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Inquiry-Based Learning in Remote Sensing: A Space Balloon Educational Experiment

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ABSTRACT *Teaching remote sensing in higher education has been traditionally restricted in lecture and computer-aided laboratory activities. This paper presents and evaluates an engaging inquiry-based educational experiment. The experiment was incorporated in an introductory remote sensing undergraduate course to bridge the gap between theory and application of relevant technology. During this semester-long experiment, titled 'ESF goes to space', students designed, built, launched and successfully acquired imagery from the upper stratospheric parts (approximately 27 000 m). Replication guidelines are presented and a post-evaluation discusses benefits and limitations for students, instructors and university.*

KEY WORDS: Inquiry-based learning, project-based learning, hands-on learning, amateur remote sensing, educational assessment

Introduction

The role of geography (remote sensing inclusive) is crucial for monitoring and analysis of environmental phenomena. Yet, higher education graduates frequently lack decision making and project application skills, characteristics necessary in their professional career (Edens, 2000). Teaching and learning need to strengthen student's ability to think about geography, supporting intellectual development and empowering students to become active users and analysts of spatial data (Lloyd, 2001). Limited efforts currently exist that assess and evaluate the geographical information science and technology (GIS&T) curricula; the body of knowledge has been developed by the University Consortium of GIS and is an isolated example that integrates the assessment of learning outcomes of curricula with professional needs and expectations required by employers (Prager & Plewe, 2009).

Experts argue that a teacher/professor should become a designer and facilitator of learning experiences and opportunities in order to engage students within the learning process (Smith *et al.*, 2005). Student engagement in the teaching–learning process can be achieved through a variety of activities and teaching strategies in order to allow students to develop their knowledge and understanding (Balderstone, 2000). The integration of technology with educational activities supports stepwise practice and knowledge

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absorption, bridging the gap between scientific and informal experience (Hennessy *et al.*, 2007). Computer-based equipment is typically used in GIS and remote sensing courses. Although the educational effectiveness of computer-based equipment is significant for memorization enhancement, the impact on student critical thinking is unclear (Renshaw & Taylor, 2000). It is evident there is room for improvement with additional educational methodologies that engage and educate students in a seamless manner. Equally important to knowledge acquisition is skill development, as identified by program outcomes set by the Accreditation Board for Engineering and Technology (ABET), for example, 'an ability to design and conduct experiments, as well as to analyze and interpret data' (ABET Outcome b) and 'an ability to identify, formulate, and solve engineering problems' (ABET Outcome e).

The objective of the paper is to introduce inquiry-based methods and more specifically a space balloon experiment as a worthy incorporation into remote sensing courses. Learning outcomes such as spatial thinking and understanding, interpersonal and organizational skills along with creativeness and imagination are targeted. The learning outcomes were integrated from multiple sources, including the ABET guidelines. Furthermore, project outcomes are assessed through student performance metrics and a student survey. To support efficient and successful replication, the experiment setup is presented in detail.

Project-Based Learning in GIS/Remote Sensing

It is a commonly accepted that when theory is combined with practice, the educational output becomes beneficial for the students' learning. Traditional teaching methods have been supplemented by other approaches, such as inquiry-based learning, which involve complex problems and scenarios with fieldwork and case studies (Marlino, 2001; Lee *et al.*, 2004; Smith *et al.*, 2006; Deignan, 2009). With inquiry-based learning, students hypothesize about results or theories and make predictions on what might happen in varied occasions. The skills obtained from such endeavors are applicable to many professional engineering fields, making students highly competitive in the working arena. During inquiry-based learning, students are in the center of learning, developing their own abilities and skills through an investigation-oriented process.

A typical implementation of inquiry-based learning is through semester-long course projects. This so-called project-based learning can be defined as a teaching technique that engages students in learning knowledge through an inquiry process while focusing on an inspiring hands-on experience (Regassa & Morrison-Shetlar, 2007) and has strong linkages to inquiry-based learning (Spronken-Smith, 2010). The practical goal of project-based learning is to acquire new skills and develop 'technical competency' while applying an example case to real-world problems. The collection of appropriate field data through a project–research activity also allows students to discover their own interests, encouraging self-confidence and self-motivation (Simmons *et al.*, 2008). Students engage further with a collaborative inquiry-based project approach, which enhances interaction with professional goals and aspirations, while acquiring valuable interpersonal skills and experience in writing reports and giving oral presentations (Corey & Motte, 2003).

Remote sensing and GIS have been fruitful ground for novel pedagogical applications design in conjunction with inquiry-based learning methods, for example, by including problem-based and field-based inquiries (Drennon, 2005; Sinton & Schultz, 2009). For further exploration of inquiry-based methods in geography, the reader is referred to

Spronken-Smith *et al.* (2008). In remote sensing education early efforts evaluated films discussing remote sensing technology (Carter, 1986), and through a survey found that a significant number of geography departments in the UK are using remote sensing in their curricula (Mather, 1989). Problem-based learning is a pedagogical approach with effective response to learning geography not only within a typical course delivery but also for an online audience (Johnson *et al.*, 2000; Prothero, 2000; King, 2008; Dong *et al.*, 2009). Fieldwork-oriented educational activities are of primary importance and facilitate hands-on participation in geography courses (Jennings & Huber, 2003; Paradis & Dexter, 2007). Dodson *et al.* (2000) developed the EarthKAM project, where middle school, high school and university students experienced a series of activities using earth images in classroom projects, such as building topography, understanding seismicity and seafloor spreading. Moreover, Sinton and Schultz (2009) indicated the importance of project-based learning, where students experience their own interpretation of data which often leads to deeper learning. Students move from passive to active learners, gaining confidence in their abilities to successfully collect, manage and analyze spatial data. These skills are very important today in a complex globalized world, helping students understand and translate spatial matters. An effort by the Association of American Geographers has resulted in a guide for teaching college geography (Solem & Foote, 2008). Recently, a problem-based learning exercise was proposed in an undergraduate GIS course with significant community involvement (Read, 2010). Additional successful examples in using active learning in GIS courses have been reported (Baker & Bednarz, 2003), and according to Read (2010) the number of activities may be higher than the current literature volume suggests.

Experiment Description and Related Work

An inquiry-based learning method was embedded in an introductory undergraduate course titled ‘Principles of remote sensing’. This course is offered within the Environmental Resources Engineering program at the State University of New York College of Environmental Science and Forestry in Syracuse, NY. The purpose of the project, called ‘ESF goes to space’, is to provide students an opportunity to design, construct and successfully launch and retrieve a remote sensing system into near space ($\sim$27 000 m) on a limited budget ($<$\$300). Students are able to utilize the engineering mechanics, advanced mathematics and physics gained over their five prior semesters, through an inquiry-based learning process that integrates coursework, assignments, presentations and fieldwork. The project was offered in conjunction with the typical course structure of lectures and laboratory exercises, as studies have found this hybrid project-based learning more efficient (see discussion in Read, 2010).

Amateur space-launching experiments have been conducted by individuals with varying goals from capturing interesting imagery (CHAB, 2006) to assessing atmospheric changes such as temperature and pressure (Meehan, 2002; HALO, 2007) to detecting cosmic radiation at near space (Verhage, 2006). Other efforts have focused on acquiring imagery with a significant budget reduction, such as the \$150 ICARUS project (ICARUS, 2009), which provided significant guidance for our work. Within academic environments, student clubs have been active such as the University of Tennessee Amateur Radio Club (UTARC, 2008) and the Cambridge University Spaceflight, a student society that develops low-cost technology for space imaging launching balloons and rockets (CUS, 2009).

Formal educational approaches are limited: a student project was introduced in the final year at the University of Waterloo, Department of Electrical and Computer Engineering, where a high-altitude imaging system, launched by a meteorological balloon, carried an embedded microprocessor that allowed wireless communication with ground control (IRIS, 2010). In addition, a High Altitude Reconnaissance Balloon for Outreach and Research (HARBOR) is a project at the Weber State University which advocates undergraduate research and engineering in space science (HARBOR, 2010). None of these approaches incorporated an assessment mechanism on student learning outcomes.

Educational Activities, System Design and Obtained Results

Educational Activities

The associated tasks in this experiment involved the design, construction, launch and retrieval of the sensing system and spanned the entirety of the semester, a period of 5 months. At the beginning of the semester, students were given the option to participate in the project. This was done to motivate further students opting in by getting a sense of commitment from students and the instructor. It also solved logistical and instructional issues by keeping the participant number at a manageable size. The 15 students who enrolled were divided into three different groups of their choice. The different educational components involved were shown in Figure 1.

During the first half of the semester all teams went through several different exercises and systematically reviewed all of the significant elements of the design. The same task was assigned to all the teams concurrently as this overlap led to informed discussions with contrasting opinions and educated debate. The groups reviewed different project aspects such as legal limitations, ascending and descending mechanisms, retrieval and

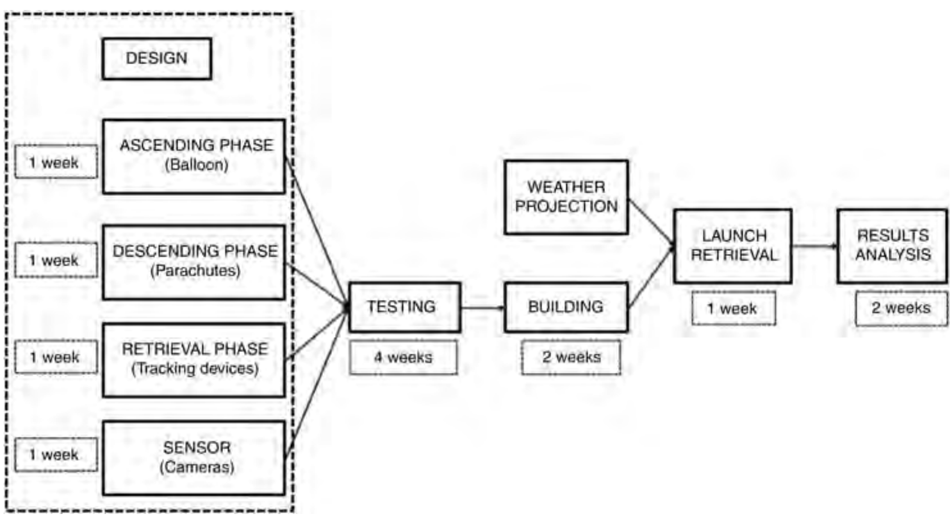

Figure 1. Educational components of 'ESF goes to space' project. (a) Design using Internet resources, educational materials and computer hardware/software. (b) Building/testing using specialized materials and various tests outside the classroom. (c) Launch/retrieval through a combination of classroom and field work. (d) Technical analysis of results.

communication hardware, along with sensor opportunities. It should be noted that in addition to safety and legal constraints, the students were presented with a maximum budget of $300.

The design of ascending, descending and retrieval phase as well as the sensor design was scheduled for the first 4 weeks. In the next 4 weeks, the parachute, camera, GPS and batteries were tested in the classroom and in the field to arrive at a complete understanding of their capabilities and limitations. After this exploration was completed, a final proposal for each specific item of the system design was submitted by each student group. The next 2 weeks before launching, the building of the system and the final testing took place. From the three proposed approaches—one from each team—a final option emerged that was implemented 1 week prior to the projected launch date. This involved the collaboration of each individual on every team and the guidance of the course instructor. During the final preparatory week, the atmospheric and weather conditions were monitored and projected for the launch date. After launch, students devoted 2 weeks to perform some basic analyses on the obtained imagery.

During this project, an assignment was provided to the students each week, in order to find all the necessary information and better understand each of the interconnected activities. Furthermore, a weekly presentation was given from each of the three groups explaining the most important findings of the assignments followed by a debate on each team's proposed approach. While early on students were hesitant to criticize other teams' work, constructive advice took place of hesitation as weeks progressed and the potential of catastrophic failure started to sink in. At the end of the experiment, students provided a written report on all project aspects including critical assessment and suggestions for improvement along with a poster and an oral presentation.

From the conceptual perspective, inquiry-based methods can be categorized as information or discovery oriented, depending on whether students are seeking existing answers or creating new knowledge (Wood & Levy, 2009). This experiment borrows elements from both categories since students were encouraged to provide creative new solutions, while also adapting the existing solutions. Furthermore, according to Spronken-Smith and Walker (2010), three cases of inquiry-based methods are identified, the structured, guided and open cases, depending on whether the instructor provides the question and the methods to approach the solution. Due to the rigid structure of the course, a guided approach was followed, where the instructor segmented the problem in several components (see Figure 1) that students independently tackled. This approach offered a proper balance to reach course outcomes in the allocated semester time.

System Setup and Replication Guidelines

This section discusses the engineering aspects of the system to act as the basis for replication by other instructors. The intent is to use this section as a guide, instructors are encouraged to adjust the experiment to fit course outcomes and student needs. For the ascending mechanism, a helium-filled meteorological balloon was selected as it offers safety, reliability and cost advantages over other methods (e.g. using hydrogen or rocket-type setup). Two balloons were purchased from Kaymont, models KCL 800 (used as a backup) and KCL 1000. The sounding balloons are designed to carry heavier payloads such as the 1.8 kg intended payload. Due to price, availability and safety, helium was the gas of choice. The balloon was filled with 4.1 m^3 of helium. The amount of helium should be calculated carefully as it dictates ascending speed and burst altitude, both important mission parameters as they relate to trajectory and stresses imposed on the equipment.

The maximum height of the flight (H_B) was calculated as 27 200 m as follows:

$$H_B = \beta_{air} \ln(\forall_L / \forall_B),$$

where constant $\beta_{air} = 7238.3$ m; volume at launch: $\forall_L = (\pi D_L^3)/6$, where D_L (diameter at launch) was 2 m and burst volume: $\forall_B = (\pi D_B^3)/6$, where D_B (burst diameter) was 7 m.

The ascent rate of the vehicle (v_a) was 4.62 m/s and is calculated from the following equations:

$$v_a = \sqrt{\frac{F_0}{0.5 C_d \rho_{air} A_L}},$$

where free lift $F_0 = 13.73$ N, balloon drag coefficient $C_d = 0.34$, air density $\rho_{air} = 1.205\ \mathrm{kg/m^3}$ and cross-sectional area at launch: $A_L = (\pi D_L^2)/4$.

Finally, the ascent time can be easily calculated as 5887 seconds (1 hour and 38 minutes) using the formula: $\Delta t_a = H_B / v_a$.

Students prepare a gondola for inclusion of all electronic components. The loaded weight was approximately 1.8 kg (4 pounds), which is the maximum payload allowed with limited regulatory constraints according the Federal Aviation Authority. The exterior of the gondola was a basic styrofoam cooler which was used not only for its structural strength, but for insulating purposes as at maximum altitude temperatures drop to −40°C. To protect further, the equipment from the frigid high-altitude temperature hand warmers, packing peanuts and fiberglass insulation were employed. Elements were added to the exterior such as reflectors and reflecting tape to make it easy to find. There was also a remotely controlled strobe light in case the search would have to continue after sunset.

In order to successfully retrieve the payload and its contents, students had to control the descending speed and activate a tracking mechanism. There is a wide variety of parachutes to choose from ranging in price, durability, deployment consistency and speed reduction capabilities. Multiple tests took place, tossing the gondola off a five-story building, in order to achieve the best combination of parachutes as well as their position into the system. After experimenting with multiple options, students designed a dual parachute system composed of two identically sized (1.52 m) parachutes in order to reduce the descending speed. The first parachute was installed between the balloon and the payload and was partially deployed at launch (Figure 2). This parachute was a pilot-type parachute that offered fast and consistent deployment; however, it does not provide a significant payload slowdown. The purpose of this parachute was to pull out a second and larger parachute; this second parachute was one typically associated with rocket launches and acted as the major slowdown component. Approximately 1.7 m of slack line was left between the first and second parachute to ensure that the primary parachute could only deploy after the balloon had burst. The secondary parachute was packed into a canvas bag so that the risers would not be tangled prior to deployment.

It was crucial to integrate a tracking mechanism in order to ensure a successful retrieval and further monitor the payload trajectory. Three aspects were considered: capturing, transmitting and visualizing the location. In general, there are two categories of tracking devices, one uses radio signals and the other GPS; the latter was chosen for its simplicity. The GPS locations were transmitted using a cell phone device, a Motorola i425. When tied

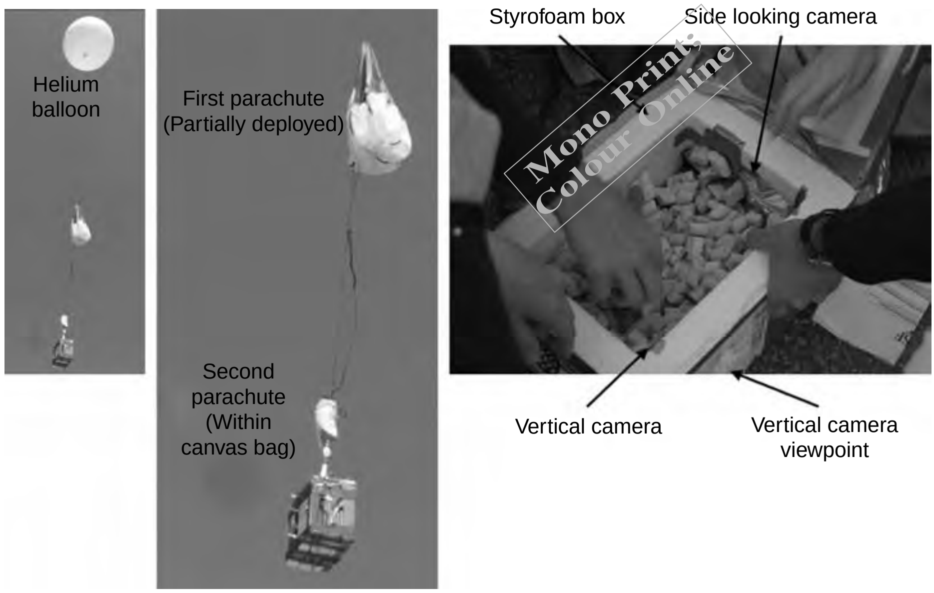

Figure 2. Final system implementation.

with a prepaid plan such as the one offered by Boost Mobile the cost is very reasonable. For visualization purposes InstaMapper was used, a free online service that only requires a username, password and valid email address. When the java-based phone application runs, a series of real-time GPS coordinates is sent to the InstaMapper account associated with that specific cell phone. A trajectory of the payload can be viewed as a map, satellite or hybrid from the InstaMapper account as it interfaces with Google maps. The GPS-enabled cell phone can hold up to 100 000 positions per device, and can send this data every 5 seconds in keyhole markup language and comma-separated values formats through an application programming interface. A major drawback of using cell phone transmission is the limited vertical coverage. Since cell phone towers are designed for horizontal dissemination of the signal, they did not support cell phone service above approximately 1800 m.

In future implementations, other compatible phones with InstaMapper such as iPhone or BlackBerries can be used. A larger variety of phones is available, if AccuTracking is selected as an alternative tracking software. Moreover, using SPOT messenger, a device with satellite-based transmission that costs double to triple the cell-based solution, the signal vertical coverage can significantly increase to approximately 6400 m. Radio-based tracking is also possible, but it requires a substantial upfront cost on receiver and transmitter purchases and a more complicated electronics setup. In some areas, local amateur (ham) radio clubs may offer assistance.

Q2 For the imaging sensors, two Canon off-the-shelf point and shoot cameras were selected, models SD550 (7.1 Megapixel) and A460 (5.0 Megapixel), respectively. Canon cameras were chosen mostly due to the availability of custom software, called Canon Hack Development Kit that allows programming for taking images at varying intervals with periods of burst of images and videos throughout the flight. The A460 was placed on the bottom of the payload looking straight down to acquire vertical photography and the

SD550 was placed on the side to capture the Earth's curvature (see Figure 2). In the future, custom infrared filters or even custom sensors could be placed onboard to adjust better to mission requirements; however, complexity and cost would increase.

System Launch and Obtained Results

In this section, the final experimental stage is discussed in common terms. The motivation is to provide engaging material for instructors and mostly students and excite them to carry on their own experiment. During the final preparatory week, atmospheric and weather conditions were monitored and projected for the launch date. The balloon trajectory forecast took place using a University of Wyoming website (UW, 2010), that turned out to be highly accurate. It is important to note that for such high-altitude experiment, it is crucial to track atmospheric conditions such as the jet stream as they can significantly affect flight trajectory and landing site location.

At the day of the launch the balloon was filled at approximately 9 am at the launch site, the SUNY ESF campus quad. The first balloon burst on the ground a few minutes before attaching the payload, probably due to the windy conditions on the ground. The backup plan was put into place using a smaller balloon that forced students to recalculate flight parameters and most importantly the amount of helium necessary. The balloon filling process was also moved to a wind-protected area 10 m away from the side of a building.

Local air traffic controllers were informed and provided a new launch window. The team successfully launched the system on Thursday April 29th, 2010, at 11:12 am EST. After launching, students were divided into two groups. The first group was responsible for tracking the system through computers in the lab, while the second group departed with the instructor for the predicted landing position. Two trucks were used as chase vehicles loaded with a boat, GPS tracking, maps, flash lights, food and two-way radio transceivers. Proper student dressing was strongly suggested as chances were in favor of a densely wooded landing area.

The balloon and payload passed out of vertical cell phone coverage approximately 15 minutes after launch at 1856 m altitude. Finally, at 1:51 pm, the payload landed and broadcasted a location reading. The landing site was a wooded farm area near Poughkeepsie, NY, with latitude 41.64874 and longitude −73.85085 coordinates. Figure 3 depicts on Google Earth the InstaMapper coordinates recovered from the GPS (Trajectory, 2010). That web link also contains an interactive Google map with 16 geo-referenced images that show interesting and recognizable places along the route.

After 1 hour of foot search, the payload was located and successfully retrieved. Other than a few superficial scratches, the payload was intact indicating a smooth descent and proper parachute deployment. GPS readings suggested an average 7.56 m/s (27.2 km/h) vertical descend rate, an excellent velocity achievement. Trajectory calculations indicated a total travel distance of approximately 254 km in 9540 seconds (2 hours and 39 minutes) leading to an average horizontal velocity of 26.7 m/s (96.2 km/h). Throughout the day, there were significant winds as the forecast indicated; however, it was the only sunny day in the weekly forecast and the end of the semester was approaching fast. Not surprisingly, the maximum horizontal velocity was recorded during descend due to the increased footprint of the deployed parachutes; it was 53.6 m/s (193 km/h) and was observed during descend over the Catskill Mountains.

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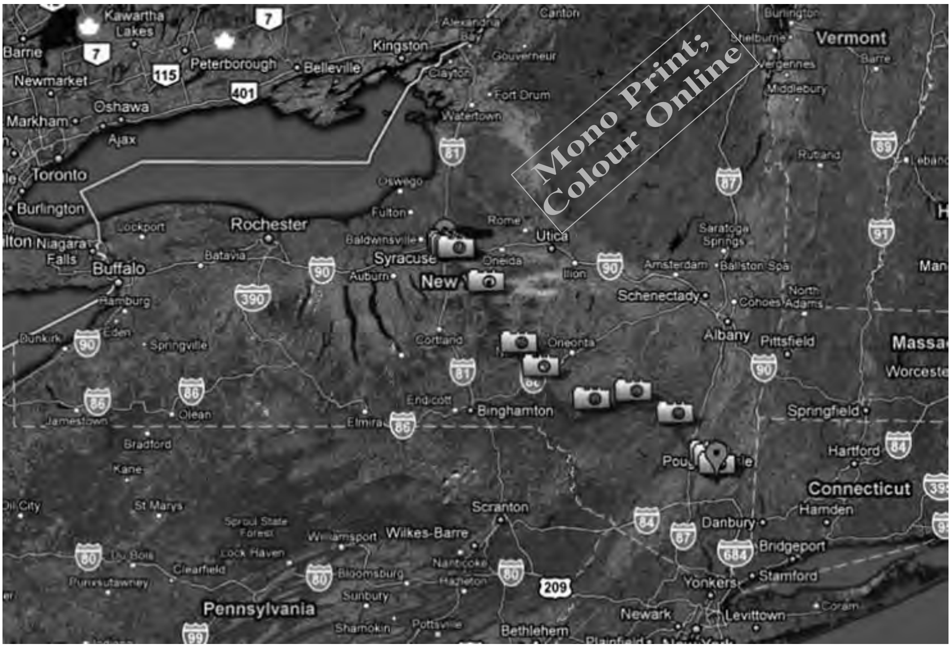

Figure 3. Payload trajectory traveling from Syracuse, NY, to Poughkeepsie, NY (approximately 254 km).

During the flight the side-looking camera collected 538 images and the vertical camera acquired 908 images and 38 short videos. Several images were selected that could be used for large-scale monitoring purposes. For example, the image taken in the Poughkeepsie area while the sensor was crossing the Hudson River (Figure 4(a)) has a ground pixel size of 1.4 m. This image is easily comparable with the corresponding image of Google Earth (Figure 4(b)) at similar scale. In addition to vertical photography, the secondary camera acquired side-looking images. Two such examples are shown in Figure 5, where the earth curvature is easily identifiable. Lens condensation (Figure 5, right) was an issue that future flights will have to account for.

Figure 6 displays one of the first and last vertical images acquired, the first showing the campus quad where the sensor was launched and the second an area close to the landing site. It should be noted that none of the presented imagery in this paper has been processed.

Assessment and Evaluation

Two mechanisms were employed to assess the educational goals of this inquiry-based learning process: an instructor-based assessment on students' performance and a student-provided survey. Students' performance was assessed using laboratory exercises that all students had to undertake in addition to the optional project. The underlying driver was to test whether students that participated in the project exhibited different performance than non-participating students. The students in the first group who participated in the project belong to the experimental group, while the other group included students which were not engaged with any part of the project (control group). The assessment took place by

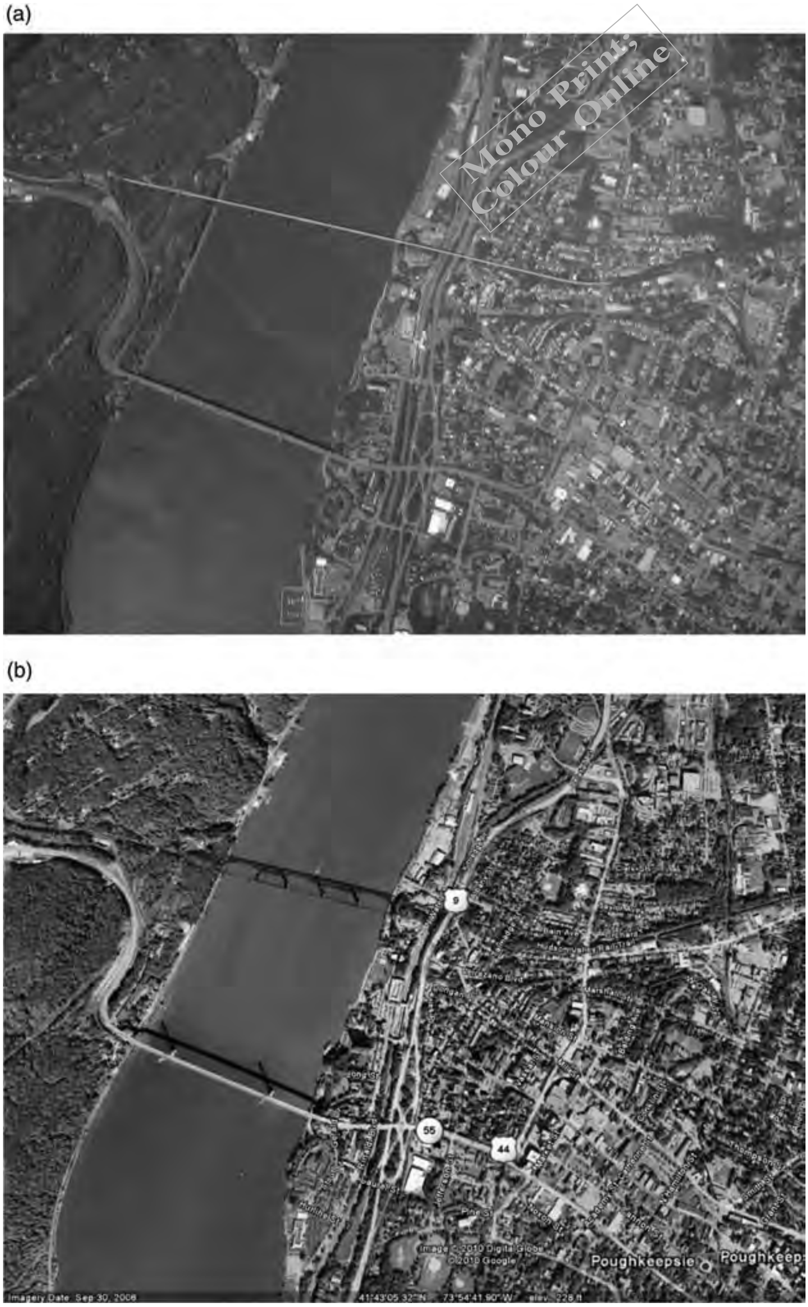

Figure 4. Visual comparison between student acquired and professional imagery. (a) Image taken from student sensor; (b) corresponding image from Google Earth.

Figure 5. Views of space from the side-looking camera.

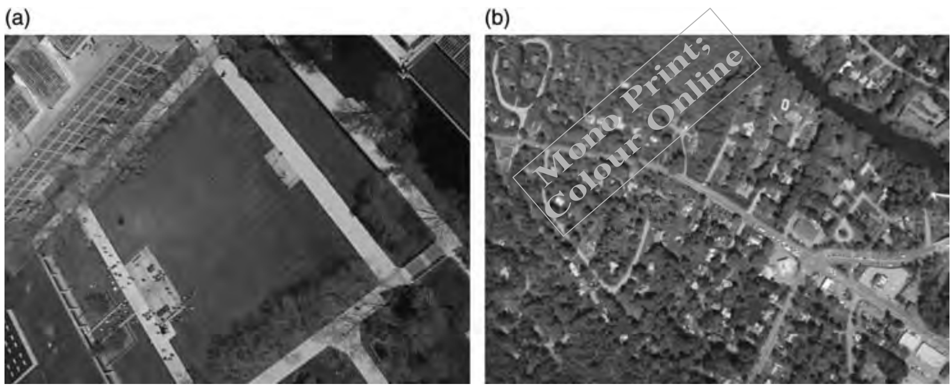

Figure 6. Images taken at (a) early ascending and (b) late descending time of flying.

comparing performance changes of the two student groups (project and non-project group) from the first four to the last five laboratory exercises of the course. As Figure 7 shows, the students participating in the project improved by 6.5 per cent compared to 3.6 per cent improvement among non-participating students. It is true that the non-project group had less room for improvement as they started with a higher average in the early labs (91.5 vs. 86.1 per cent); however, the improvement is quite substantial in the participating group bridging the performance gap significantly.

In the more detailed investigation, students were grouped further according to the overall performance of all their lab grades of each student. Three categories were created: higher achieving students, middle achieving students and lower achieving students, using the same criteria (grade thresholds) for both the participating and non-participating student groups. For the project participating group in both the lower and middle achieving categories, it can be observed that while it starts from different grades in labs 1–4 it finally reaches almost the same grade level in labs 5–9 with the non-participating project group. This indicates that the project may have engaged lower performing students to do well in other parts of the class, a similar result found in Biggs & Tang (2007). From the small population sample, it is evident that a multi-year assessment would improve confidence on the interpretation; the results in Figure 7 should be interpreted as indications rather than statistical proof.

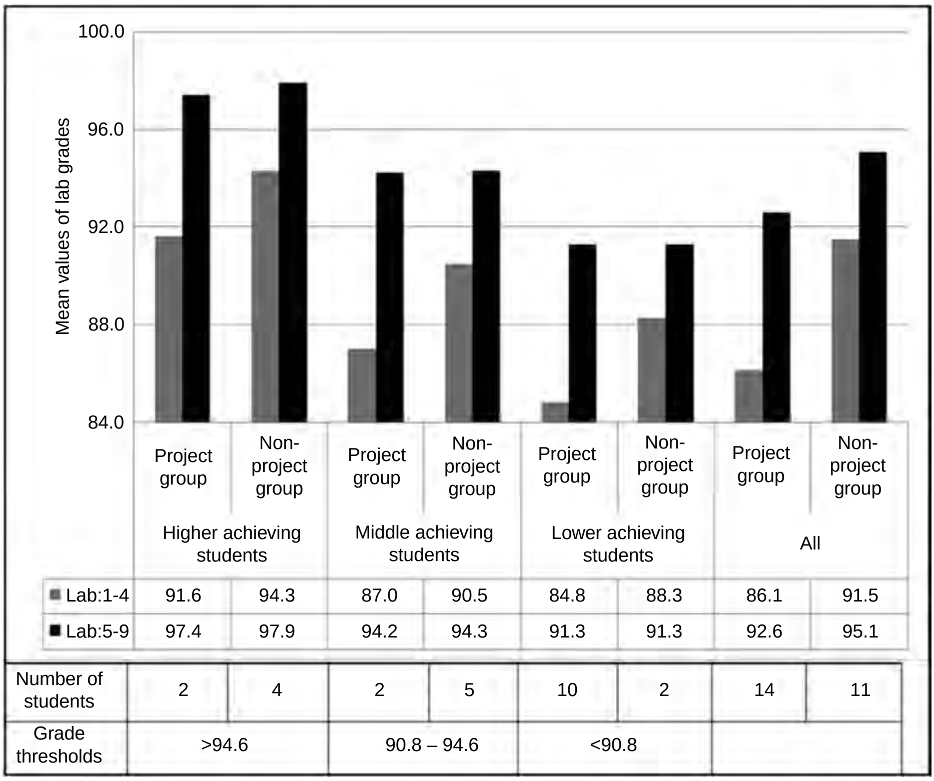

Figure 7. Student performance assessment in early and late semester laboratory exercises.

The effectiveness of any learning process cannot be fully estimated without student feedback. Informally, students were excited about the associated activities and increased their engagement as the semester progressed. After the end of the course they were supplied with a survey to assess improvements outside the strict subject matter. The survey results are presented in Table 1. Students were receptive to some of the project outcomes. The strongest signals related to the listening and delegation questions, important characteristics for successful teamwork. It has been found that a team member thinks about other students' thoughts (metacognition) and he/she is able

Table 1. Survey results on students' perception of improvement.

Question	Average	SD
Project participation improved my ability to listen to teammates.	4.1	0.5
Project participation improved my leadership ability.	3.9	0.9
Project participation improved my ability to delegate responsibilities.	4.2	0.4
Project participation improved my decision-making ability.	4.0	0.6
Project participation increased confidence on my engineering abilities.	4.0	0.9
Project participation motivated me to put additional effort in other parts of the course.	3.8	0.7
I would encourage future students to participate in this project activity.	4.7	0.5

Note: Responses in the Likert scale: 1 = strongly disagree, 5 = strongly agree.

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Table 2. Survey results on students' motivation to participate in this activity.

Question: Why did you initially sign up for the project?	
Opportunity to work on a hands-on problem	79%
Sounded like a cool project	64%
General interest for remote sensing	29%
Work with my buddies	7%
To obtain a better grade	7%
To do less work	0%
Others	0%

Note: Multiple responses were permitted.

to make a self-evaluation of the knowledge acquired, testing the overall progress on the learning goals (Hankins & Yarbrough, 2008; Fink & Ganus, 2009; Fournier, 2009).

Another interesting result from this survey was that leadership and confidence questions had a significantly higher variability indicating that probably not all students shared a leadership role, a remark consistent with the instructor's observations. Finally, students overwhelmingly indicated that they would encourage others to participate in this project, even though it involved a significantly higher workload from a typical workload of an introductory remote sensing course.

Lastly, another question on the survey inquired about the students' motivation to sign up for the project at the beginning of the semester. Table 2 indicates that the hands-on factor and the initial excitement were the two major motivating factors. It is interesting to see that less than one-third of the students were motivated by a general interest in remote sensing. Following up on that question, the same students were asked in a different survey at the end of the semester and after completing the project if they would be interested in a follow-up remote sensing course; 93 per cent responded positively. Due to the lack of an early semester survey, we cannot isolate the project's direct contribution to this interest increase toward remote sensing (e.g. laboratory exercises may have contributed); however, informal discussions suggest that the project was the dominant motivating factor. We believe the hands-on appeal of the project brought students much closer to remote sensing techniques, despite the fact that students were not extremely positive to the subject matter.

Discussion and Conclusions

The ability to make decisions is an important part of critical thinking and intellectual maturity (Renshaw & Taylor, 2000; Smith *et al.*, 2005). Project-based learning makes students active learners, because the experimental setup is based on students' ideas and concepts. In this experiment, students investigated different parachute types, methods of deployment and positions relative to the payload. Moreover, difficulties presented during GPS and camera testing were food for constructive ideas and improvements. Students were responsible of their own findings and the proposed methods; the instructor's role was not to find solutions or propose methods, but to coordinate and keep the best working environment. This was consistent with the philosophy that instructors should be designers of learning experiences, engaging students with materials and methods (Smith *et al.*, 2005). The selection of the appropriate building materials and the most effective system design were also two crucial parts of the decision-making process. Students, testing their

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own ability of creative imagination and inspiration, took ownership and associated risks. The successful outcome reinforced their decision-making process providing them with confidence to tackle future problems. This project was offered at the junior year, and it is expected to prepare further our engineers for the semester-long capstone project in their senior year.

Project-based learning is an important pedagogical technique in engineering education, because it can easily extend to most engineering practices. A project-based learning as a part of inquiry hands-on experience can provide substantial benefits to students ranging from professional development to life-long skills. The ABET has established 11 educational outcomes to assess and accredit engineering programs (known as a through *k* outcomes). In terms of ABET outcomes, early mathematics and physics courses found application in the design aspect of the project overlapping with ABET Outcome a: ‘an ability to apply knowledge of mathematics, science, and engineering’. Furthermore, the integration of design and construction taught students ‘an ability to design and conduct experiments, as well as to analyze and interpret data’ (ABET Outcome b) and ‘an ability to identify, formulate, and solve engineering problems’ (ABET Outcome e). The hands-on learning combined with real constraints presented to the students (e.g. FAA regulations, budget limitations) addressed ABET Outcome c: ‘an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability’.

The project also taught students the value of collaboration over competition. There is a dynamic relationship between individuals and their team. Any student can support the team by identifying problems, formulating techniques and proposing solutions. There is reflection from their team, as well as from other teams. Therefore, the system student team is supportive and complimentary in order to achieve the desired performance goals (Chen, 1998). Students provided frequent oral presentations, wrote project reports and actively participated in numerous debate sessions; these activities targeted ABET Outcome g: ‘an ability to communicate effectively’. For a balanced exposure students leading each weekly activity alternated throughout the semester within each student group.

Currently, there is a disconnection between two major remote sensing processes: the image acquisition and the image analysis. Users are not typically exposed to the image acquisition process as imagery is captured and preprocessed by a governmental or private entity, outside the users reach. Projects like this allow further appreciation of the difficulties involved in remote sensing data acquisition and provide awareness and appreciation on the obtained imagery. Furthermore, proliferation of Internet-based geographic applications such as Google Earth has significantly increased information accessibility for the non-expert. Unfortunately, such applications are designed to hide engineering ‘impurities’ of the data by disguising or even ignoring acquisition errors. Inquiry-based remote sensing projects that expose students to imagery acquisition have the potential to further engage students in a meaningful way, for example, by realizing constraints associated with sensor limitations (e.g. lens quality) and atmospheric conditions (e.g. clouds, lens condensation).

In addition to student engagement, this project may act as an outreach vehicle for remote sensing technology, increasing visibility of the instructor and the institution in the local community. The sensor launch was covered by two local TV channels and two articles were devoted on the launch and the results, respectively, on the most popular local newspaper (material available at ESF Goes to Space I, 2010). Several departmental and institutional publications also showcased this experiment as an excellent example of engineering teaching.

Remote sensing instructors are highly encouraged to incorporate a variant of this experiment in their courses and share results in relevant scientific conferences/meetings. It is indeed a time-consuming and high-risk experiment to incorporate into an undergraduate course; however, the benefits could be substantial. It is recommended that instructors start with high redundancy (e.g. build multiple sensors) on their first semester and build on that in consecutive years. We would also suggest the integration of this experiment with other courses concurrently taken by the students to identify interesting applications of the experiment (e.g. water monitoring).

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