ELEMENTARY SCHOOL EDUCATION AND OUTREACH THROUGH THE EX-ALTA 1 CUBESAT MISSION

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The University of Alberta (UAlberta) is creating new teaching materials that link active interdisciplinary research to student-accessible discovery learning sessions. In this paper, we present an outreach program run by members of AlbertaSat; a University of Alberta student group focused on the development of cube satellites. Cube satellites are nano-satellites developed to standards defined by a program initially developed by Consulting Professor Robert Twiggs of Stanford's Space Systems Development Laboratory [1]. This outreach program from AlbertaSat adds to teaching materials and programs already available at the University of Alberta which focus on space science and engineering. For example, the Canada/Norway student rocket program [2] uses a week-long, hands-on field course where undergraduate students instrument, launch, and analyze data from a sub-orbital sounding rocket to train them in space science and engineering as well as bridging them into graduate studies or the aerospace industry. In addition, 21 students from multiple departments and programs have worked on senior undergraduate design projects that involved components for AlbertaSat. While these programs focus on undergraduate and graduate study, the three in-school presentations (referred to as sessions) discussed in this paper provide instruction to elementary and secondary students (K-9) regarding fundamental physics concepts, experimental design, as well as project-based and hands-on laboratory skills.

Space is an interdisciplinary research area which spans all areas of science, technology, engineering, and mathematics (STEM) and fascinates people young and old. Space therefore presents an opportunity to attract students to careers in the STEM disciplines while also introducing students in the community to cube satellite development. All three sessions are based on aspects of Experimental Albertan Satellite #1 (Ex-Alta 1) and use this satellite as an anchor and concrete example of work being done in the space science industry. This UAlberta-built cube satellite was designed and built as part of the international QB50 mission (www.qb50.eu) and was launched in 2017 from the International Space Station (ISS). The sessions have been successfully delivered by undergraduate students from the University of Alberta to over 3000 students in schools throughout Edmonton. These sessions are now booked several months in advance.

SUMMARY

We present three successful classroom education and outreach in-school presentations (sessions) for grades K-9 focusing on science, technology, engineering and mathematics (STEM) that are based on the Experimental Albertan Satellite #1 (Ex-Alta 1) cube satellite.

THE EX-ALTA 1 CUBESAT MISSION

A team of UAlberta students, mentored by Faculty members from the Faculties of Engineering and Science, have recently designed, built, tested, and flown the Experimental Albertan #1 (Ex-Alta 1) spacecraft [3]. Ex-Alta 1 is a 3-unit (3U) cube satellite (or CubeSat) as shown in Fig. 1. Its structure adheres to the CubeSat Standard [4] and is designed to study space weather in Low Earth Orbit (LEO). Ex-Alta 1 will demonstrate and test the in-space functionality of new university-built spaceflight hardware, including a miniature magnetic field instrument [5], and it will contribute to the international QB50 CubeSat constellation mission [6] to study the lower thermosphere. Ex-Alta 1 was launched from Cape Canaveral, Florida to the International Space Station (ISS) on April 18th, 2017 and was deployed from the ISS into its own orbit on May 26th, 2017.

The educational outreach sessions created by AlbertaSat members focus on spacecraft design, solar energy and electronics, and the Northern Lights. These concepts are contextualized using short presentations on the Ex-Alta 1 mission which are discussed below.

SESSION 1: DRAW THE NORTHERN LIGHTS

The Northern Lights session is designed for grades K-2 (ages 5-8). In this session, presenters introduce the Earth's magnetic field and describe how it acts like a force field by protecting the Earth from the solar wind which continuously flows from the Sun, especially during extreme

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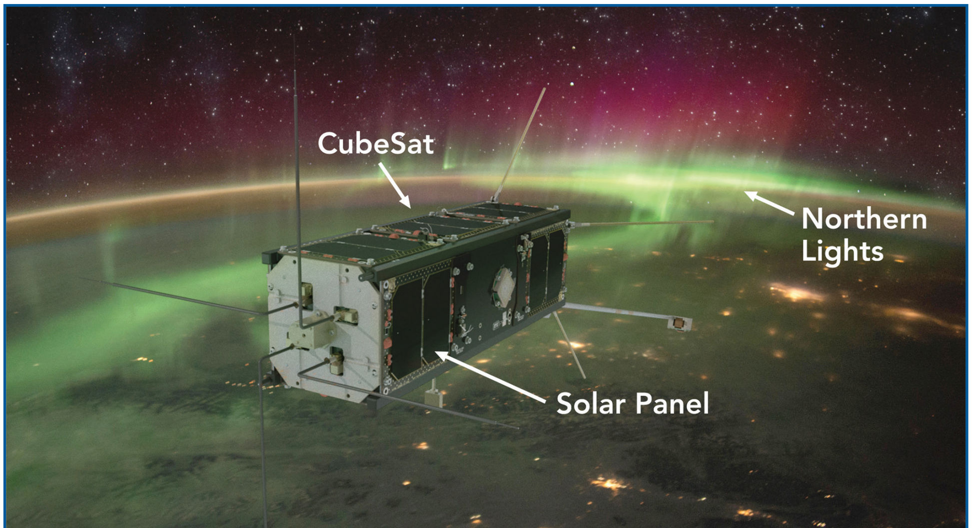

Fig. 1 Artist rendition of Ex-Alta 1 showing the CubeSat, solar panels, and the Northern Lights, the three topics that anchor our classroom activities.

events following strong solar activity such as coronal mass ejections (in which the sun releases a cloud of particles) and solar flares. Students learn how the interaction of the solar wind with the Earth's magnetic field causes disturbances in the field, resulting in particles striking the Earth's atmosphere near the poles, and producing the Northern Lights (Fig. 2, top). Students demonstrate their understanding by painting or drawing their own image of the Northern Lights (Fig. 2, bottom), including the different colours that occur at different altitudes. As part of our efforts to create an interdisciplinary and well-rounded program, students are encouraged to be thoughtful when creating their images and to include more than the minimum requirements. For example, some students choose to include the Sun and solar wind in their painting.

This session has been well-received by teachers, eliciting feedback such as "learning about solar flares hitting the [magnetic] field to make northern lights encouraged deep thinking from our young kindergarten children." [7]

ACTIVITY 2: DESIGN A CUBESAT

The CubeSat design session is aimed at students from grades 3-6 (ages 8-12), however it has been taught from kindergarten to grade 8. The presenters begin by outlining important factors to be considered when planning a space mission and explain typical CubeSat requirements. Students are then asked to sketch their own CubeSat (Fig. 3) using 10 cm × 10 cm × 10 cm cubic units. Their cube satellites may range in size from a single unit (1U) to up to twelve cubic units (12U). Students also consider function and placement of the components and the conditions in space during a discussion of the following components: on-board computer, radio, Global Positioning System (GPS), attitude determination and control system (ADCS), antenna, solar panels, and battery pack. Students must also plan an experiment to test a hypothesis with their spacecraft mission. This session is the most popular of our offerings due to its practical focus on experimental design.

ACTIVITY 3: SOLAR ENERGY AND CIRCUIT DESIGN

The Solar Energy and Circuit Design session is designed for students in grades 6-8 (ages 12-14). Students learn about energy and its forms, conversion, and storage through the use of two photovoltaic cells (solar panels) to power a light emitting diode (LED). The activity implements scaffolding, an instructional method to support learning where complex concepts are built up through simpler examples. Students work through two stages of circuit design with increasing complexity (Fig. 4, top) as they assemble small solder-less breadboard electronics kits (Fig. 4, bottom) that include the required components.

In stage 1, students connect two photovoltaic cells (Fig. 4, PV1 and PV2) in series with an LED (Fig. 4, D1) and a current limiting resistor (Fig. 4, R1, 1000Ω). The LED will shine when the photovoltaic cells are exposed to light, showing how solar energy hitting the cells is converted to electricity in the circuit and back into light emitted by the LED. Students cover the photovoltaic cells and observe that the LED will not shine without its energy source. In stage 2, a few additional components are added to demonstrate energy storage. A capacitor (Fig. 4, C1, 100 μF), and a current limiting resistor (Fig. 4, R2, 100 Ω) are added to store electrical energy, and a switch (S1) is added so that the LED can be turned off, allowing the capacitor to become fully charged. Students store energy by exposing the photovoltaic cells to light with the switch open. After a few seconds, the students cover the photovoltaic cells and close the switch, powering the LED with the energy stored in the capacitor. At the end of the lesson, the students have built a useful circuit with inexpensive components by following a simple progression of steps.

PEDAGOGY & IMPLEMENTATION

All three sessions are designed using principles of inclusive education [8] and are provided free of charge. These sessions use the excitement of space exploration and specifically the Ex-Alta 1 satellite as illustrative examples to motivate students,

Fig. 2 (Top) Reference images and diagrams on the board at a Northern Lights session. (Bottom) Kindergarten students drawing the Northern Lights. The students have selected the order of the colours after discussing how different emissions cause different colours at different heights. Photo provided courtesy of the Roberta MacAdams School in the Edmonton Public Schools district.

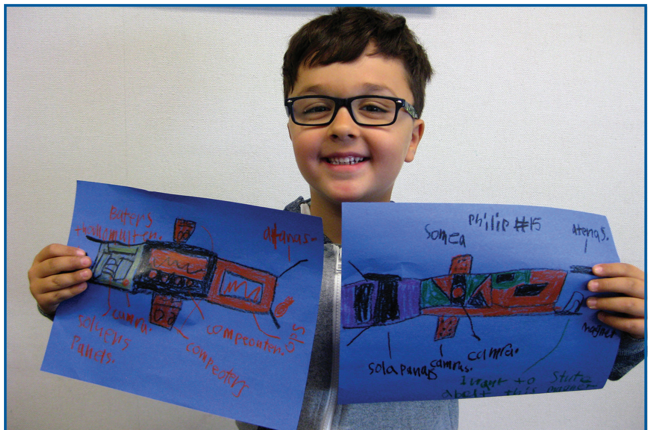

Fig. 3 A Grade 2 student's design of a cube satellite that would take images of the Earth from space. Photo was provided courtesy of Lynwood School in the Edmonton Public Schools district.

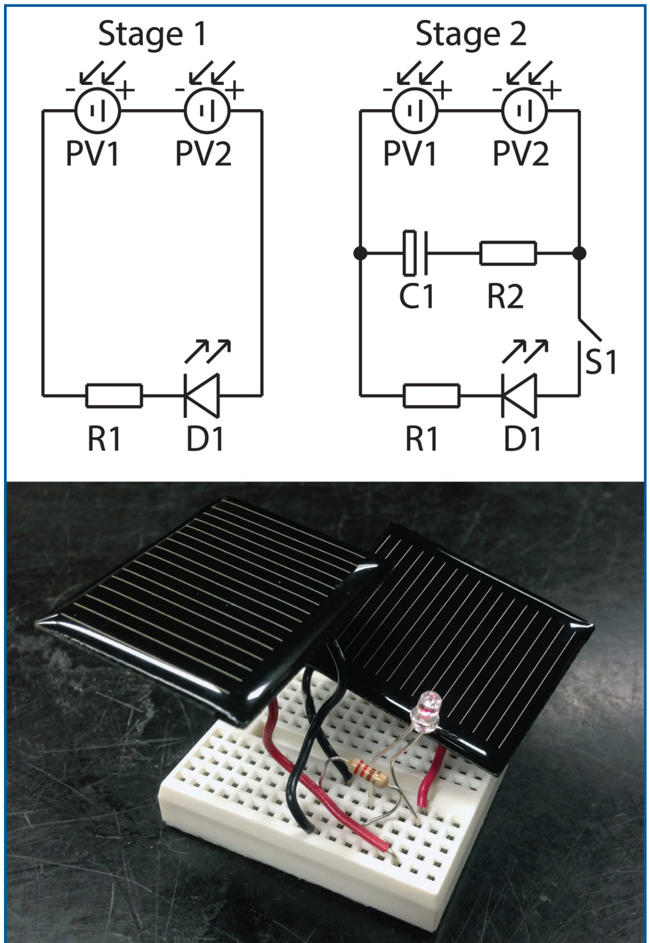

Fig. 4 (Top) Schematic of the simple Stage 1 circuit and the more complex Stage 2 circuit. (Bottom) Completed solar powered LED stage 1 circuit implemented in a small breadboard.

while avoiding the potentially high costs often associated with field trips and in-school presentations. All required supplies (electronics, paper, paint, and paintbrushes) are provided by the AlbertaSat project which is funded by a combination of grants, crowdsourcing, and internal University of Alberta funds. This minimizes the barrier to entry, allowing students from schools in low-income neighbourhoods to be reached. Furthermore, the practises of inclusive education [8] are applied by using multiple methods to teach the material. Each session begins with a short lecture paired with a visual presentation, followed by a kinetic activity (drawing, painting, or assembling) to reinforce the information and fine-tune motor skills. Lecturing and then having students work through an activity helps students understand abstract ideas (such as solar energy or the Northern Lights) by providing them with concrete examples [9] that they can examine. For example, putting together a circuit shows students in a tangible manner how electricity flows from a solar cell to power an LED. These topics are often completely new to students so the sessions implement scaffolding [10] through step-by-step instruction, exemplars, and simple to complex instruction in which students complete one task and the a more complex version of the same task. As an example of scaffolding, in the session on designing CubeSats, students are walked through the requirements and provided an exemplar to help students understand the requirements of this task. The scaffolding in our sessions helps prevent cognitive overload [11] by ensuring students do not get overwhelmed by the new information and level of detail and complexity of each activity.

OUTCOMES

The sessions outlined above are interdisciplinary and give students the opportunity to engage with Alberta's science [12] and art [13] curriculums (Table 1). For example, the Northern Lights activity is aligned with the art curriculum and uses a space science motivation. Spacecraft design is used as an anchor application in the CubeSat design activity to align it with the elementary science curriculum. The session on solar energy encourages further development of students' problem solving skills, as students must work in groups to fix any errors in their circuit. The sessions help students build practical skills such as project planning and group cooperation as "through teamwork they learn that planning, communication, cooperation and flexibility are important to the overall result, even though parts of a task can be worked on individually" [12]. Furthermore, students demonstrate their ability to apply these analysis and design skills while making meaningful connections to their learning as they consider real-world implementation and feasibility in their CubeSat blueprints or circuit designs.

The sessions have been delivered by undergraduate students at the University of Alberta to over 3000 students in the Edmonton area since September 2014 through presentations at elementary schools, junior high schools, and summer camps. In addition, our program has reached over 2000 students and professionals through events such as ScienceFUNday [14], the 7th Annual CubeSat Symposium [15], Science Literacy Week, and the Greater Edmonton Teacher's Conference Association [16]. The program has been exceptionally well-received; teachers who provided feedback via a standardized questionnaire that focused on rating aspects of the program gave it an average overall score of six out of seven. The program received a four out of five regarding overall "effectiveness" and a 4.6 out of five for "would recommend this program".

FUTURE WORK

AlbertaSat's educational outreach program was developed and delivered in parallel with the design and construction of the Ex-Alta 1 spacecraft. Ex-Alta 1 is now operating on-orbit and students and professors have begun work on the development of concepts for the follow-on Ex-Alta 2 mission. We are currently expanding our education outreach program to include sessions

TABLE 1

MAPPING OF HOW THE THREE ACTIVITIES MEET OUTCOMES AND PURPOSES SET OUT BY THE ALBERTA ART [13] AND SCIENCE [12] CURRICULUMS.

NORTHERN LIGHTS (GRADES K-2, AGES 5-8)	CUBESAT DESIGN (GRADES 3-6, AGES 8-12)	SOLAR ENERGY (GRADE 6-8, AGES 12-14)
SCIENCE – GRADE 1, OUTCOME 5:	**SCIENCE – GRADE 3, OUTCOME 3, FOCUS:**	**SCIENCE – GRADE 5, OUTCOME 5-6:**
Identify and evaluate methods for creating colour and for applying colour to different materials. … identify colours in a variety of natural and manufactured objects.	Identify the purpose of the object to be constructed: What is it to be developed? What is it for?	Construct simple circuits, and apply and understanding of circuits to the construction and control of motorized devices.
ART – GRADE 1 AND 2, PURPOSE 5:	**SCIENCE – GRADE 5, OUTCOME 4:**	**SCIENCE – GRADE 5, OUTCOME 5-4:**
Students will create an original composition, object, or space based on a supplied motivation.	Demonstrate positive attitudes for the study of science and for the application of science in a responsible way.	Demonstrate that a continuous loop of conducting material is needed for an uninterrupted flow of current in a circuit
	Science – Grade 6, Outcome 1-3:	Science – Grade 6, Outcome 1-3:
	Construct, with guidance, an object that achieves a given purpose, using materials that are provided.	Construct, with guidance, an object that achieves a given purpose, using materials that are provided.

built around Ex-Alta 2 and creating sessions for high school classes. Due to demand for our sessions, we are developing teaching resources for teachers which will include our session plans, potential assessments, extension activities, and resources. These teaching resources aim to bring our program into schools located outside of the Edmonton area, or into schools whose schedules do not allow for a session to be hosted during class time. We also hope these resources will be of use to teachers who want to use parts of our sessions in lesson plans which address the relevant curricular elements in their classrooms (cf. Table 1). As part of the development of these resources, we recently presented at the Greater Edmonton Teachers' Convention Association (GETCA) [16] on March 2nd, 2017 and hope to attend in 2018. We also intend to present at professional development days for teachers in Edmonton. Teachers interested in utilizing the described teaching materials or having AlbertaSat present at a school should visit https://albertasat.ca/educational-outreach/ or contact the corresponding author.

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