An Introduction to the NASA Robotics Alliance Cadets Program

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Abstract

The 2006 report *National Defense Education and Innovation Initiative* highlighted this nation's growing need to revitalize undergraduate STEM education. In response, NASA has partnered with the DAVANNE Corporation to create the NASA Robotics Alliance Cadets Program to develop innovative, highly integrated and interactive curriculum to redesign the first two years of Mechanical Engineering, Electrical Engineering and Computer Science. This paper introduces the NASA Cadets Program and provides insight into the skill areas targeted by the program as well as the assessment methodology for determining the program's effectiveness.
The paper also offers a brief discussion on the capabilities of the program's robotic platform and a justification for its design into the program. As an example of the integration of the robotic platform with the program's methodologies, this paper concludes by outlining one of the first educational experiments of NASA Cadets Program at Cornell University to be implemented in the Spring 2007 semester.

I. Introduction

To be an engineer is to be a designer, a creator of new technology, and the everyday hero that solves society's problems through innovative methods and products by making ideas become a reality. However, the opportunity to truly explore these key concepts of being an engineer are often withheld from most incoming engineering students until at least their junior year causing many new students to lose motivation and potentially leave the program. Problems like this one have been voiced at the national level for years in such high profile documents as the 2003 *NASA Education Enterprise Strategy* but continue to remain a key issue as was recently emphasized in the 2006 report *National Defense Education and Innovation Initiative.*[1,2]

Furthermore both the *NASA Education Enterprise Strategy*, and the *National Defense Education and Innovation Initiative* have sighted the need to reach the far too often untargeted "Underrepresented and Underserved" student populations and was voiced quite clearly in the *National Defense Education and Innovation Initiative* as the need 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." [1,2]

Out of this identified need, the NASA Robotics Alliance Cadets Program was created as a far-reaching, innovative project aimed at developing new highly integrated and interactive college undergraduate level curriculum centered around robotics and focusing on the content of at least the first two years of Mechanical Engineering, Electrical Engineering and Computer Science. This project is being co-led by author David Schneider and Mark Leon, NASA AMES Director of Education with the three part goal of improving students' academic performance and knowledge retention, inspiring students to take their technical education and careers further, and ultimately to broaden the American technology base. [3]

The NASA Cadets Program and the methodologies for reaching its goals are outlined briefly in Section 2, but in general are beyond the scope of this paper. However, this paper addresses the broader concern that if methodologies are to be created by any organization, there must be assessment methods in place to determine the methodologies' effectiveness. [2,4,5,6,7] Therefore, one of the deliverables of the NASA Cadets Program is a suite of assessment tools that can be used as a standard in a variety of STEM higher education fields. As ABET acknowledged while discussing the use of outcomes-based methodologies in a 2006 report "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." [8] Hence, the NASA Cadets Program's assessment suite is being developed to be used not only to evaluate a single educational program but to also provide a common basis of comparison.

The paper is arranged so that the sources for creating the suite of assessment tools are discussed in Section 3. This section and the next section also describe the targeted evaluation areas with a particular focus on critical thinking, innovation, troubleshooting and community which are areas that extend beyond the traditional ABET focus of breadth, depth, and professionalism. These areas are highlighted because they have been identified as highly important if not crucial areas by the educational research community. [9,10,11] With the assessment suite concepts introduced, Section 4 then provides a discussion on the robotic platform as a key element to the program and its role in aiding in the assessment. Then finally in Section 5, an experiment being developed for the Cornell University Spring 2007 Semester is outlined as an example of how the assessment methods and robotic platform can be integrated with various lesson plans.

II. 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 curriculum that 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.[1,2,3]

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 containing an outline of the core concepts and equations that are traditionally taught, include active and cooperative learning techniques, planned discussions on evaluation methodologies and applications, and real world motivations. Combined with carefully constructed homeworks and labs, together these lesson plans ultimately move engineering education beyond merely the Knowledge and Comprehension levels of Bloom's Learning Taxonomy that most current first and second year courses are limited to, into the higher levels of Analysis, Synthesis and Evaluation.[12]

In order to make this leap possible, partnered with the NASA Cadets Instructor's Manual is a newly designed robotic platform. This platform is designed to be a highly robust yet modifiable testbed that is low cost enough to allow every student to own their own robot. Given the robot's modular nature, 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 help re-enforce the cross-course connections as well as provide a constant source of reviewing older concepts while relating them to new material. A summary on the details of the robotic platform as well as support for the use of robotics platforms as an educational tool is provided in Section 4.

The design 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 be accessible to even junior colleges nationwide. Part of the reason for this objective relates back to the NASA Education Enterprise Strategy identification of the commonly untargeted Underrepresented and Underserved student populations within STEM fields. Since the 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 incorporating the NASA Cadets Program into their programs. Steps have already been taken to ensure that the NASA Cadet's Instructors Manual can be easily obtainable through the NASA Robotics Curriculum Clearinghouse (RCC) a currently well established, NASA run on-line service that provides robotics related curriculum materials to educator members at low or no cost. Furthermore, the DAVANNE Corporation, is dedicated to providing the program with a fully autonomous base robot at a cost of approximately $375, a price which equates to less than an inexpensive textbook per course in an projected base 6-course program.

As part of integrating the robotics testbed into the lesson plan curriculum, the project will also be designed around the need to incorporate effective assessment strategies from the beginning. The assessment methodology is detailed in Section 3 but is overviewed briefly here. In addition to following the accreditation rules and guidelines set forth by ABET, the educational model of Learning Objectives was chosen to aid in both the efficient design of NASA Robotics Alliance 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 students who are 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 would be 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 would allow 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 formalized 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 project is named an alliance as more than just bringing together the skills and resources of government agencies like NASA and higher level academic institutions such as Cornell University, this project 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 are lacking in many of the key skills necessary for them to succeed in the workplace. [2,9,10,11] This concept 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." [9]

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 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. 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, that are significantly integrated and build upon one another's course content while utilizing the testbed listed above and discussed in Section 4, as well as and the assessment suite discussed further in Section 3. These courses will cover at least the accreditation requirements of the first two years of 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 publicly released. Based upon the highly anticipated success of the 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 is mentioned above is potentially very rewarding for all those involved. For more information on the project, please contact Co-Founders David Schneider or Mark Leon.

III. The Assessment Suite

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. In order to meet this need, an entire suite of various assessment tools must be developed and compiled. However, as validating the educational assessment methods is often just as complicated as validating the educational methods themselves, there is a strong desire to incorporate, whenever possible, assessment tools that already have a well proven history.

Essentially this area of the project will look at two aspects in the development of assessment tools, as well the effectiveness of curricular changes using robots as a learning platform. The first aspect will be to review the validity and utility of the assessment tools developed. Once the project develops the assessment tools, they will be reviewed based on a similar methodology described in *Assessing Student Performance On EC2000 Criterion*. [13] In a review of the literature, the project will identify a collection of assessment instruments, and adapt the instruments for use in the engineering courses. [14,15,16,17] These instruments will then be pilot tested to determine if they are appropriate measures for the identified outcomes. Then the instruments will only be considered a part of the final assessment suite after a final revision.

The second part of the suite development will look at the impact of assessment techniques and curricular changes on student learning. This project will collect data using student surveys and interviews, faculty interviews, and data on class performance to compare the impact of self-assessment and regular feedback on student learning in the course. In addition, the assessment will also include an examination of the effectiveness of the robotic platform on student learning.

One of the main focuses in creating the first part of the assessment suite will be the development of rubrics. For each assignment, a rubric will be constructed to measure if students met the learning goals for that assignment as well as met what are traditionally deemed in engineering as “softer skills” such as the application of communication, teamwork and problem solving skills during the assignment. [10,11] The set of rubrics will be incorporated into the instructors manual and tied directly to the identified learning objectives. The rubrics will also provide students with criteria for assignments, communication and teamwork skills. Having the rubrics available to both instructors and students will provide a clear outline of the learning objectives for the assignments. Instructors will be able to tie the assignment to the concepts being taught, and students will have descriptions of skill levels expected.

As important as these assessment values are, there are many arguments for the purposes behind various kinds of assessment. However, 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." [7] As this is a view shared by the NASA Cadets Program and as well as 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 assessment suite. [6,18]

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 supported as well as is stated in such references as Ref. 18, “By using CATs, instructors can monitor students’ learning while engaging students in reflective evaluation of course concepts.”

Many of the CAT’s tools also include active learning and self-assessment techniques which have been shown to encourage critical thinking skills in students. [19,20] In fact, many of the assessment methods to be implemented in the project will also 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. [19,21,22] Overall CATs provide an excellent source for general assessment methods to be incorporated into the assessment suite. As the NASA Cadets program also strives to improve student learning in such areas as innovation and troubleshooting as identified in Ref. 10,11, specific techniques must be used to assess other skills such as these. Although the areas of innovation and troubleshooting are relatively newly recognized, many of the concepts these areas encompass are often grouped in the better known, better analyzed areas of problem-solving or critical thinking skills.

The need for critical thinking skills has been well voiced in a numerous educational reports such as Ref. 23 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.”

For this project, we have selected various classroom assessment techniques methods that will be used to assess learning, problem solving and critical thinking. A few of these techniques that CAT has identified as assessing knowledge of core concepts and design include knowledge gain tests (knowledge probes), various misconception/preconception checks, the muddiest point method, and in-class or online minute papers. Similarly, CAT's Methods that the program intends to use for assessing lab activities and problem solving skills include the: [6,18,24]

- *Punctuated Lecture*: which divides the lecture, lab or other activity, into shorter segments that are punctuated with asking students questions about their thinking process and application of concepts.
- *Self-assessment*: at the end of the lab, include self-assessment in a quiz or survey. For self-assessment of learning, the method will include questions that probe students confidence in their knowledge, and why they do or do not understand a concept/process.
- *"Process analysis" for Problem solving*: where given a problem students must resolve, they will re-describe the problem and the steps as well as the reasons behind their solution. After they apply the solution, they will review why or why not the proposed solution worked with special attention given to their problem solving approach. This can structured as a form of pre/post self-assessment as well.
- *Analysis of Performance:* after completing a lab and receiving their grade, students will analyze how well they did compared to their expectations and may be asked to develop specific rubrics themselves. Different than "process analysis", this method pays additional attention to analyzing the problem itself and their problem interpretation skills, i.e. what prevented them from doing better in the activity, evaluating their readiness for the activity and what they plan to do differently in order to improve on the next activity.

III.A. Measures of Critical Thinking

In the NPEC Sourcebook on Assessment , there are many instruments available to assess critical thinking skills. "Critical thinking is defined in seven major categories: Interpretation, Analysis, Evaluation, Inference, Presenting Arguments, Reflection, and Dispositions." [25] Each of these tests assess aspects of critical thinking. The project will review the instruments for the characteristics they assess, determine which tests measure the skills for engineering, and how the test can be implemented into the NASA Cadets Program suite of assessment tools.

California Critical Thinking Dispositions Inventory
CAAP Critical Thinking Assessment Battery
California Critical Thinking Skills Test
Cornell Critical Thinking Test
College Outcomes Measures Program – Objective Test
ETS Tasks in Critical Thinking
Measure of Intellectual Development
Problem Solving Inventory
Watson Glaser Critical Thinking Appraisal
Critical Thinking Scoring Rubrics [25]

The CATs' assessment methods for critical thinking and problem solving skills can also be used to enhance curriculum development. For example, Ref. 17 offers the following advice as well as warning to use well established and researched methods across courses as a way for aiding the comparison process, "Use a standard research-based problem-solving strategy across several (and ideally, all) courses in an instructional program. …. Select an evidence-based strategy such as the six-stage McMaster Problem Solving Strategy: "Engage", "Define the stated problem", "Explore", "Plan", "Do it" and "Look back." Similar methods such as "Guided Design, active/cooperative learning approaches, (and) Thinking-Aloud Pairs Problem Solving (TAPPS)." [17] will also be applied in developing learning objectives, assignments and implementing assessment methods.

III.B. Measure of Team and Communication

To assess the team work during lab projects, we will implement a peer evaluation form "that assigns numerical ratings to four different components of effective teamwork: attending meetings on a regular basis, making an effort at assigned work, attempting to make contributions and/or to seek help within the group when needed, and cooperating with the group effort." This peer rating system is based on the form developed at the Royal Melbourne Institute of Technology and additional research on measures of cooperative learning included in Ref. 26, 27, 28. Peer ratings have been shown to be an effective in aiding instructors to "assess individual performance of team members and to adjust the team project grade for individual team members based on their average ratings." [26]

III.C. Measures of Learning Skills

A goal of engineering education programs include the development of lifelong learning skills. As a measure of student learning readiness at the beginning and end of the first year, the project will review the use of the Self-directed Learning Readiness Scale. This Likert-scaled questionnaire probes student attitudes toward learning, such as self-generation of knowledge, responsibility for learning, individual vs. group learning, curiosity about learning, learning environment preferences, study skills, and the importance of continual learning. [29,30]

Despite the number and validity of the methods already in existence, a significant 2006 report [31] 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." [31] This report is not alone however as Ref. 2,4,5 state similar requests of the community calling for the development of "...a structured, documented system for continuous improvement." [5] where the comparison assessment methods can also be used to show developmental progress. Therefore, ultimately all of the assessment methods must be themselves analyzed collectively by such processes as those outlined in *Assessing Student Performance On*

EC2000 Criterion. [13] with special attention given to the methods' consistency and ease of use by faculty.

IV. The Robotic Platform

A keystone to the NASA Cadets Program is a low cost, highly modular robotic platform that is being developed by the DAVANNE Corporation. As stated in Section 2, 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 Sections 2 and 3.

Already there are many examples of research that demonstrate how robots can be excellent learning tools in engineering courses for making the connection between classroom theory and application, as well as developing problem solving and critical thinking skills. [10,11,15,16,32,33,34,35] Furthermore enough research has occurred to even study the long term benefits as is stated in Ref. 15, "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."

In an investigation made by the NASA Cadets Program in the Fall of 2005, 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 is stated in Ref. 10, "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. [11] Although no current robotics system has been found adequate for the NASA Cadets Program cross-discipline educational needs, robotics studies like those performed with the TekBot provide not only strong evidence that the NASA Cadets Program's target skill sets can be addressed using robotics but that these studies can also be drawn upon for existing educational robotic assessment tools that already have a proven record.

Furthermore, investigation into current robotic educational systems has shown that most robots are designed for a specific task or at best a small specific set of learning objectives. However since the DAVANNE robot is designed to be more flexible, robust and still low cost with enough pre-packaged features that an incoming freshman can modify significant components, there is a much higher probability that this system can become a standard across academic communities. To make the robot even more attractive, the robot has also been designed to be expansive enough to be utilized by cutting edge NASA research groups. A large reason that this has never been done before is due to 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. However, since the potential for such a system to the educational and research community is so great, this is why NASA has taken the lead in conjunction with the DAVANNE Corporation to design a robotic platform to meet this challenge.[36]

Aside from the technical advantages of such a system, there are also numerous psychological benefits. 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 & 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 every changing nature of a robotic platform, particularly since students are often the cause of 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 lesson plans are designed to work with the robotic platform to ensure that students experience these factors early on. Ultimately, success breeds success and the modular nature and packaged exercises allow students the chance to experiment and have the experience that they can indeed demonstrate a level of mastery over the material. Realization of the ability 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 to even reach out for knowledge outside of the standard curriculum. As is stated in Ref. 15, the "…positive impact of (robotics) on student learning (extends) well beyond the boundaries of specific technical concepts in robotics" Hence it is through experiences like 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 and has spread to over 800 high schools across the U.S. [37] Competitions offer a mixture of well specified goals, with constrained problems and yet leave open areas for invention and experimentation and thereby can offer more controlled and even more learning outcome targeted versions of real world scenarios. After all, it is now common knowledge that "Research suggests that the development of any skill is best facilitated by giving students practice and not by simply talking about or demonstrating what to do." [17]. More than providing a link from theory to practice, the process of dealing with the competition's problems and constraints while attempting creative solutions will inevitably force students to gain experience in the area of 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.

It is for this reason, the NASA Cadets Program is developing several competitions that range from year long projects, to laboratory experiments to weekly homework "challenge problems". Many of NASA's current competitions will provide inspiration for the NASA Cadets Program competitions as will competitions outside of NASA such as the worldwide RoboCup

Competition where program contributor Cornell University has been world champion 4 out of 7 times it competed.

The key in 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 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.

Similarly, in any situation where multiple solutions are possible, the need for effective communication for describing the reasoning behind decision making becomes self-evident. Similarity having a base system, like the robotic platform, that all students are working from, encourages the exchange of ideas and a common language element for passing knowledge between students. Furthermore, including elements for 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 the NASA Cadets Program will reach its goals.

V. Lesson Plan, Robotics Platform and Assessment Suite Integration: The Robotics Triathlon Example Module Description

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. As an example of this integration, this Section outlines one stand alone module of the NASA Robotics Program called the Robotic Triathlon that was originally designed for Cornell University.

As the name implies the Robotic Triathlon is a three part competition, where the target audience 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 the module is two 2 hour lab sessions with 2 week period in-between each lab. The class size is approximately 35-40 students and the students are broken into groups of 3-4 students per group. The equipment provided to each student group is one PC station and a single robot with a set of modular components, along with handouts and a small 20 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 with familiarity of the equipment.

With regards to the three target areas, the main general learning goals of the module 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 a week to 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 20 pages. Students are asked to review the reference guide and complete 2 pages of worksheets before the first lab. The students are also asked to complete a third brief worksheet the night just 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 3.5 hours and the students and the worksheets are collected at the beginning of the first lab session.

In the first lab session, the students are engaged in an active learning session 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 listening to keystrokes from the PC keyboard. As was introduced in Section 4, 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 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 certain 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 classes' 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 for students to make mistakes in. 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 as mentioned in Section 3 as well as the instructor providing 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 following section, 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 to first formally analyze the problem's constraints and requirements. Then students must develop their solutions and evaluate them themselves based upon provided criteria. Furthermore, students are then allowed 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 though 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.

The modifications the students are allowed to make are changing the gearing of the robot's motors using provided gears, changing the length of an arm of a provided gripper tool on the robot, i.e. which has influence on the torque the arm can provide, and thirdly, 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. Due to the modular nature of the robotics platform, all of these changes can be done within a few minutes time, allowing the students significant time to consider their design choices carefully. Once the group has made their 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 grade 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 be innovative in their 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 all 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 both aid in their design process and in the instructors evaluation of the module's execution. The students' final reports include both team submission and individual submission components to not only ensure both group and individual accountability, but 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 Section 3, 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. 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 being able to identify the value of future module's components on their own.

VI. Conclusions

The NASA Robotics Alliance Cadets Program is a highly innovative, integrated, and interactive curriculum established to redesign the first two years of Mechanical Engineering, Electrical Engineering and Computer Science. In addition to the lesson plans of the NASA Robotics Alliance Cadets Program Instructor's Manual, this program's goals are achievable through the incorporation of the low cost, highly modular yet robust DAVANNE robotics platform and the program's assessment suite developed in part by Cornell University. Furthermore, the educational purpose behind both the robotics platform and the assessment suite can be clearly seen through the example of the program's Robotic Triathlon module.

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