefits, such as that 'lessons learned (from working with robots) are not transient, and that comfort with technology and a willingness to participate in technology-related projects may be the key long-term benefits of such an educational robotics program' [36].

An investigation made by the NASA Cadets Program in the Fall of 2005 found that nearly all current robotic educational systems are designed for a specific task or at best a small specific set of learning objectives. However, one of the best current systems used in higher education is the Oregon State TekBot. This system was developed to focus primarily on elements of the Electrical Engineering field, but in its five year history of being used in a higher education environment, it was demonstrated that robots like the TekBot can be used to reach a wide range of learning outcomes. As stated in Ref. [19], 'The integration of TekBots into two freshman/sophomore courses at OSU improved several important key attributes of the course, including innovation, community, troubleshooting, depth, breadth, and professionalism', where trouble-shooting, community, and innovation are characteristics that were identified from a widely ranged survey of successful industry and academic faculty leaders as crucial components of engineering education that are not adequately targeted for today's workplace needs [20]. Although no current robotics system has been found to be adequate for the NASA Cadets Program cross-discipline educational needs, robotics studies like those performed with the TekBot provide strong evidence that the NASA Cadets Program's target skill sets can be addressed using robotics. Furthermore, these studies can also be drawn upon for existing educational robotic assessment tools that already have a proven record.

In order to establish the DAVANNE robotic system within the NASA Cadets Program as a standard across academic communities, the DAVANNE robot has been designed as a far more flexible, robust and affordable platform than previous educational robots, with enough pre-packaged features that an incoming freshman can modify significant components. At the same time, it also has been designed to incorporate enough capabilities to be scheduled for use by several cutting-edge NASA research groups. The highly significant time and effort required for developing any robotic system for even a single task, let alone a system capable of being able to meet the educational needs of undergraduates across three disciplines as well as the needs of a NASA research scientist is substantial. However, since the potential for such a system to the educational and research community is so great, NASA has taken the lead in conjunction with the DAVANNE LLC to design a robotic platform to meet this challenge [31] Technical specifics on the DAVANNE robot will be made available via the Robotics Curriculum Clearinghouse pending IP release, however more details on how the platform is utilized in an Active Learning setting is provided in the next section.

Active Learning techniques are particularly well suited for helping to bring out the numerous psychological benefits of working with the robotics platform as well. One of the most obvious is the simple allure of being able to 'own your own robot'. This general appeal tied in with the stimulating creative aspects of robotic design and development captivates students' curiosity. Overall, the use of robotics as an attractive element to students is actually a very significant asset to the program. When attempting to combat the trends of attrition, the ever changing nature of a robotic platform, particularly since students often cause the change, is a very useful tool for providing continual motivation and excitement.

The robot is also used to establish a sense of ownership in a project, a sense of accomplishment as robotics platforms are naturally results-oriented, as well as a sense of pride in seeing tangible results from one's labor. The NASA Cadets Program lesson plans are designed to work with the robotic platform to ensure that students experience these factors early on with Active Learning techniques used to provide quick in-class assessment. Ultimately, success breeds success and the robotics' modular nature and packaged exercises allow students the chance to experiment and have the experience so that they can indeed demonstrate a level of mastery over the material. The realization that they can to gain proficiency in a subject matter as well as recognizing what the proficiency of skills enables them to accomplish, are highly empowering events for students. Furthermore it is events like this that encourage them to look for the value in lessons on their own and even to reach out for knowledge outside of the standard curriculum [51]. As stated in Ref. [36], the ' . . . positive impact of (robotics) on student learning (extends) well beyond the boundaries of specific technical concepts in robotics'. Hence it is through experiences such as those provided through incorporating robotics that the ability to innovate is born.

To aid in the development of this ability, NASA has traditionally encouraged the formation of nationwide competitions, the most famous of which is the US FIRST robotics competition which was supported in part by Apollo XI Astronaut Buzz Aldrin. Today this program has spread to over 800 high schools across the U.S. [52] Competitions offer a mixture of well specified goals, with constrained problems and yet leave open areas for invention and experimentation. Thereby competitions can offer more controlled and even more learning outcome targeted versions of real world scenarios. After all, it is now common knowledge that 'the development of any skill is best facilitated by giving students practice and not simply by talking about or demonstrating what to do' [53]. More than providing a link from theory to practice, the process of dealing with the competition's challenges and constraints while attempting creative solutions inevitably force students to gain experience in troubleshooting. In addition, competitions also generate an incentive for students to excel and 'win' that can often exceed the drive created by offering only grading rewards for achievement.

For this reason, the NASA Cadets Program is developing several competitions that range from laboratory experiments and weekly homework 'challenge problems' to year-long projects. Many of NASA's current competitions will provide inspiration for these new competitions, as will competitions outside of NASA, such as the worldwide RoboCup Competition, in which program contributor Cornell University has been world champion four out of the seven times it competed.

The key to developing the competitions is that the rules and execution of the competition is constructive to the student community. This can be achieved by tapering the emphasis on 'winning' as compared to promoting every student and team to simply 'score' the best that they can. Allowing students various areas to succeed can aid in creating this environment and simultaneously help create diversity in the students' solutions. Once again the use of rubrics and their explanation and open availability to students becomes a useful tool. With the design of multiple success criteria into a competition, this also creates a need for students to prioritize goals, budget resources and ultimately develop project management skills. Furthermore adding to the experience Active Learning exercises like those mentioned in the section above, *In class assessment through active learning*, allows instructors to highlight pitfalls, ensure that students are taking into consideration all the requirements and constraints, as well as being a conduit for general discussion on these design concepts.

Similarly, in any situation where multiple solutions are possible, the need for effective communication for describing the reasoning behind decision making becomes self-evident. Therefore having a base system, like the robotic platform, that all students are working from encourages the exchange of ideas and a common language for passing knowledge between students. Furthermore, including elements such as Active Learning that allow peer assessment through various forms of constructive criticism can also help to build community. Combining all these benefits, it becomes clear that the robotic platform will be an exceptional tool in ensuring that the NASA Cadets Program will reach its goals.

LESSON PLAN, ACTIVE LEARNING, ROBOTICS PLATFORM AND ASSESSMENT SUITE INTEGRATION

One of the founding concepts behind the NASA Cadets Program is that the integration of the assessment suite and the robotic platform with the lesson plans will result in more effective products than any component would be on its own. To demonstrate this integration, this section outlines one standalone module of the NASA Cadets Program called the Robotics Triathlon, which was originally designed for Cornell University.

As the name implies, the Robotics Triathlon is a three-part competition. The target audience for this module is incoming Freshmen with little to no experience in any of the three target areas (Mechanical Engineering, Electrical Engineering, and Computer Science). The time frame for this module is two 2-hour lab sessions with a 2-week period in between each lab. The class size is approximately 30–40 students, divided into groups of 3–4. The equipment provided to each group is one PC station and a single robot with a set of modular components, along with handouts and a small 15-page C++ reference guide, which will be described later in this section. The recommended instructor support is one key lecturer and 1–2 teaching assistants who are familiar with the equipment.

The main learning goals of the module for the three target areas can be described most easily by walking through the implementation of the Robotic Triathlon. This description is intentionally made general in parts in order to convey to the reader more of an overview of the style of the NASA Cadets Programs deliverables. The module actually begins about 1–2 weeks before the actual first lab, i.e. perhaps in an earlier laboratory session or classroom lecture. In this session, the instructor lays out the Robotic Triathlon Competition as well as communicates the precise learning objectives for the students for the Robotic Triathlon lab sessions. Furthermore, the instructor also issues the first part of a knowledge gain exam on the learning objectives.

After completion of the exam, the students are then given a copy of a small C++ reference guide. The reference guide covers the topics of a few variable types, arithmetic, relational and logical operators, as well as if/else statements and while loops in 15 pages. Students are asked to review the reference guide and complete two pages of worksheets before the first lab. The students are also asked to complete a third brief worksheet the night before their first lab session to allow the concepts to be fresh in their minds. The anticipated time required for the students to complete these tasks is approximately 3 hours and the students' worksheets are collected at the beginning of the first lab session.

In the first lab session, the students are engaged in active learning using such techniques as polling to review the material read, address any misconceptions and to be introduced to a compiler. Through a step by step process the students slowly build a program to give them experience with the material they learned as they work towards programming the robot to move forwards and backwards and turn to either side by responding to keystrokes from the PC keyboard. As was introduced in the last section, in order to make this project feasible for incoming Freshmen, pre-packaged components such as low level motor control, communication protocols and other platform functionality is already provided for the students and these components' use is simplified with the aid of wrapper functions.

Aside from merely practicing the material, throughout this lab session students are challenged via Active Learning methods, like those mentioned in the section above, *In class assessment through active learning*, to identify errors in given code and assess for themselves what the outcome of various code changes may be. This in turn helps to target the higher levels of Bloom's Taxonomy as well as the key area of troubleshooting. Also as some students have difficulties with various components during the lab, these issues are addressed in such a manner that a student is not dubbed completely wrong but rather the situation is that 'one of your fellow student teammates needs the class's help'. This can obviously help bring attention to typical mistakes to the entire class, but potentially even more importantly this can be used to instill the sense of community and the need for teamwork. As small syntax errors are both common and often relatively easy to correct with programs of this scale, more than just reinforcing troubleshooting skills, this introduces early on a relatively safe environment in which students can make mistakes. Furthermore, as the negative impact of making a mistake is minimal, this can actually reduce the fear of failure and increase the willingness to experiment and readiness to innovate in the next lab section. The students are challenged at the end of the first lab session to modify their code in order to have the robot drive in a square with only a 'Go' input from the keyboard.

The session ends with the use of assessment methods mentioned in the section above, *In class assessment through active learning,* in order to determine how effective the lesson was and to provide students post-session feedback on their abilities as well. The instructor also provides an introduction for the students on the next homework and lab section with a particular focus on how these activities relate to the top three levels of Bloom's Taxonomy: Analysis, Synthesis and Evaluation.

In the homework assignment for the next lab session, the students are given a problem where they must choose a limited set of vectors from a provided library of potential vectors that can be combined to transverse several simple maze-like grids. At face value the problem provides an introduction to the concepts of algorithm development, but the solution reporting process is geared to ultimately force students first to formally analyze the problem's constraints and requirements. Then the students must develop their solutions and evaluate them themselves based upon provided criteria in the same way as the Active Learning troubleshooting exercise they experienced during the first lab session. The familiarity of the exercise helps the students to realize the benefits even though they are now asked to perform the same activities on their own.

In the last step of the homework assignment, the experience is taken further by allowing students to modify one of the constraints and provide reasoning on why this relaxation would allow potential solutions that would better meet the problem's requirement criteria. Finally, students are made aware once again that the process they just followed fits within the Analysis, Synthesis and Evaluation levels of Bloom's Taxonomy. It is important to note, however, that if the students' curriculum has not yet covered vectors and vector addition, a suggested lesson plan is provided as a part of this module.

The second lab session begins with a more specific description of the Robotic Triathlon. In the Robotic Triathlon each team of students will be asked to modify their robot to increase its ability to navigate an obstacle course and perform some timed simple tasks. To prepare the students for this task, students are then led through a small series of active learning individual exercises to teach the Mechanical Engineering concepts of gear ratios and torque. Students are also given a very general overview of the ideas of feedback control and the incorporation of sensors from more of an Electrical Engineering perspective, which will also be useful knowledge for them in making modification decisions for their robots.

This instructional component is designed to last no more than 45 minutes allowing the students 1 hour and 15 minutes to make the modifications. However during this instruction, several Active Learning exercises are conducted so that the students have a better awareness of their own personal capabilities and what they will be able to offer to the design group and what areas they may want to confer with others or the instructor before moving forward. The instructor is also able to identify whether large groups of the class are having troubles with a particular area and hence address the issue with the entire class instead of having to repeat the clarification to each student group during the Triathlon.

The modifications that the students are allowed to make are: (1) changing the gearing of the robot's motors using the gears provided; (2) changing the length of an arm of the provided gripper tool on the robot, i.e. influence the torque the arm can provide, and (3) modifying a gain input to a provided function that influences the robot's motion controls where there are trade-offs such as between speed and control sensitivity. Owing to the modular nature of the robotics platform, all of these changes can be done in a few minutes, allowing the students significant time to consider their design choices carefully. Once the group has made its modifications, the students run their robot through the course and receive a score based upon their task performance and completion time.

Each student group is actually allowed to run their robot through the Triathlon twice. After receiving the score for their first run, students are allowed to make any changes to their robot once again and then run the robot for a second time. The best of their two runs' scores is the group's final score. However, the score itself counts for only a small amount of the students' grades and far more weight is given to the calculations and reasoning used to justify their modifications.

The second lab session as described here clearly demonstrates how many of the NASA Cadets Program's targeted areas can be integrated together. Topics in all three disciples of Mechanical Engineering, Electrical Engineering and Computer Science are covered simultaneously. Similarly, the students are asked to make innovative use of the provided components to meet the challenges of the Triathlon. The implementation of their modifications and multi-run aspect of the Triathlon will give experience in troubleshooting. Then throughout the event the group set-up and competition component of the module aid in the development of the community target area.

The community target area, as well as other elements of the module, are also ameliorated through the use of assessment suite components throughout the module's execution. Peer review and constructive criticism exercises are also used as a component of the module's assessment. Additionally, throughout the module, students are asked to employ self-assessment techniques to aid in both their design process and in the instructors' evaluations of the module's execution.

The students' final reports include both team submission and individual submission components to ensure not only both group and individual accountability, but also to act as an evaluative check to the in-class assessment components. The questions the students are asked to address in these reports also delve into the Analysis, Synthesis and Evaluation levels of Bloom's Taxonomy as well as the innovation, troubleshooting, and community target areas. By measuring the students' responses using the verified rubrics mentioned in the section above, *In class assessment through active learning,* the report can also aid in the module assessment. Furthermore the report is also used as an assessment tool by making part of the report's individual component the second half of the knowledge gain test. Indirect measures such as surveys and interviews can also be employed for additional data collection.

As a final step to the module, the instructor is encouraged to share and discuss the results of all of the evaluation tools with the students as a group, while reminding students that their grades are independent of the assessment tools results. This can help to both reiterate to the students the value of each component of the module and especially the assessment methods employed as well as aid students in identifying the value of future module's components on their own.

CONCLUSIONS

The NASA Robotics Alliance Cadets Program's assessment suite is focused on fulfilling the nationally recognized need for a standard system to identify the most effective innovations within today's engineering education programs. Key components to this suite that have been recognized by ASEE are the Active Learning activities that have been extended and enhanced by the NASA Cadets/DAVANNE robotics platform. Together these tools achieve the accessibility and sustainability needs as well as the program validation requirements established by the 2006 *National Defense Education and Innovation Initiative* report. Additional educational benefits of the program to target areas such as troubleshooting, innovation, and community are also highlighted in the description of the NASA Cadet Robotics Triathlon module developed in part with Cornell University.

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