

MULTIDISCIPLINARY PROJECT-BASED LEARNING IN STEM: A CASE STUDY

Bowen Brawner Ph.D.
Tarleton State University
Department of Mathematics,
Box T-0470 Stephenville, Texas 76402
brawner@tarleton.edu

Abstract

A project-based multidisciplinary course was designed at Tarleton State University in the 2011-2012 academic year. A NASA design-build-fly competition was used to frame the course; however, the main reason was to provide a real multidisciplinary experience across the STEM fields. The objective was to mirror industry's research life cycle from end-to-end. The first offering of the course included 10 students from mathematics, physics, computer science, biology, and engineering. The competition that framed the experience was the 2012 CanSat Competition hosted by the Naval Research Labs (NRL) and NASA's Goddard Space Flight Center.

Introduction

The initial impetus for the course was driven by student interest. Students at this university were seeking a real world research experience in aeronautics. Since no aeronautics program existed, the mathematics department implemented a problems course that centered on a complex task, namely the Statement of Work (SOW) set out by NASA for the 2012 CanSat Competition. The mission was to research, design, build, and launch a Planetary Atmospheric Entry Vehicle. The instructor's motivation was driven by several factors: the first being a belief in the benefits of project-based learning; the second was the university's new focus on applied learning experiences and, in particular, undergraduate research; the third factor was the need within the College of Science and Technology for a multidisciplinary research experience that followed industry's design life-cycle.

Project-based learning

In project-based learning (PBL), students explore real world problems and challenges that require skills that pull from across several disciplines. It also necessitates that students work collaboratively in reaching a solution. It is often seen as an alternative to the traditional textbook-centered learning that relies heavily on rote memorization and teacher-centered classrooms.

There are several benefits to project-based learning:

- a deeper of understanding of concepts,
- broader knowledge base,
- improved interpersonal and communication skills,
- enhanced leadership skills,
- increased creativeness, and
- improved writing skills.

Project-based learning falls under the definition of inquiry-based learning (IBL) and is similar to problem-based learning where students are presented with a real-world problem-solving situation; however, project-based learning requires students the creation of some kind of product, artifact, or presentation. (Barron & Darling-Hammond, 2008; Thomas, 2000).

PBL actively engages students in their learning. The “need to know” drives the learning process and inspires students to delve deeper into concepts. They become researchers actively seeking the background knowledge needed to tackle a larger problem as opposed to studying for narrowly-defined questions on an exam or quiz. Research also indicates that PBL increases long-term retention of content, improves problem solving, and improves students’ attitudes toward learning (Strobel & van Barneveld, 2009; Walker & Leary, 2009).

Applied Learning Experiences

Applied Learning Experiences or ALEs, as they are commonly referenced, are divided into five areas at the university. They are Undergraduate Research, Service Learning, Leadership, Internships and Practicum Experiences, and Study Abroad/Study U.S. Schwartzman (2009) notes “Diverse as applied learning may appear, all its manifestations share certain characteristics. Concrete experience, *learning by doing*, lies at the core of applied learning. This pedagogy represents active learning at its most literal level, the activity of putting intellectual principles into practice” (p. 4).

Within the ALEs at this university, Undergraduate Research is defined as “student engagement in original research, scholarly activity, and/or creative activity, mentored by a faculty member, with the goal of publication, presentation, performance, or exhibition of the results or products.” (Tarleton State University, 2015a)

Student learning outcomes exist for ALEs at the university and stipulate that upon successful completion of a research applied learning experience, the student will be able to identify and summarize background information related to their research question or problem; develop a research plan to address their question or problem; collect and interpret data in an attempt to address their question or problem; articulate findings in written or oral form; demonstrate awareness of the importance of ethical behavior in conducting research (Tarleton State University, 2015b). In addition, it is agreed that students should have access a good (state-of-the-art) environment, an opportunity for attendance at professional meetings, earn pay or credit, design some aspect of the project, work independently (of faculty), and have an opportunity to work on a team (of peers), and feel ownership of the project.

Thus, project-based learning can be viewed as an applied learning pedagogy. As evidenced in the description above, project-based learning and applied learning experiences share the intent of nurturing learning and growth through a reflective, experiential process that takes place outside of the traditional classroom settings. The primary premise is that the best learning environment is one

that is active, engaged, and collaborative. The experience should allow students to connect theory and practice, to learn in various contexts, to interact with peers, and to apply knowledge and skills.

Educational Objectives

Educational objectives are needed in the development of a successful course. Course and student objectives provide the framework necessary to evaluate the effectiveness. The following objectives were developed:

1. Provide students with an opportunity to achieve the ALE student learning outcomes for successful completion of a research applied learning experience described earlier (Tarleton State University, 2015b).
2. Provide students with an opportunity to develop the research skills needed to be successful in future employment. The students were expected to research, design, document, test, and produce a working product.
3. Provide students with an opportunity to apply the textbook knowledge and skills from their classes to the end-to-end life cycle of a complex project. Students were expected to complete all subsystems and an integrated final product.
4. Provide students an opportunity to work in a project oriented environment that followed industries research life-cycle. Students were expected to develop time and resource management skills need to work within the budget and time constraints.
5. Provide students an opportunity to work within a multidisciplinary team environment. The students were expected to develop the communication skills needed to work with colleagues from diverse backgrounds.
6. Allow students to evaluate and critique the effectiveness of themselves, others, and of their designs.

The mechanism chosen to meet these educational objectives was the 2012 CanSat Competition hosted by the Naval Research Labs (NRL) and NASA's Goddard Space Flight Center. Students were expected to complete all CanSaT competition requirements.

CanSat provides research teams an opportunity to experience the complete design life-cycle of an aerospace system. The competition reflects a typical aerospace program and includes all aspects of an aerospace program from the preliminary design review to post-launch assessment review. The mission and its requirements are designed to reflect various aspects of real world missions including ground telemetry requirements, station development, and autonomous operations. The teams engage with NASA scientist and engineers in a contractor type relationship allowing a unique opportunity to experience an engineer to customer relationship. In addition, each team is

provided feedback and scored on real-world deliverables such as schedules, design review presentations, and demonstration flights (NASA, 2012).

Thus CanSat provided the framework and mission for a project-based multidisciplinary research course. Students from across the Science, Technology, Engineering, and Mathematics (STEM) fields participated. The first offering of the course included 10 students from mathematics, physics, computer science, biology, and engineering. Such design-build-launch competitions engage students in the interdisciplinary end-to-end life cycle of a complex engineering project from conceptual design, through integration and test, actual operation of the system and concluding with a post-mission assessment.

Research Life Cycle

NASA's Mission Directorate (2010) describes Principal Investigator Led Missions:

"PI-led missions" are cost-capped missions, addressing narrowly focused science objectives. Proposals must be technically mature in order to ensure the missions remain within or close to their cost cap. A wide range of organizations may manage a PI-led mission, such as a NASA Center, a university, a nonprofit organization, or a commercial entity. A NASA Center program office is assigned to provide management oversight. Selection of a PI-led mission is through a rigorous process of scientific and technical peer-review. (p. 32)

The process begins with a competitive proposal selection process. Upon acceptance teams participate in a series of design reviews that are submitted to NASA. These reviews mirror the NASA engineering design lifecycle, providing a unique real-world experience and prepares students for the STEM workforce. Teams must successfully complete a Preliminary Design Review (PDR), Critical Design Review (CDR), Flight Readiness Review (FRR), Launch Readiness Review (LRR) that includes safety briefings, and an analysis of vehicle systems, ground support equipment, and flight data. Each review must be pass in order to move to the next phase of development. Teams presented their PDR, CDR, and FRR to a review panel of scientists, engineers, and technicians via video conference. Review panel members and subject matter experts provide feedback and ask questions in order to increase the fidelity of the research, and score each team. Through this process the students are prepared to enter the workforce familiar with the engineering research lifecycle. (NASA, 2015)

NASA's project life cycle sets out the plan for the design, build, verification, flight operations, and disposal of the desired system. It also maintains consistency between projects, sets expectations for Project Managers, Scientists, & Engineers, details plans and deliverables to ensure fidelity and timing. The project life cycle is divided into six phases, A through F.

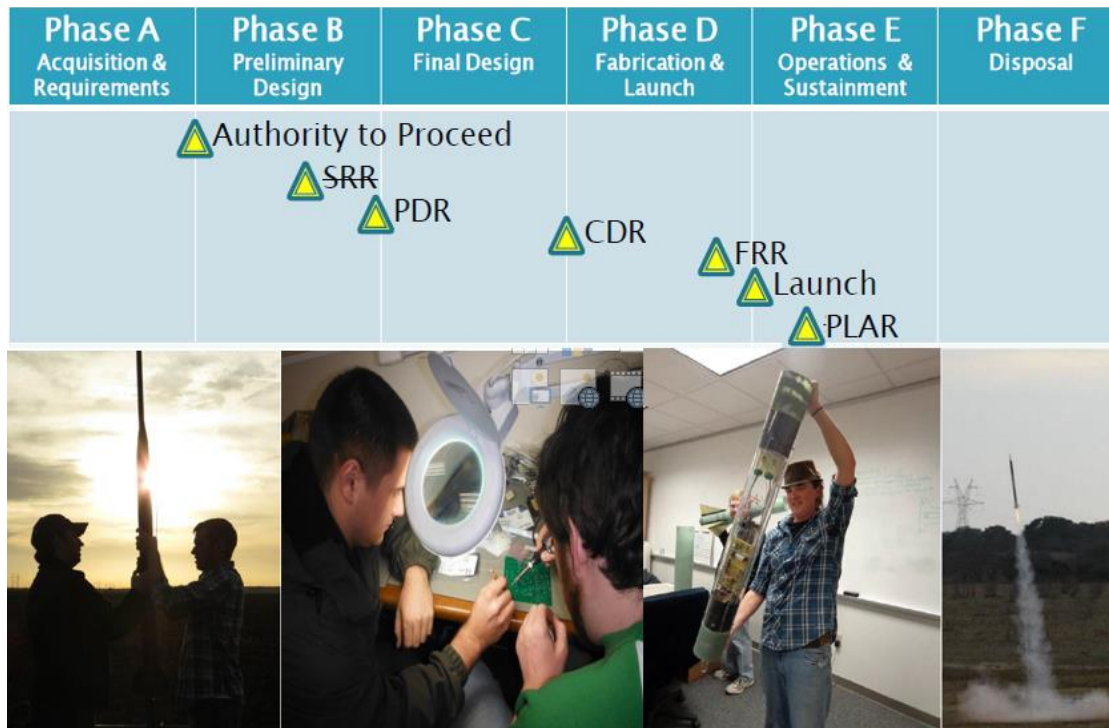


Figure 1 Project Life Cycle

Phase A - Concept and Technology Development

This phase provides the opportunity to explore concepts based on operational needs, existing technology availability, risks and affordability. A complete understanding of mission needs and the Statement of Work is achieved. The students submitted a full proposal to NASA for review and presented, via video conferencing, several conceptual designs. After that, they received permission to proceed.

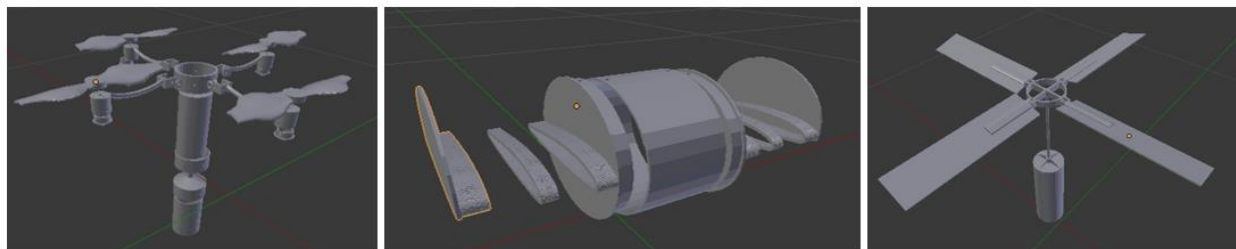


Figure 2 Preliminary Designs

Phase B –Preliminary Design and Technology Completion

The objective of this phase is to prove the feasibility of building and launching the rocket/payload design. All system requirements must be met before receiving authority to proceed to the Critical Design. This phase included an assessment of technology maturity, user requirements and funding

considerations. All components were defined, demonstrated, and tested. The subsystems were then integrated into a complete system. The prototype was demonstrated and risks and mitigations were determined.

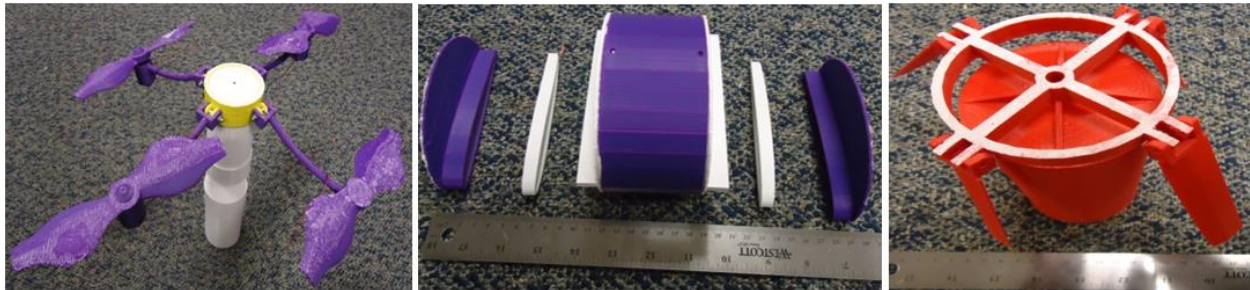


Figure 3 3-D Printed Prototypes

Typical products at this stage preliminary design discussion, drawings, sketches, identification and discussion of components, analyses (such as Vehicle Trajectory Predictions) and simulation results, risks, mass statement and mass margin, schedule from PDR to launch (including design, build, test), cost/budget statement, mission profile (Concept of Operations), interfaces (within the system and external to the system), test and verification plan (for satisfying requirements), ground support equipment designs/identification and safety features. (NASA, 2015)

The preliminary design review was submitted to NASA and presented via video conference. After the review, authority was given to the team to proceed into Final Design.



Figure 4 Video Conference

Phase C – Final Design and Fabrication

In this phase, the team continues to test the maturity of design and function. They then enter into production readiness where initial operational tests and flight test occur under competition conditions. The objective of this phase is to complete the final design of the rocket/payload system and to receive authority to proceed into Fabrication and Verification phase. In a perfect world, fabrication/procurement of the final system wouldn't begin until a successful completion of the

Critical Design Review. However, due to schedule constraints, it was necessary to start procurements and fabrication prior to CDR. Procurements and Fabrication that start prior to CDR add an extra risk to the Project because design issues may be discovered at CDR that impact procurements or fabrication. (NASA, 2015)

Typical products at this stage are PDR deliverables (matured to reflect the final design), discussion and documentation of completed tests, procedures and check lists. A CDR was submitted by the team to NASA and presented via video conference. Final Design was reviewed and authority was given to proceed to build the system.

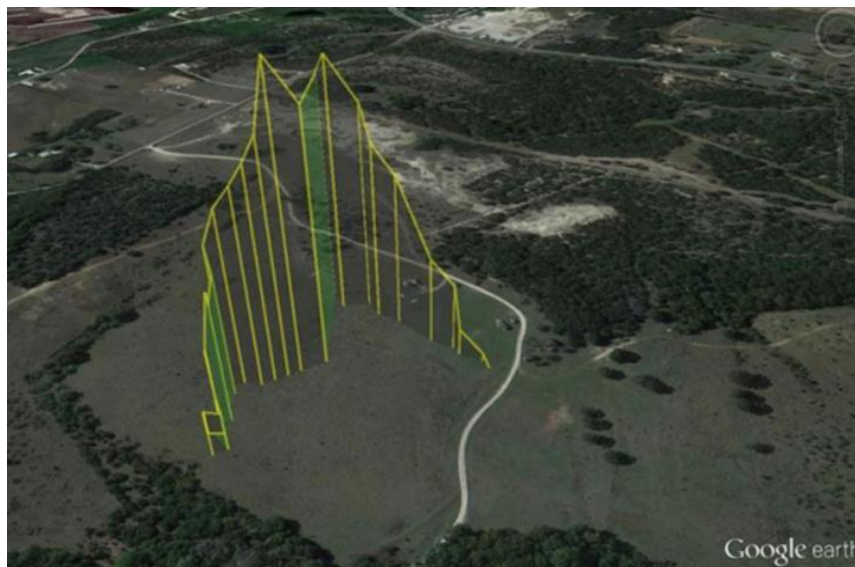


Figure 5 Flight Analysis

Phase D – Fabrication and Launch

The objective of phase D is to prove that the Rocket/Payload System has been fully built, tested, and verified to meet the system requirements. Typical products at this stage include a gant chart, cost statement, design overview, key drawings and layouts, trajectory and other key analyses, completed mass statement and remaining risks and mitigation charts, analysis and models (using real test data), system requirements verification, launch day procedures and check lists. The Flight Readiness Review was submitted by the team and presented in person. A check list of safety concerns and required mitigations were given to the Team. Upon verification by NASA that all changes were performed, permission to proceed to launch was received. (NASA, 2015)

Phase E- Operations

Upon the team's launch of the rocket and payload, data is collected and analyzed, and the Post Launch Assessment Review (PLAR) is conducted. Presentation of vehicle and payload results is

made. The team makes comparison to predicted results and draws conclusions based on the results. Any anomalies are analyzed and discussed and lessons learned from the project are presented.

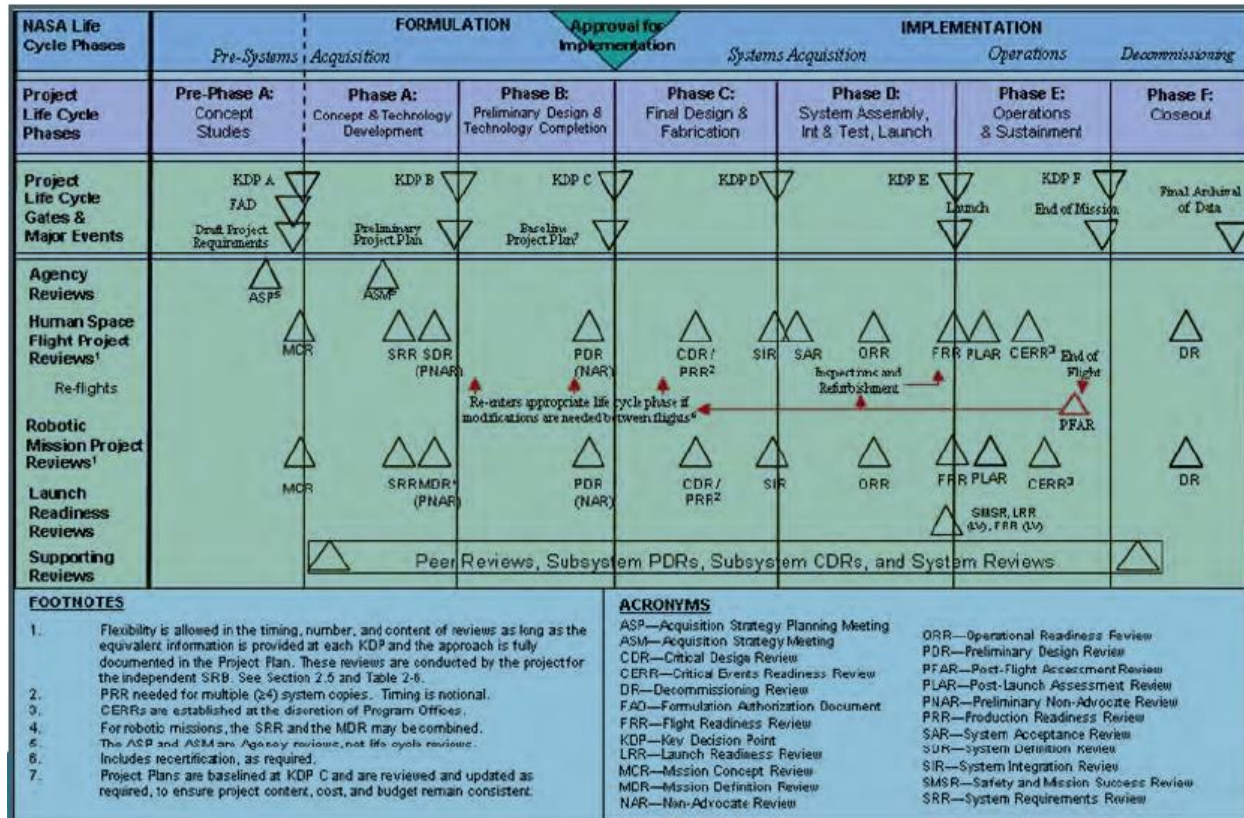


Figure 6 NASA's Project Life Cycle (NASA, 2015)

Conclusions

CanSat and similar competitions are competitive, research-based, and experiential exploration projects that provide relevant and cost-effective opportunities for student research and development. It connects educators and learners with NASA education opportunities that align with NASA's Science, Technology, Engineering, and Mathematics education engagement initiative. Such NASA missions and the provided resources open up opportunities for students that do not exist within universities alone. The project involves bringing a broad array of universities research teams from across the nation together in an 8-month commitment to research, design, build, and launch a satellite on high-power rockets. The challenges center on highly technical tasks that are relevant to current real-world research missions and require teams complete an industry standard project life cycle. Students must learn the hard and soft skills required to be successful in today's workforce. Communication skills both orally and written are developed along with leadership, time management, and budgeting skills. As well as, the hard STEM skills applied to completing such a highly technical project. Such competitions are unique project-based learning opportunities that are built on a mission as opposed to courses designed around textbook knowledge. This type of course can provide a unique capstone experience within any STEM college.

References

Barron, B., & Darling-Hammond, L. (2008). Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning. In *Powerful Learning: What We Know About Teaching for Understanding*. San Francisco, CA: Jossey-Bass

National Aeronautics and Space Administration (2010) *Science Plan for NASA's Science Mission Directorate 2007 – 2016 (PDF)* Retrieved from http://science.nasa.gov/media/medialibrary/2010/03/31/Science_Plan_07.pdf

National Aeronautics and Space Administration (2012). *CanSat Competition Guide (PDF)*. Retrieved from http://www.cansatcompetition.com/Mission_files/competition_guide_alt1_120710_r8.pdf

National Aeronautics and Space Administration (2015). *NASA Student Launch Handbook (PDF)* Retrieved from http://www.nasa.gov/sites/default/files/files/NASA_SL_2015_Handbook.pdf

Schwartzman, R. (2009). Celebration to Critical Investigation: Charting the Course of Scholarship in Applied Learning. In *Journal of Applied Learning in Higher Education*, 1. Missouri Western State University

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms (Abstract). In *The Interdisciplinary Journal of Problem-Based Learning*, 3(1).

Tarleton State University (2015a) Office of Student research and Creative Activities. Retrieved from <http://www.tarleton.edu/studentresearch/>

Tarleton State University (2015b). Undergraduate Research and Creative Activities SLOS Retrieved from <http://www.tarleton.edu/ale/SLOs/researchSLOs.html>

Thomas, J. (2000) *A Review of Research on Project-Based Learning (PDF)* Retrieved from http://www.bobpearlman.org/BestPractices/PBL_Research.pdf

Walker, A. & Leary, H. (2009). A problem-based learning meta-analysis: Differences across problem types, implementation types, disciplines, and assessment levels (Abstract). *Interdisciplinary Journal of Problem-based Learning*, 3(1): 12-43.