OpenOrbiter: Analysis of a Student-Run Space Program

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Students at the University of North Dakota, as part of faculty-mentored teams in a student-lead program, are working to broaden participation in humanity's exploration of space. The OpenOrbiter Small Spacecraft Development Initiative (OSSDI) is demonstrating two complementary paradigm-changers. First, the initiative facilitates student involvement in all aspects of a space program, without the preconceptions present in established space activities. Second, it is demonstrating a low-cost framework for small spacecraft development. These combined activities are poised to demonstrate a new way forward for space exploration: combined, they allow risk-taking exuberance and a cost of entry that makes risk-taking exuberance acceptable, even desirable.

The Open Prototype for Educational NanoSats (OPEN) will be comprised of a complete set of design documents, operating software, testing plans and fabrication and integration instructions that allow a 1U CubeSat-class spacecraft to be created with a parts budget of approximately USD $5,000. This price point allows the project to be paid for from teaching and other accessible and risk-tolerant internal funding sources, allowing student control.

This paper presents the OpenOrbiter Mission and the paradigm changes it is enabling. It compares and considers the mission from a national/international policy perspective and as a pedagogical tool.

I. INTRODUCTION

Students and faculty at the University of North Dakota are working to broaden participation in humanity's exploration of space. The OpenOrbiter Small Spacecraft Development Initiative (OSSDI) is demonstrating two complementary paradigm-changers. First, the initiative facilitates student involvement in all aspects of a space program, without the preconceptions present in established space activities. Second, it is demonstrating a low-cost framework for small spacecraft development. These combined activities are poised to demonstrate a new way forward for space exploration: combined, they allow risk-taking exuberance and a cost of entry that makes risk-taking exuberance acceptable, even desirable.

The OSSDI has involved hundreds of students and 15 faculty members from more than five colleges and numerous departments of the university. These individuals comprise 16 groups focusing on topics including typical STEM-related disciplines (e.g., electrical design, mechanical design, software design and development), mission operations, space policy, outreach and publicity. In addition to providing students with the opportunity to be involved in a fully integrated space program, it also allows them to learn about the disciplines that they will likely be required to work with in industry (whether aerospace or otherwise) and how practitioners in these industries work. Because of the educational environment, low cost and risk levels and, in many cases, a lack of knowledge about how things are 'supposed to work', innovative approaches have been tried and their level of success documented as part of the program.

To allow the level of flexibility desired, a low-cost approach to small spacecraft design had to be arrived at. The Open Prototype for Educational NanoSats (OPEN) design [1] that is being developed and implemented by the students and faculty involved, thus, represents the other aspect of the paradigm change. OPEN will be a complete set of design documents, operating software, testing plans and fabrication and integration instructions that allow a 1U CubeSat-class spacecraft to be created with a parts budget of approximately USD $5,000 [2]. This price point allows the project to be paid for from teaching or other internal-to-the-university funding sources that don't carry with them the same risk of failure to the responsible faculty member (allowing control to be turned more freely over to students).

This paper presents the OpenOrbiter Mission and the paradigm changes it is enabling. It compares and analyzes the mission from a national/international policy perspective and as a pedagogical tool.

II. BACKGROUND

OPEN and OpenOrbiter draw on a significant legacy of prior work related to small spacecraft and CubeSat
design, the incorporation of small spacecraft into courses and the project-based/experiential educational pedagogical techniques. A brief overview of this prior work is now presented.

II.1 CubeSats

The concept of the CubeSat was invented by Robert Twiggs and Jordi Puig-Suari as a way to facilitate student learning about spacecraft development [3, 4]. They aimed to make the form factor conducive to a project that wouldn’t be cost-prohibitive and could be completed within the span of a typical student’s academic career (providing the satisfaction and learning experience of potentially being able to be involved in a project from initiation to integration and launch).

Growth has occurred: Swartwout [5] proffers that the “flood” of university-class satellites has finally arrived, with nearly 100 universities participating in small spacecraft missions (some collaborating with others to build a satellite and others having completed multiple ones). Many of these are CubeSat-class spacecraft.

Problematically, even a one-unit (1U) CubeSat (with dimensions of 10 cm x 10 cm x 11 cm and a mass no greater than 1.33 kg) may cost tens or even hundreds of thousands of dollars to build. Kit-based solutions (excluding labor costs) may be available in the $50,000 range, while it has been estimated that building one from scratch may cost as much as $250,000 (inclusive of significant labor costs) [6]. Lower-cost solutions have been proposed (such as Interorbital’s CubeSat starter kit); however, they may not be suitable for various missions. In recognition of this problem, smaller and even-lower-cost form factors have been developed (e.g., [3, 7-9]).

While some are pursuing smaller spacecraft, others are producing form factors that are multiples of the 1-U standard: 2-U, 3-U, 6-U and such [10]. These larger sized craft are targeted at real science, technology demonstration or other missions (e.g., [11-15]). Some are constructed by government agencies or business (e.g., [16, 17]); others are produced by (or in conjunction with) academic entities, allowing costs to be borne by a prospective user and students to get hands-on experience on a real project.

The availability of launch opportunities, as a secondary payload, at low or no cost to developers is further enabling CubeSat adoption. In the United States these are provided by NASA’s Educational Launch of NanoSatellites program (ELaNa) [18]. The European Space Agency’s (ESA) ‘Fly Your Satellite’ program offers similar access for those in European and affiliated states [19]. Several commercial vendors are also working to serve the small spacecraft community with dedicated launch vehicles [6, 20].

II.2 Small Spacecraft Development Process

Small spacecraft development, in many ways, mirrors the development of larger spacecraft. The project scope and size, of course, is diminished along with budgetary and staffing requirements. Wertz, et al. [21] and Fortescue, et al. [22] have developed frameworks for this design process. Many others (e.g., [23, 24]) have created purpose-specific frameworks.

While conventional spacecraft development is normally an exercise in caution and avoiding risk, Swartwout [25, 26] proffers that university-run programs have an imperative to assume risk (in their more risk-accepting environment) to advance the state of the art. This positive “disruptive” effect is born from students thinking outside the conventional box (perhaps because they haven’t learned why the box exists or its boundaries).

II.3 Learning by Doing: Experiential & Project-Based Learning

The concept of learning by doing is certainly not new; apprenticeship has been utilized, historically, as a training mechanism [27, 28]. Project-based learning (PBL) and experiential education (EE) put this concept into practice within the formal education system. PBL and EE have been shown to be effective at all levels of education: primary to university level [29-35]. Its utility in a multitude of disciplines has been shown. These include electrical [36, 37], mechanical [38-40], computer [41] and aerospace [42, 43] engineering, computer science [44, 45], engineering entrepreneurship [46], project management [47] and others. Doppelt [48] has shown the benefits of this approach on student motivation and self-image. Ayob, et al. [49] demonstrated PBL and EE’s positive effect on student creativity. Hotaling, et al. [50] and Fasse, et al. [51] have shown the positive impact of the use of PBL and EE on student placement following graduation. Gilmore [52] goes as far as to contend that STEM education will determine the future viability of nations and PBL and EE are critical to the United States’ ability to compete globally. The utility of PBL and EE in the context of small spacecraft development has also been demonstrated [29, 53, 54].

II.4 OpenOrbiter Program

The OpenOrbiter program at the University of North Dakota is a student-conceptualized, student-run small spacecraft development effort. It began with a basic notion of building a small spacecraft. The difficulty in raising the needed sum of money to purchase (particularly all at one time) and integrate a spacecraft based on space qualified off-the-shelf components drove brainstorming and the notion of not only fixing the problem at hand for the individual program, but doing so more generally was born.
The OpenOrbiter initiative seeks to develop and demonstrate the OPEN designs [1], beginning the process of their space qualification and driving the confidence required for their adoption elsewhere.

The large number of student participants and their varied areas of interest has also facilitated the ability to assess the program’s educational benefits [29, 55] (including those provided to students of particular disciplines [56]) and the utility of various collaboration and management tools [57]. The utility of the design for various scientific mission types has also been considered [58].

The program has provided numerous opportunities for student publications (including a journal author with an undergraduate first author [59]) and conference presentations. Students have gained confidence in their technical abilities as well as demonstrating their capabilities in emotive and exciting-to-prospective-employer ways. They have also gained ancillary benefits such as learning about workplace expectations and gaining experience working with those from other disciplines.

III. OBJECTIVES

The OSSDI program’s objectives can be divided into three groups. First, it has technical objectives: the creation of a CubeSat-class spacecraft and the OPEN framework. Second, it has student-oriented objectives: educational and ancillary benefits. Third, it aims to develop institutional capabilities and advance the practice of small spacecraft development, a risk-involved process that is poised to deliver a risk-level-commensurate set of rewards. These objectives are now discussed.

III.I Low-Cost Framework for Small Spacecraft Development

The development of a low-cost framework for small spacecraft creation is the key technical goal of the OSSDI and OPEN programs. The benefits of this are multi-faceted.

First, the designs are incorporating low-cost, highly-available components. These have been previously shown [2] to allow the fabrication of a small spacecraft (excluding payload components) with a parts budget of approximately USD$5,000. This places the spacecraft at a financial cost level that is affordable to the teaching supply or other institutional funding budgets of many institutions. In addition to design documents, OPEN will also include a complete set of operating software code, fabrication instructions and a robust testing plan. The creation of a set of curriculum-integration recommendations is also planned.

Second, OPEN seeks to make the process more error-resistant and modular. The OPEN design [1] includes four interconnected board locations, each with access to the spacecraft exterior, and an internal payload cavity. While some integration between units is still required (e.g., solar panels will likely be placed on five of the six sides in most designs), the level of integration is reduced, aiding the ability to have subsystems developed by different groups (or by groups across multiple years of instruction).

Third, the aforementioned modularity and the developed designs should aid instructors or investigators who wish to focus on a single area of spacecraft design. For example, an instructor might have most of a spacecraft commercially fabricated and have students redesign a subsystem (for instructional, scientific or engineering purposes) and integrate the commercially produced and student-constructed designs. An investigator, could similarly use other OPEN subsystems to allow them to test their newly developed subsystem or scientific experiment. Because the plans are freely available, it is not necessary to develop from scratch as might be required if working in conjunction with a commercial parts vendor (who would likely be hesitant to provide schematics for their boards).

III.II Student Involvement

The OSSDI also has distinct student participant-related goals. These include allowing student participants to develop and demonstrate specific technical skills, time and project management skills, presentation skills and comfort giving presentations, leadership skills and experience and an understanding of how to work with those in other disciplines.

The technical skill category is perhaps the most straightforward. Many students participate/participated in the area of their academic major (or a closely related area); some opted to gain experience and knowledge in an entirely different area that interested them. In addition, all participants learned about the spacecraft design and development process and unique spacecraft development considerations.

Time and project management skills also an area of identified focus. The large scale and level of involvement in the project facilitates the application and appreciate of the importance of these techniques in a way not possible in many smaller projects (where, simply by virtue of the closeness of group members, good results may occur in spite of poor management). Time management learning, while certainly possible in the context of smaller projects, is aided through (1) its use and (2) the importance of delivering what is promised on time when others are waiting for it.

To aid project management, a variety of tools have been introduced. Software development groups have learned to use source code management tools and techniques [57]. Other groups have benefited from the group’s web-based project management system and from other online points of presence.
Presentation skills and comfort were initially identified as another area of focus. Numerous presentations have been made including a significant number with undergraduate student first authors (see [60-70]). Opportunities for presentation skill learning, use and improvement have also occurred in regularly scheduled group meetings where students must present the results of their weekly efforts to other members of their group.

Leadership skill development was not initially identified as a core focus (though it was explicitly acknowledged as a benefit) and was not assessed during initial program assessments. However, due to student feedback regarding it being a reason for and a valuable benefit gained from participation [55], it has been added as a focus area and will be assessed in the future.

Working with those in other disciplines is another area of benefit. Students learn about the informational, workplace and other needs of practitioners in other disciplines. They also learn the terminology used in these disciplines. As most students, upon entering the workforce, will be required to interact with those from different disciplines (e.g., managers, subordinates, co-workers) this experience prepares them and gives them an advantage (both during the hiring and initial work periods) as compared to others without this experience.

Preliminary work on the assessment of student expectations and desires from small spacecraft program participation indicates that at least 26 different prospective sources of perceived benefit exist. Current work focuses on analyzing these sources and which are more highly desired and valued.

III. III Acceptable Risk-Taking

Risk is an area of intense focus for the OSSDI. This focus is in three areas. First, OSSDI aims to reduce risk by reducing costs. Second, the identification of risk factors forms a critical component of the development of fabrication instructions, testing plans and even training as all of the foregoing can serve to mitigate risk factors. Third, the project aims to provide students with experience in risk identification and management.

Project risk, for small spacecraft development projects in an academic environment, flows from the risk of damage to an investigator’s reputation if a project doesn’t deliver what has been proposed. This failure could be due to problems with design, implementation or integration. It could also be caused by damage caused during these phases or testing. While the potential for a launch failure also exists, this is generally seen as being outside the control of the investigator (and thus does not carry the same risk).

This risk is borne (as discussed in [71]) from both conventional sources of risk (those that would be

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**Figure 1. Diagram of OpenOrbiter Configuration [1].**
IV. EVALUATION

Three areas of evaluation are now considered. These include the spacecraft platform, student participation and the benefits derived from student participation.

IV.I Spacecraft Platform

The OpenOrbiter / OPEN designs are shown in Figures 1 and 2. Work to-date has validated the structural compatibility of design elements. This has been performed both via computer-aided design (CAD) software as well as with a physical 3d-printed model.

Ongoing work currently relates to subsystem design, validation and integration. Additionally, several prospective augmentations of the previously presented OPEN design are under consideration, based upon changes introduced in the recently (August, 2013) released provisional CubeSat Design Specification, revision 13 [72].

IV.II Student Participation

A wide variety of students have participated in the OSSDI, spanning numerous disciplines and educational levels. This section provides a brief overview of why they are participating and areas of participation.

Figure 3 depicts very preliminary results from an ongoing survey which is assessing reasons for student participation. Students were asked to select their top three reasons for participation from a list of 26 (or any additional areas not explicitly listed). Among those selected by students were:

- improved technical skills
- leadership experience
- an item for their resume
- large group experience
- knowledge about project management
- knowledge about spacecraft design
- project management experience
- real world project experience
- inclusion as an author on a technical paper
- experience with a structured design project
- knowledge about a technical topic
- improved project management skills
- improved change of being hired
- improved time management skills
- experience with other disciplines
- to gain understanding of a related discipline

The importance of improving technical skills (the top choice for first most important), real world project experience (the top choice for second most important) and an improved change of being hired (the top choice for third most important) are clear. The choices item for resume, experience with a large group project and knowledge about spacecraft design also have high interest levels (spread across multiple choices).

In Figures 4 and 5, some of the ways students gain this experience are shown. Figure 4 shows GitHub, used by OSSDI participants for code version tracking, collaboration and progress monitoring. Figure 5 depicts the RedMine project management system which is used to manage and monitor overall project progress.

Figure 2. CAD Model of OpenOrbiter Spacecraft [64].
Figure 3. Preliminary Responses to Survey on What Benefits Students Hoped to Attain Through Participation.

Figure 4. Progress Monitoring and Issue Tracking in GitHub [57].

IV. III Student Benefits

The benefits attained by students through their participation are now considered. A survey was conducted which asked students to indicate their pre-participation and post-participation status with regards to a number of different areas of focus. This survey also asked students about whether they attributed whatever improvement they may have indicated to program participation. The specifics of this survey, the questions asked and how they were analyzed can be found in [55]. Figures 6 to 9 present data from this survey.

Figure 5. Gantt Chart in RedMine Project Management Software [57].

Participants were asked to indicate their status with regards to the particular technical skills that their team utilized, with regards to spacecraft design in general, with regards to their level of excitement about space and with regards to their level of skill and comfort giving a presentation. These results are depicted in Figure 6. Notably, participants improved in all five categories. These responses were indicated on a nine-point scale ranging from one being the most unfavorable response (e.g., novice / not excited / not comfortable) to five being neutral to nine being the most favorable (e.g., expert / very excited / very comfortable).
The average level of improvement enjoyed by participants in each of the four categories assessed is depicted in Figure 7. Figure 8 presents the attribution of benefit attainment to the program (again using a nine-point scale ranging from one indicating no attribution to five being neutral to nine indicating very high attribution). This shows that attribution exists for technical skills and space interest (between 5-neutral and 7-agree), while the level of attribution for presentation skills is barely above neutral.

Finally, the benefits of being a team lead versus a non-lead participant were assessed. This is depicted in Figure 9. More team leads were shown to enjoy improvement in three of the five categories assessed.

In addition to the foregoing, analysis has been performed with regards to the performance of computer science students and undergraduates, which is included in [73] and [74], respectively. Significant additional analysis can also be located in [55], which includes consideration of the participants grade-level, GPA and other factors, among other topics.

V. CONCLUSIONS AND FUTURE WORK

This paper has presented the goals and limited technical details of the OpenOrbiter Small Spacecraft Development Initiative. It has discussed the objectives of this program and the results of analysis of its
efficacy, from an educational perspective. Initial results of an ongoing project to analyze the reasons that students decide to participate in small spacecraft development have also been discussed. A limited evaluation of the spacecraft platform has also been considered. From this, it is clear that OpenOrbiter is providing value across a variety of categories and to a number of divergent groups (participants, mentors, other institutions, etc.).

Future work will include continued development of the OpenOrbiter spacecraft and its template, the Open Prototype for Educational NanoSats. Continued data collection and analysis for the assessment of reasons for participation is also ongoing as is a longer-term study assessing the benefits of program participation.

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