A Curriculum-Integrated Small Spacecraft Program for Interdisciplinary Education

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Space generates inspiration, aspiration, and passion in many students, traits that are often lacking in the traditional college classroom. By utilizing a meaningful space project with a tangible product, which serves a valuable purpose in the curriculum, instructors can generate passion in their students with regards to the topics being explored. Additionally, it can fuel interest in aerospace science and commerce, guiding more students towards valuable STEM degrees and job opportunities, which can lead to future growth and fresh blood in the aging aerospace employee pool.

OpenOrbiter is a student-run research project at the University of North Dakota that can serve as a basis for developing this type of integrated interdisciplinary education. To date, it has involved over 200 students. When the design specifications, called the Open Prototype for Educational NanoSats (OPEN), are published, a cross-departmental effort towards building a CubeSat for as little as $5,000 (payload excluded) in parts cost is possible.

This cross-departmental effort can span across both undergraduate and graduate programs and include a large number of college departments. The professors in these departments can create suitable projects that involve the small spacecraft in their curriculum. This paper evaluates both qualitative and quantitative benefits that this type of integrated approach has in fostering interest in STEM degrees, increasing students’ enthusiasm for class materials.

I. Introduction

There is a need, in the context of collegiate education, to provide students with hand-on experiences that enrich their learning and aid in material understanding and retention. These experiences can be simplistic and limited in scope to an individual subject or lesson or they can be broad-based and provide the students with learning opportunities outside of the scope of the particular subject at hand. A course in electrical engineering might, for example, teach students time management skills, in addition to circuit design and analysis skills and a computer science course could provide students with leadership opportunities.

In both of these cases, however, students are still well within their comfort zone. They are working with their classmates (many, for those in the later years of a degree program, of whom they have taken multiple classes with). These are also, generally, students who speak the same field-of-study language. Hotaling, et al. [1] suggest that this may not be the best approach, as students gain significant benefits from working in an interdisciplinary environment. They gain skills that are valued by employers and which caused (in their work) students to be more employable (as indicated by the percentage receiving a position upon graduation).

This paper presents the educational benefits of the OpenOrbiter small spacecraft development program as an example of a multi-disciplinary educational program based on project based learning (PBL) and experiential education (EE) principles. It presents an overview of the program and describes the educational benefits that participants receive. The program’s efficacy in delivering these benefits is then assessed and conclusions are presented.

II. Background

Three areas of prior work are now reviewed. First, work on PBL and EE is reviewed. Next, an overview of

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A. Project-Based Learning and Experiential Education

Project-based learning (also commonly known as problem-based learning, experiential learning or experiential education) has been shown to be effective as a component of collegiate (and other levels of) education. The approach provides students with the opportunity to gain practical experience in a workplace-realistic setting, apply lessons learned through conventional lecture-style education (thus gaining an appreciation for the importance of the material, internalizing it and increasing its retention) and to learn new skills which may fall outside of the boundaries of individual courses. These skills (e.g., project management, teamwork, cross-disciplinary collaboration techniques) may be as important or more important to the students’ long-term success than particular technical skills.

The implementation of PBL and EE in an educational environment can take several forms ranging from a completely PBL/EE-driven course (where objectives are attained via directed student tasks and inquiry) to the incorporation of limited-duration PBL/EE exercises within the context of a more formally structured course. The former is typical of project-style courses, such as senior capstone projects, while the latter may serve to augment courses with specific skill-development focuses. Larsen, Nielsen and Zhou [2], for example, integrated small satellite development into a PBL component into a variety of undergraduate and graduate engineering courses. They state that the PBL content of these courses was approximately 50%, with the remainder consisting of traditional-style course activities. Hoic-Bozic, Mormar and Boticki [3] show that a blended learning approach, consisting of PBL, collaborative and independent learning activities increased academic achievement levels and decreased the student dropout rate.

Okudan and Rzasa [4] proffer that PBL incorporation can be utilized to drive entrepreneurship in student participants. They review the results of an entrepreneurial leadership engineering course during which students had to develop and produce a product to sell. These results were largely positive and indicated that the course facilitated development in key areas including “leadership, motivation, innovation, communication skills, teamwork and writing business plans”. It also was demonstrated to encourage entrepreneurial behavior in students. Doppelt [5] shows that PBL has benefits that go far beyond the classroom. This work showed that PBL with a “scientific-technological” focus increased student motivation and even their self-image. This work, in the context of middle and high school education was also shown to increase student performance on critical exams and even their college acceptance rates.

B. Small Spacecraft Development

The CubeSat form factor was developed by Robert Twiggs and Jordi Puig Suari in the late 1990’s as a way to allow direct student participation in the development of a spacecraft [6]. By reducing the size of the spacecraft, project scope as well as development and launch costs were reduced. This allowed greater risk taking and more opportunity for student involvement and leadership. Numerous small spacecraft have been produced; Swartwout [7] has identified nearly one hundred universities who have successfully flown a mission. Many of these universities have conducted more than one mission and many more have missions under development.

The costs of small spacecraft development, however, are still outside the capabilities of many institutions. Complete development, from scratch, of a CubeSat may cost $250,000 or more [8]. Kits that provide all of the functionality required (except payload components) can cost as little as $40,000 [8]; however, this cost fails to consider payload development, integration, testing and other expenses. The use of a kit also may reduce student participation and limit innovation due to a need to conform to the integration requirements of the vendor producing the kit. Modification of a kit component, generally the proprietary property of the vendor, may require its redevelopment from scratch, making a minor change a significant expense. The replacement cost of these components may also have the effect of reducing acceptable risk levels and (desirable) risk taking by students. Prior work [10] identified a variety of risk factors salient to this type of student project and presented a model for assessing the impact of these risks on project success. At a minimum, utilizing student workers (who may lack sufficient experience to assess the level of risk that they are taking or fail to realize that an action may damage a component) necessitates increased reserve funds for component replacement. This, again, raises project costs.

C. The OpenOrbiter Program

The Open Prototype for Educational Nanosats (OPEN) aims to make all of the details required to develop a CubeSat-class spacecraft from scratch available to prospective developers worldwide. These will include complete schematics, fabrication instructions, assembly instructions, spacecraft and ground station control software, a testing plan and suggested curriculum incorporation guidelines. The spacecraft will be able to be constructed for a parts

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cost (excluding developer-selected payload components) of under USD $5,000 [11]. The spacecraft [12] incorporates a vertical-insertion approach (designed to prevent components from unseating or being inadvertently mis-seated) and allows a payload bay at the center of mass of the spacecraft (maximizing the focal length of optical assemblies and allowing the placement of a propellant tank at the center of mass, among other prospective uses). An extrapolation of this design to a 3-U configuration has also been performed.

The OpenOrbiter spacecraft will be the first spacecraft produced based on the OPEN designs. Its construction will inform the fabrication instructions and test plan. Validation activities will be used to refine the design to remove any issues detected. Its eventual orbital operations will serve to begin the space qualification process for the design and reduce risk for its future users.

In addition to the aforementioned technical goals, several educational goals have been identified for the program [13, 14]. First, it seeks to provide students with an opportunity to gain new or apply and gain understanding of discipline-specific technical skills (either in their discipline of study or another discipline of interest). Second, the program aims to provide students with a workplace-realistic experience in working with individuals from other disciplines. Third, the program aims to allow students to gain and refine project management and associated skills via providing a large-scale project to apply them to. Finally, it seeks to document the educational benefits produced to allow others to assess whether a similar program (or aspects of the program) would be well suited to their institution’s program’s or course’s learning needs.

III. Program Overview

The OpenOrbiter program is working to create the OPEN deliverables and build the OpenOrbiter spacecraft. It is comprised of seventeen groups spanning from technical implementation (e.g., electrical design groups, software design groups) to publicity and public policy [14]. Each group has a student team lead and a faculty mentor (a few groups that span multiple skillsets have multiple faculty mentors). Many of these groups fall under area managers who manage several team leads and coordinate the activities of multiple groups in their focus area. Each group, generally, has a weekly meeting (in addition to team-lead and participant scheduled working times). A bi-weekly leads meeting is held to coordinate between all of the teams. Regular meetings, open to all participants, are also held to foster excitement and provide an opportunity for members of teams from different disciplines to meet and interact informally. A variety of social events to build team unity have also been held.

IV. Educational Benefits

The initial design of the OpenOrbiter program aimed to augment and allow practical use of students’ team-of-participation-specific technical skills. It also sought to allow students to gain experience in an interdisciplinary work setting that would be similar to the cross-disciplinary environments that many would be seeking employment in. An improvement in student-participant presentation-giving comfort and presentation skills was also identified as an objective. Feedback from participants indicated that in addition to meeting these goals (though the attainment of the presentation skills / comfort goal was not as pronounced as desired), numerous additional educational benefits were enjoyed [13]. These included leadership skill development, providing perspective with regards to the importance of certain educational areas, improving writing skills and generally increasing student confidence.

V. Assessment of Educational Benefits

A participant survey was administered to assess whether desired educational goals were met. This survey, which included students from multiple departments (e.g., electrical engineering, computer science, space studies, entrepreneurship) including both STEM and non-STEM majors, asked students whether they received benefit, in each of five categories, and whether they attributed this benefit to program participation. The responses were on a 9-point scale with 9 being the most favorable (highest skill / excitement / comfort / attribution level), 5 being neutral and 1 being the most unfavorable (lowest skill / excitement / comfort / attribution level). The results of the survey, which was conducted anonymously, are presented in Figures 1(a, b) and 2(a, b).

These results show improvement, on average, in all categories. It also shows that the improvement was practically significant (between 1 and 2.5 points on a 9-point scale – representing a 11% to 28% improvement) for those that showed improvement. This improvement was also attributed to program participation in all cases, with this attribution being strongest for technical skills and space interest.

The student responses to this survey indicated that the program had met its goals within a short timeframe. Other results [13] indicated a strong correlation between serving in a leadership role and the level of benefit received and between the duration of participation and the level of benefit received. Also, anecdotal evidence suggests that a variety of other benefits, related to the central learning themes of the program were enjoyed by
participants. The assessment of these additional benefits has been identified as a subject for (currently underway) future work.

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**Figure 1.** (a) Comparison of reported pre-participation skill / comfort / excitement level and post-participation level, left [13]. This figure shows that students, on average, improved in all categories. (b) Average improvement in skill / comfort / excitement level, right [13]. This figure shows the average level of improvement was greatest in spacecraft design, followed by technical skills and space excitement.

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**Figure 2.** (a) Average improvement in skill / comfort / excitement for students showing improvement in each category [13]. Shows that improvement was greater than 1-point in all cases and 2-points or greater in two cases. (b) Attribution of benefit to program participation [13]. Shows that students attributed technical skills and space interest improvement to program participation to a greater extent than increases in participation skills (all were greater than 5 and thus positive attributions).

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**VI. Conclusions and Future Work**

This paper has demonstrated the value of utilizing a small spacecraft program to provide students with discipline-specific and cross-disciplinary skills. It has provided examples of how the OpenOrbiter program has included students from disciplines not traditionally associated with small spacecraft development and the benefits that the program has had for both STEM and non-STEM students. The program has been presented as a model for...
prospective emulation at other universities and, through the use of the OPEN framework being developed, is poised to enable cross-disciplinary programs at these other institutions. For students with an interest in pursuing careers in the aerospace industry, these programs provide specific skills and experience that can be directly applied on-the-job; for those planning to seek other career paths, the scale of the project and necessary attention to detail required by the space environment provide excellent general training.

Future work will include the completion of the Open Prototype for Educational Nanosats framework and the testing of the OpenOrbiter spacecraft (which will demonstrate and begin the space qualification of the OPEN design) on orbit. Additional activities to assess the educational benefit provided by the program are also planned.

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