

# New Heights in Science, Technology, Engineering and Mathematics (STEM) Undergraduate Learning

## Taylor University Grant Proposal for

National Science Foundation Course, Curriculum, Laboratory Improvement (CCLI)  
\$217,668

### 2.0 Project Description

**2.1 Introduction** Watching the experiment made with your very hands launched (Fig. 1) by a high-altitude balloon and receiving your data in real time as it ascends into near space (Fig. 2) - this has been the thrill that undergraduates in physics and engineering have experienced over the last four years. Funding through NASA and Taylor University enabled the development of the High-Altitude Research Platform (HARP) system that successfully executed 40 launches (100% recovery) while providing novel, hands-on classroom learning that was implemented easily and cost effectively (\$250 per launch expendable operating cost). In addition, StratoStar, LLC was spun off to make the HARP system commercially available.

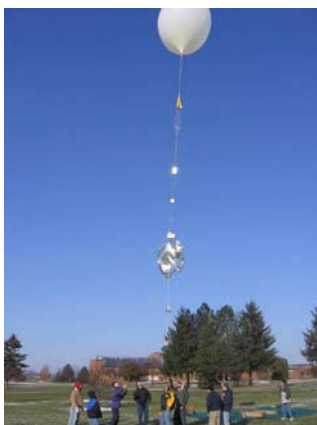


Fig 1: Advanced Lab projects including a stratospheric airship design test.

The launch, though, is only a part of the excitement. Students are engaged in the full learning cycle (Fig. 3) of theory, research, instrumentation, launch, operations, data analysis and



Fig. 2: Image taken at approx. 95,000 feet by students on first balloon launch

publication. The high altitude/near space launch makes each of these steps both exciting and practical. Students learn about the real-world obstacles that need to be overcome through troubleshooting and innovative solutions. Their hard work pays off when their experiment is launched, and the data are acquired. They are then faced with the challenges of data analysis and interpretation which they meet with tenacity due to the real world aspect of the work. Finally, the students produce higher quality presentations and publications of their results due to their high level of interest and commitment. Anecdotal evidence shows that students are found to have a high technical readiness for graduate schools and careers, high motivation for future coursework,

strong resumes, confidence and enthusiasm for STEM (science, technology engineering and mathematics) areas and high retention in physics and engineering programs. A scientific assessment is needed in order to confirm these impacts.

The beauty of the HARP system is that students get drawn into the scientific method (Fig. 3) by the excitement of high altitude and near space, by the challenge of a real-life problem and by the use of technology (GPS, wireless communications, miniature sensors, video capability, etc.). In addition, the HARP system enables creative experiments across all STEM areas

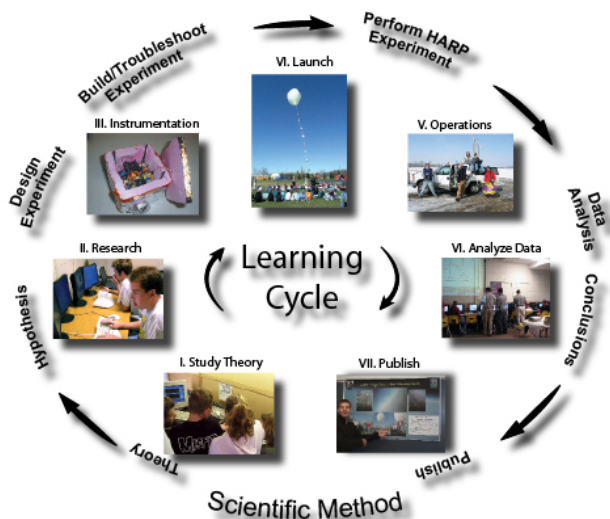


Fig. 3: The Learning Cycle involves experiencing the Scientific Method and much more: Challenge, Ownership, Inspiration, Fun, Creativity, Problem Solving, Hands-On, Systems, and Multidisciplinary Team Work.

(engineering, chemistry, biology, computer science, physics, mathematics, astronomy, environmental science, geology, etc.) to be carried out as a function of altitude (into the Stratosphere) or remote sensing of the earth, sun, and stars from near space. The system is designed to interface the experiment with robust microelectronic data acquisition and communication capability that can transmit and store data in real time while the balloon is ascending, floating, and descending. The HARP system provides the high-altitude balloon and data acquisition capability, enabling the faculty member to focus on teaching the desired learning outcomes from the specific experiment to be executed.

The next step for the HARP system is for implementation into STEM curricula at other colleges and universities. This phase 2 CCLI proposal reduces the barriers these institutions may have in implementing HARP. The work proposed includes documentation of the HARP system, documentation of a suite of experiments and creation of a website for obtaining up-to-date information, sharing results and networking. This is followed by workshops for faculty at other institutions to be trained in the HARP experimental process by designing and building an experiment, launching it, obtaining real time data and analyzing the data. The workshop participants would then receive assistance from Taylor University and StratoStar, LLC in executing their first HARP experiment as part of a course at their own institution. Table 1 shows a list of universities and institutions who have sent letters of support.

Table 1. Universities who have sent letters of support and/or intent to participate.

University	Professor	Workshop Interest	Comments/Quotes
DePauw (IN)	H. Brooks	Yes	“It is a low-cost method of conducting meaningful scientific investigations of an under explored region of our Atmosphere.”
U. of Illinois	G.Swenson	Yes	“The two (former Taylor) students are among the top master’s graduate students this year.”
Purdue (IN) IN Space Grant Consortium	B. Caldwell	Yes	“ This type of mutually beneficial regional and state collaboration is something in which both ..., and are at the heart of the CCLI goals.”
Stanford (CA)	J. Cutler	Yes	“Their balloon platform would provide an excellent foundation to conduct additional experiments at Stanford.... The excitement of students seeing their systems launched was impressive.”
Valparaiso (IN)	G. Morris	Yes	“ The workshops will provide, in a compact format, training for students in my group as well as promote awareness of remote sensing and regional pollution.”
Cedarville (OH)	C. Allport	Yes	“The Taylor concept of collaboration and sharing is key.”
Wisconsin Space Grant Consortium	R. Aileen Yingst	Yes	“We enthusiastically support the efforts... and will be pleased to make our resources fully available to Taylor.”
Tufts (MA)	William H. Waller	Yes	“I look forward to participating in the ...workshops and helping enable new STEM curricula and assessments ...”

Finally, a scientific assessment of faculty development and student learning will be executed as a result of the workshops and implementing HARP experiments at all participating institutions. This will give data that can be used to improve the effectiveness of HARP as a teaching strategy for STEM education and also point to new research on undergraduate STEM teaching and learning.

## 2.2 Background

**2.2.1 Program History:** The HARP program was started in 2003 through an Indiana Space Grant Consortium (INSG) grant, and was the recipient of four consecutive grants for the continuation of the program, as well as matching funds from Taylor University, Taylor’s Center for Research

& Innovation (funded by the Lilly Endowment, Inc.). The HARP program revolutionizes education by providing classroom knowledge and simultaneously cementing it with real experience. The HARP program is affordable. After an initial expense of \$9,000, each launch costs \$250 total in consumables (balloon, helium, recovery vehicle operation, etc). Thomas Nicol, a student in Taylor's 2006 Introduction to Electronics class said, "Working on the balloon project was an excellent opportunity to put theory into practice; not only the electronics portion, but working as a team and planning ahead."

In Taylor University's implementation of the HARP program into its curriculum, students

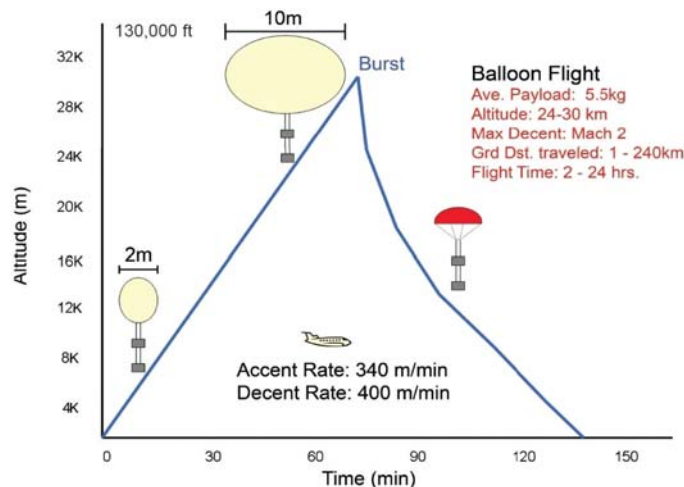


Fig. 4: A typical high-altitude flight profile

experience a truly professional research project. Once a problem is identified, the students are required to study the associated theory. This process starts in the classroom, but the students quickly explore the finer points of how best to perform their research as a sense of ownership builds. This ownership moves students from a "teach me" attitude to one of "I want to learn." The result is that the theory presented in the classroom is amplified and retained.

The students are then required to do background research into the specifics of their chosen investigation, which enables them to ideate, prototype, build and test their own instruments. At Taylor this has included such experiments as the adaptation of Geiger counters for high-altitude energetic particle sensing, and the modification of an electrocardiogram to sense E-fields in the atmosphere. In these kinds of projects, students begin to see the links between the theory presented in the classroom and the components that they are working with. Their education also becomes suddenly practical, as they troubleshoot, refine, and calibrate real instrumentation. For example, troubleshooting can be a frustrating, but it is made easier by the ownership that each student takes of his/her own project. Students experience the need for testing, too. Their experiments will experience environmental extremes – altitudes in excess of 100,000 feet (Fig. 4), and temperatures as cold as -40°C. Jared Schlak, a student whose team developed a digital camera system to observe both infrared and visible light images, wrote "there will always be some sort of problem that I had not planned on. But in the end when I finally got to see the balloon go up, I felt good about all the hard work that I put into the project."

It is at this point that students begin to experience some of the most unique aspects of an education involving high-altitude balloon experiments. There are real procedures which must be followed to ensure a successful launch, profitable data collection, and safe recovery of their payload. Students experience the excitement of a launch, and the requirement for effective post-launch operations. Working in a "mission control" environment, students can keep track of their data, command and control their experiments, and keep track of the progress being made by the balloon recovery team. The experience of how to handle operations in a stressful environment is valuable to students. David Patterson, the student director of the HARP program, indicates that the "success in my professional experiences as a short-order failure analysis engineer for a major government contractor is due to the experiences I had while directing the balloon team."

Taylor University has two options for mission control operations: a fixed base station located in the Nussbaum Science Building, and HARP's Mobile Command Station, a 12' cargo trailer, modified to be a fully-functional command platform (see Fig. 5).

All students learn about safety during the launch and recovery effort, including how to be aware of where the payloads and tether lines are at all times, the need to observe speed limits during the tracking effort, and how to make every reasonable effort to obtain permission before entering property to recover the payload. In addition, our payloads are designed to meet the Federal Aviation Requirements, sections 101.1, 101.7, 101.31, 101.33, 101.35, 101.37, and 101.39.

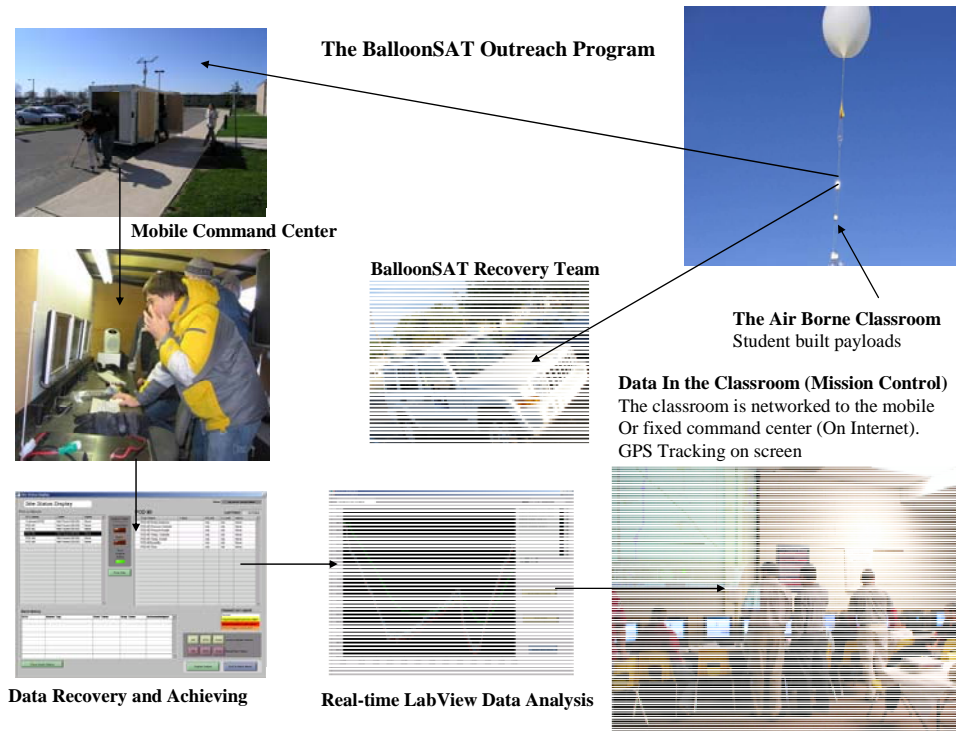


Fig 5: HARP can be used in large classes and for outreach since the real-time data can be ported into the classroom or onto the internet. Many launches have been combined with advanced payloads and relatively simple general education experiments.

After the launch, students are required to analyze their data in detail. Because the students are not receiving “canned” data, the analysis process is more involved, and students tend to put more into determining the meaning of their data, and reduce noise and background, often coming up with exciting insights into how their instruments respond to changes in their environment.

After the data analysis, the students experience one final, important part of scientific research: written and oral communication of the findings. Students are required to generate a scholarly paper documenting their research, investigation and findings and present it to their peers. This experience helps to prepare students for professional careers in STEM-related fields where documentation and good communication skills are critical for success.

Since the HARP program started at Taylor, the enrollment of undergraduate students in Physics, Engineering Physics, and Computer Engineering has increased by 20% (Fig 6). Twenty classes have directly participated in balloon launches, for a total of 250 students, including students from the Computer Science, Education, and Business

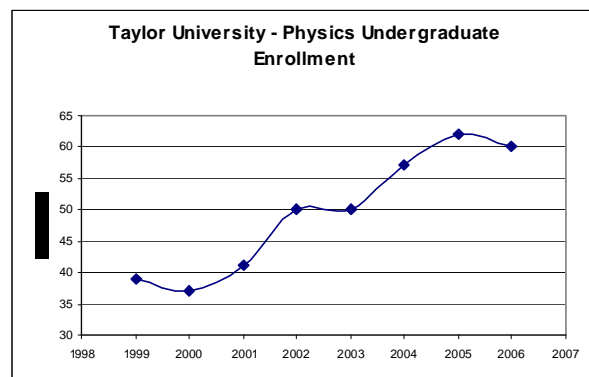


Fig. 6: Growth in Physics Department

departments. Four universities have flown payloads either as primary or secondary mission payloads on Taylor balloon missions, and a total of over 350 college students have benefited from the unique experience of high-altitude research.



Fig. 7: Main Command Pod electronics with Zigbee wireless to Experiment Pods, 110 kbit spread Spectrum telemetry and command link. Also includes GPS, Battery, data storage, processors, and

**2.2.2 Technology:** On each flight (Voss et. al. 2006), payloads are constructed modularly, and connected to the Main Command pod (Fig. 7) via a wireless network (using the 50 kbaud Zigbee wireless protocol). Once all of the payloads with experiments have been verified, and a communications link has been established between the telemetry pod and both the recovery team and the mission control center, the payload is released and ascends to altitudes ranging from 15 to 20 miles, beyond 98% of the earth's atmosphere. Throughout the flight, experiment and position telemetry are reported over a 110 kbit link via 900 MHz spread-spectrum radios, and backup position data is broadcast via Amateur Radio APRS technology. During ascent the balloon expands due to the reduced ambient pressure. Eventually the balloon bursts and the payload returns on parachute at 1000 feet per minute – gentle enough to be safely caught.

**2.2.3 Results for Prior NSF Support:** Dr. Hank Voss (PI) is currently working on NSF grant (ECCS-0619712, 2006-2009, \$250K) MRI-RUI: Development of a Cost-Effective 25MeV Electron Accelerator. This includes conversion of a medical treatment linac into a powerful electron accelerator for research

and education. Conceptual work for the control system was completed. The accelerator is currently being moved from Marion General Hospital to Taylor. Dr. Voss (PI) successfully completed the NSF grant (ATM-9513241, \$80K, 1996 to 1998) with Stanford University on the Location and Size of Whistler-Electron Interaction Regions Using Correlated Energetic Electron and Whistler Data. A number of papers in national journals resulted from this research.

**2.2.4 Present State of Knowledge and Work in Progress Elsewhere:** Although weather balloons and high-altitude balloons have been around for many decades their use has been very limited due to recovery loss, very low data rates, and heavy payloads. Recent technology now allows dual GPS tracking systems on the balloon with both unlicensed spread spectrum ISM band (100kbit link) and Ham Radio APRS links. Small payloads are now possible with recent progress in miniaturization using Micro-Electrical-Mechanical Systems (MEMS), GPS receivers, wireless devices, Digital Signal Processors (DSPs), new advanced microchips, and upcoming nanotechnologies. The new technology now makes the HARP system and new payloads affordable as demonstrated by the many successful launches.

There are many small Balloon Sat programs in operation at universities, NASA space grant programs, amateur radio groups (Edge-of-Space), and NASA, NOAA, DOD, NSF and other government agencies but no easy way for new universities to get started and advance to a HARP capability (see attached Cedarville Endorsement Letter).

**2.2.5 HARP in Relation to Other Work in Progress by PI:** The Balloon Program at Taylor has also been instrumental in advancing our freshman and sophomore students in building professional hardware and understanding STEM for our satellite and rocket work that approaches graduate level. Entering students come up the learning curve quickly and are retained by mixing their book knowledge with the joy of creating their own real investigations (with mentoring).

## 2.3 Creating Learning Materials and Teaching Strategies

2.3.1 Documentation of the HARP System: The goal of this effort is to allow institutions to conduct a balloon launch solely from the documentation of the HARP system. This documentation will be created by Taylor University and StratoStar Systems LLC; a company created by Taylor graduates to distribute the technology and expertise Taylor has gained through, developing and testing HARP technology. StratoStar has taken Taylor University's HARP technology and created a turn-key complete flight package called StratoSAT. StratoSAT includes all the components needed to conduct balloon launches with HARP technology, including equipment, software, and warranties. StratoStar is located on Taylor's campus at the Center for Research & Innovation in a business incubator created to take Taylor's research discoveries to market.

Preflight procedures, launch procedures, safety instructions, experiment integration and interface, tracking procedures, trouble shooting, and recovery will all be documented. Once completed, the documentation will be available to the public at no charge. This will give other universities the opportunity to start using HARP technology in their classroom.

2.3.2 Documentation of a Suite of Experiments: One of the deliverables enabled by this proposed work is a finished set of documents for a suite of experiments successfully performed by Taylor University. This suite will include experiments, ranging from the simple (temperature sensors) to the whimsical (pressure inside of a can of Pringles as it flies to 100,000 feet and back), to the genuinely challenging (Geiger counters, E-field probes, aerial imaging with and without filtration). This documentation would be tiered in such a way that versions of selected experiments could be integrated directly into non-engineering classes (for example, physical science surveys on weather and elementary physics education classes) in ready-to-fly form, while other versions would be more technically oriented in kit form, and, in the final level of technicality, only the most critical components would be provided, along with documentation on how to modify the instrumentation.

This tiered approach would enable the rapid institutionalization of the unique advantages of high-altitude research at levels appropriate to the class. In introductory classes, the instructor could gain the excitement and freshness of a balloon launch with minimal technical work, while an advanced laboratory instructor could have his students work through the circuit design and construction, with the security that the obscure components have been tested and pre-proven. The end result is a rapidly deployed, highly flexible, personally adaptable educational experience through high-altitude technology.

Taylor has performed experiments in many different areas including:

- **Physical and Chemical Atmospheric Sensing**  
*In Situ:* pressure, temperature, humidity, winds, electric fields, O<sub>3</sub>, cosmic rays
- **Testing flight hardware systems**  
Nanosatellites: Internal Taylor University nanosatellite testing; link margin analysis, ground station functionality testing, deployable subsystem functionality, scanning mechanisms, imagers, gyros, sensors
- **Communication**  
Local area (payload) wireless networking and Wide Area (balloon to balloon) wireless networking.
- **Remote Sensing**  
Earth Science: spectral images (visible, IR), video cameras/filters, digital imaging, sprites and lightning,  
Space Science: VLF waves, airglow, aurora, e- x-ray precipitation,  
Astronomy: Solar UV and X rays, Gamma ray bursts, supernova
- **Energy**  
Solar concentrators and photovoltaic arrays, microwave-IR beam (conceptualized)

**2.3.3 Website Creation:** Access to up-to-date materials, documentation, and support is a key need for other institutions to implement HARP experiments into their curricula. Taylor and StratoStar plan to build a website to meet this need. This website will be a gathering spot for professors and students to obtain documentation on the suite of experiments, documentation on the HARP system, and support for everything related to ballooning from StratoStar, Taylor and the others involved in ballooning. We want to create an opportunity for the synergism of collaboration to take place through this site. The result would be optimal use of the HARP system for improved STEM education.

The website will have a section for students and professors to post their results from balloon experiments, whether in the form of papers, posters, or presentations. These results can then be viewed by people all over the world and will help other institutions gain ideas of how to implement HARP into their curricula. The vision for the website also includes developing the capability to share ideas and best practices.

Through the website we will also release updates and results from new research enabling institutions to use these innovations in the classroom immediately after discovery. This site will also allow for feedback from people who are implementing our discovery. This will enable us to refine our innovations to better improve STEM education.

StratoStar will be responsible for website maintenance and the long-term sustainability of the website. This includes tagging products and materials produced through this grant with descriptive metadata to ensure indexing and cataloging within the National Science Digital Library.

**2.4. Developing Faculty Expertise**

**Workshops for Faculty and Instructors at Other Institutions:** Four one-day workshops will be held to train faculty and instructors at other colleges and universities to implement experiments using the HARP process in their courses. At each workshop, the participants will be able to participate in a HARP balloon launch by examining the theory, designing the experiment, building and troubleshooting the experiment, preparing the balloon and equipment for launch, launching the balloon with experiments in the payloads, obtaining real time data, recovering the balloon and payloads, analyzing the data and drawing conclusions. By going through this full cycle, faculty will learn the complete HARP experimental process that is used in the classroom.

The HARP system is designed to interface an experiment with robust microelectronic data acquisition and communication capability that can transmit and store data in real time while the balloon is ascending, floating, and descending. As the balloon ascends into the Stratosphere, the scientist is given a unique environment or set of conditions to perform experiments. For example, the ambient conditions (temperature, pressure, UV intensity, chemical concentrations, atmospheric interference, etc.) vary considerably. In addition, there is the ability to communicate over large distances on the earth surface or gather data across a large area of the earth. Near space conditions give the ability to gather unique data on the sun and stars. With the President’s initiative to go back to the moon and to Mars, there is increased interest in learning how humans can live and operate for long periods of times in space. This gives opportunities for relevant biological experiments at near space conditions. By coupling creativity with the expertise from a variety of STEM fields a myriad of experiments could be conceptualized. Table 2 gives a few possibilities.

Table 2. Examples of Experiments for Various STEM Fields

STEM Field	Examples of Experiments
Engineering	Mechanical and electrical engineering for HARP. Sensor development.
Chemistry	Analysis of atmospheric chemicals. Chemical reactions in near space conditions.

Biology	Biological functions in near space. Agricultural and wildlife mapping of the earth.
Computer Science	Software programming for HARP system and HARP experiment data analysis.
Physics	Sensors for Space Science, Nuclear Cosmic Rays, NanoSat hardware testing, Mars flight simulation.
Math	Application for HARP operation and HARP experiments.
Astronomy	Cosmic Rays, Remote sensing of sun, stars.
Environmental Science	Ecology mapping of the earth, animal tracking/diagnostics, river data communication

For the workshops, the type and complexity of experiment may be selected based on the need for the faculty/instructor’s course that is being considered for HARP implementation. An experiment from the suite of experiments from Taylor University may be used or an original experiment may be designed for the particular learning outcomes desired. In this case, preparation in advance of the workshop may be needed. For more advanced courses, faculty may want students to conceptualize and execute their own experiments, giving them real-life, experiential learning similar to what they will encounter in their careers or graduate school. The HARP system provides the high-altitude balloon and capability for data acquisition and communication. This frees faculty to focus on developing the desired learning outcomes from the specific experiment to be executed.

Up to 12 different experiments can be performed at each workshop, allowing up to 12 institutions to participate. Therefore, it is expected that over 40 different institutions will be able to attend a workshop during the period of this proposed work. Therefore, these workshops for training faculty will be a major step in implementing at other colleges and universities the unique HARP process.

## 2.5. Implementing Educational Innovations

On-site Launches at Other Institutions: Even after the experience of the workshop, there may still be some obstacles to overcome in the institutionalization of HARP experiments at participating institutions. As a result, Taylor University, in cooperation with StratoStar Systems, LLC, will work with instructors to customize a first launch experience for each university. The performance of a launch in a curricular environment is a powerful persuasion to continue high-altitude research, both in and out of the classroom. Such has been the experience of DePauw University. Within a week of renting a high-altitude package from StratoStar, and receiving launch support from Taylor University, Howard Brooks placed an order for a complete system for the Physics and Astronomy Department at DePauw. Furthermore, as is indicated by his letter of support for this endeavor, he believes that high-altitude research will be an important addition to the curriculum in his department.



Fig 8: Nighttime launch of Astronomy Payload with dual Balloons

Taylor University will work with each participant to determine the specific requirements of their intended application of high-altitude technology in their program. The appropriate level of support will be provided accordingly, ranging from minimal flight support to a fully-staffed launch day. It is understood that the experiments involved would be compatible with the specifications of the data interface, and would be constructed as a part of assigned coursework by students at participating institutions. Enabled by StratoStar equipment, and with the strength of the experience of Taylor University’s HARP program, participating institutions will be able to experience the benefits of high-altitude coursework with a minimal risk level.

For institutions that are relatively self sufficient and/or where innovation and self-teaching are a priority on every level, minimal support would be needed. This support would include the data

and communication infrastructure, training and access to documentation. Students and faculty of the participating institution would handle every aspect of launch and recovery of the payload.

The next level of support would include the HARP program's Mobile Command Station, and an expert on hand to assist with the launch procedures. In addition, the Taylor/Stratostar team expert would run a backup recovery mission, assisting when needed, and remaining as inconspicuous as possible. This support level, modeled after DePauw's experience, would give the students involved in the flight a chance to do most of the work for a launch and successful recovery, with the security of knowing that Taylor and StratoStar staff are ensuring that everything goes smoothly.

Finally, the most intense level of support would include a fully staffed launch and recovery team, with the Mobile Command Station and the recovery team led by experienced HARP / StratoStar staff. Involved students would be walked through the launch procedure, and would ride along on the recovery mission, to gain experience. This level of support is intended for a setting in which the participating institution cannot or does not desire to handle the launch and recovery of the payload.

Each of these levels can be modified to meet the individual needs of each participating institution. Taylor staffing levels can be raised or lowered, along with the technology and materials available. Ultimately, Taylor University and StratoStar will be working closely with each university to ensure that the best possible first launch experience is achieved, and that the benefits of the institutionalization of high-altitude research are fully realized. Though some funding is budgeted, the participating institutions will need to contribute to enable this to happen.

## **2.6. Assessing Learning and Evaluating Innovations**

Assessment of Student Learning and Faculty Development: The implementation of the HARP system as a novel teaching strategy means that HARP's impact on student learning and faculty development needs to be assessed. The following describes the assessment plan for both of these areas which will take place at all participating institutions.

Theory Base: A cognitive apprenticeship (situated learning) model of instruction will be implemented in the STEM educational experience. This educational model assumes that learning and doing are inseparable to the learning process. The intellectual goal of this model is to develop an undergraduate student's cognitive skills and strategies through sustained participation within a community of learning (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989; Lave, 1988, 1990; Lave & Wagner, 1991; Prawat & Floden, 1994). In this model of learning, students are able to see how experts tackle problems, and learn to solve problems through a mentoring process (Collins, et. al., 1989).

Central Assessment Question: The assessment of the advanced High-Altitude Research Platform (HARP) program will endeavor to determine if the cognitive apprenticeship approach can effectively increase student and faculty's intrinsic motivation, knowledge at an application level, cognitive skills, and the valuing of STEM educational experiences and applications. The moderating variable of length of time using the HARP program will also be evaluated.

Few empirical investigations have been conducted to measure the impact of cognitive apprenticeship teaching (Hendricks, 2001). The typical investigations have been case studies (Palincsar & Brown, 1984; Young, 1993) or ethnographic descriptions (Lave, 1988; Lave & Wenger, 1991; Saxe, 1991; Scribner, 1984). Those investigations that have empirically assessed cognitive apprenticeship learning have not provided a molar educational experience where students are involved in a complete learning cycle (Fig. 3 - study theory, research, instrumentation, launch, operation, analyze data, and publication) using their own real time data (Hendricks, 2001). This investigation will seek to improve on these assessment flaws.

Assessment Design: The assessment of HARP will be a three year longitudinal study assessing participating faculty and students' intrinsic motivation, application knowledge, cognitive skills, value of science, and intellectual and material products. Faculty will be evaluated before an educational workshop, after the workshop, and at the end of the analysis of data in the Learning Cycle (Fig. 3 - study theory, research, instrumentation, launch, operation, analyze data, and publication) and then after each semester that the HARP program is implemented. Students will be assessed before the first phase of the Learning Cycle, the study of theory, then after the analysis of data stage of the Learning Cycle and after each semester that a student participates in the HARP program. Product assessments occur after each semester that a University is involved in the HARP program.

Assessment Variables:

***Intrinsic Motivation:*** Student and faculty's intrinsic motivation will be measured using Lepper's (1988, 2000) modified model for intrinsic motivation. The model includes contextualization, curiosity, challenge, control, and cooperation. Contextualization or application means to overtly or covertly personalize knowledge to current or future life situations in order to change and grow. Curiosity is generated when new information creates inconsistencies or discrepancies in people's prior knowledge or their present expectations. Curiosity generates a feeling of wanting to investigate, become involved, or expand oneself to incorporate new information and have new experiences with the person or object that created the interest (Fredrickson, 1998). Challenge means calling a person to a demanding task that requires special effort and dedication in a supportive group. Control is the perception that one is an origin of the activities she attempts rather than a pawn. The student will believe she has self determined the activity undertaken or the product created. Cooperation means to pursue win-win situations where you and the other individual grow, accomplish tasks, and enjoy the process together. In this learning structure, knowledge is gained by support, participation and nurturing with others (Johnson, Johnson, & Smith, 1991; Johnson, 1976). These areas of motivation will be assessed because of their strong connection to achievement, spending time on complex activities, learning and growth goals, the use of deeper and more reflective strategies for learning, more risk taking and the focus on the learning process (Lepper & Henderlong, 2000).

***Application Knowledge:*** Application knowledge is procedural content that allows one to be able to access information successfully during a cognitive operation. Faculty and student's knowledge of how to apply problem solving, the process of prototyping, the processes of evaluating and calibrating, the scientific method, the performance of precise documentation, and the metacognitive knowledge and processes will be evaluated.

***Cognitive Skills:*** A cognitive skill is a mental operation that requires the integration of knowledge into a system of procedural steps to perform a complex activity at the appropriate time. The increased ability to use the cognitive skills of problem solving (trouble shooting), prototyping, evaluation and calibration, the scientific method, documenting for repeatability, and skillful data analysis will be assessed.

***Metacognitive Processes:*** The metacognitive processes of control (planning and assessing) and monitoring of one's cognitive processes will be assessed to see if they increase through the student's participation in the HARP program (Beyer, 1987). Planning metacognitive planning involves stating a goal, selecting an operation, identifying potential obstacles or errors, identifying ways to recover from the obstacles, and predicting results desired and or anticipated. Metacognitive assessing involves evaluating goal achievement, judging accuracy and adequacy of the results, evaluating appropriateness of procedures used, assessing how well one handled the appropriateness of procedures used, assessing handling of obstacles, and judging the efficiency of the plan and its execution. Monitoring involves keeping the

goal in mind, keeping one's place in a sequence, knowing when a sub goal has been achieved, deciding when to go on to the next operation, spotting errors or obstacles, and knowing how to recover from errors or obstacles. Metacognition has been selected to be assessed because of its key role in transferring knowledge and skills (Belmont, 1982; Brown, & Bransford, 1983), effective problem solving (Carlson, 1997; Glaser, Chi, 1988), thinking and learning (Nelson, 1996; Swanson, 1990; Cohen, Freeman, & Wolf, 1996), and memory (Jarman et al., 1985; Moses, & Barrd, 1999).

**Valuing Science:** It is a goal of the HARP program for students to learn to value science education, discovery and future careers in science. This goal will be assessed specifically by measuring the increase in students valuing the problem solving process, the calibration process, the scientific method in application to real life problems, the documentation for repeatability as well as analyzing data, metacognitive planning, monitoring and assessing, cooperating for scientific advancement, and managing time to meet deadlines.

**Modes of Measurement:** The HARP program will be assessed through self reporting survey data of faculty and students, faculty observations of students, the quality of project outputs, and interview data of students and faculty.

**Self reporting surveys** measuring increases in student and faculty intrinsic motivation, application knowledge, cognitive skills, and their value of science will be evaluated from the beginning to the end of a university's participation in the HARP program each semester.

The **quality of the products** developed through the HARP program will be assessed by a standard rubric completed by faculty at the end of the data analysis segment of the Learning Cycle.

Faculty and students who were involved in the HARP program at different levels will be **interviewed**. These interviews will be conducted at the end of the data analysis in the Learning Cycle. A team of four interviewers will visit each participating institution and conduct interviews with each participating student and faculty member. Standard open ended questions will be developed and utilized to assess intrinsic motivation, application knowledge, and cognitive skills, metacognitive process abilities and values toward science education.

A final assessment of the **quantity of academic and scientific products** of the three year HARP program that is being funded will be reported. These products will include the number of balloon launches, the percentage of balloon recoveries, the number of universities participating, the number of students participating in the program, the amount of interdisciplinary team work, the number of professional presentations, the number of submissions for publication, the number of unique hardware systems created, the amount of web site sharing, and the retention of students within these programs..

**Data Analysis:** A **MANOVA** will be conducted to measure the within and between differences of students throughout the HARP program. Differences within students will be investigated in their educationally perceived gains before, and after the first semester and then after any other semester a student participates in the program. Differences between participating universities will be measured based on the length the HARP program has existed and the unique qualities of each university's program.

A **dependent t test analysis** will be conducted on the development of the participating faculty by comparing pre and post data of the professors.

A **step wise regression model** will be developed from the data of this program to show what specific variables of the program have the most impact on the educational and product quality of the HARP program.

A **content analysis** will be conducted based on interview data from each of the participating universities. This will provide a thick description of both faculty and students to help explain why the program elements were perceived to be needed and to stimulate further research questions.

**Ethics in Human Subject Data Collection:** The procedures for collecting data from subjects participating in this proposed work are currently being submitted to the IRB at Taylor University. We have applied for exempt status under the DHHS (Title 45 Code of Federal Regulations part 46.101 (b)) guidelines. This stipulates that research involving the use of educational tests, survey procedures, interview procedures or observations of public behavior are exempt if the subjects information is recorded in a manner that does not link them directly to this data. We will use recording methods that will do this. To secure the confidentiality of subjects further, we will have them sign a consent form that stipulates that we will not directly connect their data to their name, the general purpose of the assessment and contact information of the principal researcher. This ensures compliance with the NSF’s requirements for Proposals Involving Human and Animal Subjects outlined in the Grant Proposal Guide.

**2.7 Management Plan** Table 3. shows the key activities during the three years of the project.  
**Table 3. Management Plan – Key Activities**

	<b>Key Activities</b>
<b>Year 1</b> 8/1/07-7/31/08	Complete documentation of HARP System and Suite of Experiments Complete Baseline Website Complete Learning Assessment Tools 1 <sup>st</sup> Workshop
<b>Year 2</b> 8/1/08-7/31/09	2 <sup>nd</sup> and 3 <sup>rd</sup> Workshops On-site launches at other institutions Update and maintain Website Gather learning assessment data from launches at other institutions
<b>Year 3</b> 8/1/09-7/31/10	4 <sup>th</sup> Workshop On-site launches at other institutions, maintain website Gather learning assessment data from launches at other institutions Complete analysis of learning assessment data Final report

A timeline of the activities for this proposed work is shown in Figure 9 below.

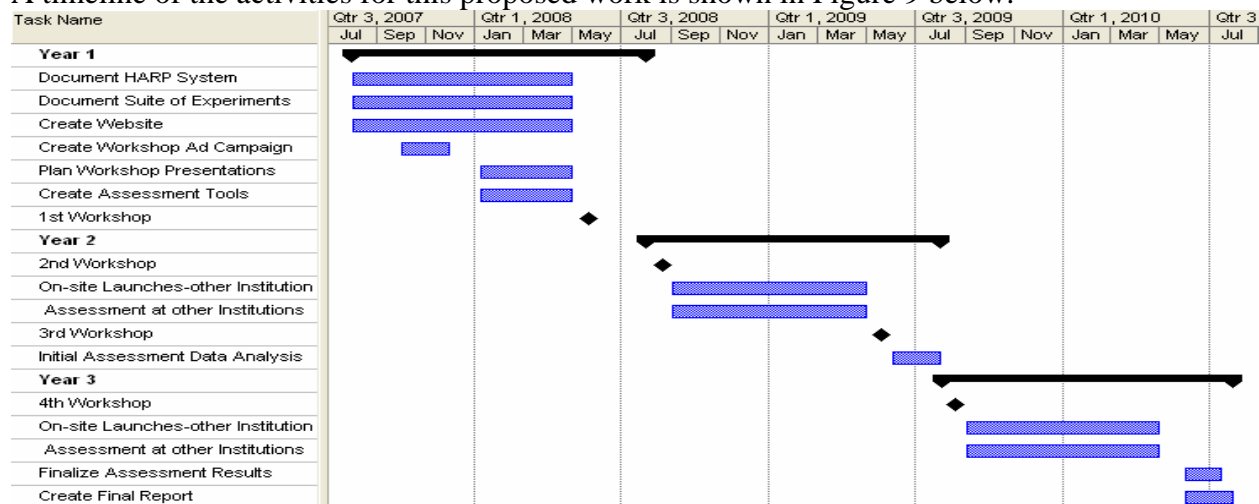


Figure 9: Timeline of Proposed Work

A summary of personnel responsibilities and qualifications is shown in Table 4.

Table 4. Summary of Personnel Responsibilities and Qualifications

Name	Responsibility	Qualifications
Dr. Hank Voss	PI. Direct and supervise all scientific aspects of the project.	PhD in Electrical Engineering. Professor of Physics at Taylor. PI on a number of multimillion dollar satellite and rocket instrument developments. Conceived, developed and implemented HARP at Taylor.
Dr. Don Takehara	Co-PI. Direct and supervise all administrative and management aspects of the project. Assist PI in directing and supervising scientific aspects.	PhD in Chemical Engineering. Director of Center for Research & Innovation and Assoc. Professor of Research at Taylor. Industrial R&D for 17 yrs at Dow Corning Corp. Reaction engineering and catalysis expertise.
Dr. Steve Snyder	Faculty Associate. Direct and supervise the study on assessing student learning and faculty development.	PhD in Psychology. Professor of Psychology at Taylor. Current research on assessment of critical thinking curriculum in a high school as well as other assessment studies at Taylor.
Mr. David Patterson	Research Engineer in Training. Documentation of suite of experiments, execute workshops, assist with on-site launches at other institutions, website development, documentation of HARP system.	Full-time Research Engineer in Training for the Center for Research & Innovation at Taylor. Currently leading student team responsible for planning and executing HARP launches. Pursuing B.S. in Engineering Physics at Taylor.
Undergrad Science Students	Assist with documentation, website development, workshops and on-site launches at other institutions.	Students pursuing various Physics, Engineering, Computer Science BS degrees.
Undergrad Social Science Students	Student researchers. Assist with developing assessment tools, gathering & analyzing assessment data, drawing conclusions from assessment data, writing final report.	A team of six students pursuing Psychology bachelors degrees. This team will have had at least eleven hours of course work in human subject research methodology, statistical analysis, interviewing, and consulting experience.
Stratostar Personnel	Commercial provider of balloon equipment. Documentation of HARP system, website development & maintenance, assist at workshops and on-site launches at other institutions. Assist institutions in implementing HARP into curricula.	Business and engineering skills related to HARP system. Experience with many HARP launches.

**Facilities Summary** The Center for Research & Innovation (CR&I) houses over 1500 ft<sup>2</sup> of lab and project space dedicated to the design, physical construction, testing, and implementation of different systems, and is very well suited to handle the demands of high-altitude projects. The machine shop includes a Bridgeport milling machine, a Dyna Myte 2000 benchtop CNC mill, two lathes, and several other machining implements. The electronics lab features standardized software, tools, equipment, and supplies at each of the six anti-ESD stations, and is appropriate for most payload construction efforts, while the Technological Innovation Lab is a more customized environment, with high-end tools and equipment available to projects as needed. In addition, a full suite of engineering software is available in the CR&I, including software designed for 3D CAD (NX4, Inventor), electronics prototyping (Multisim, Ultiboard, Ultiroute), fluid dynamics (AMESim), data acquisition (LabVIEW) and data analysis (MatLab) tools. The Nussbaum science building houses a clean room environment, including a class 10,000 air-flow workbench, as well as thermal / vacuum environmental testing equipment for payload validation. The combination of the three areas results in the capability for end-to-end project handling, with students and researchers equipped with everything needed to perform the desired experiments

**2.8 Important Project Features** The following Important Project Features directly addresses the NSF CCLI solicitation.

2.8.1 Quality, Relevance and Impact: The falling behind of the U.S. in the area of science and technology compared to other countries is a legitimate concern. Motivating undergraduates to enter STEM degree programs is one way to help turn the tide. The HARP system does this by teaching the scientific method via applying experiments in the exciting high altitude/near space field and by using state of the art technology. In addition, training students to apply theory to real-life problems in a practical way makes them better prepared for graduate school or employment in industry by teaching them to solve problems and overcome obstacles. By performing original (never been done before) experiments in real world settings, HARP experiments meet this need. Theory “comes to life” for these students.

2.8.2 Student Focus: The mind of today’s student needs to be captured in order to engage him/her in the learning process. The idea of doing experiments in a place that the typical person has never been is able to capture this mind. The high altitude and near space area fits this bill. In addition, the millennial student is well versed in multitasking with technology. Therefore, the use of high tech via microelectronics for GPS, wireless, videos, miniature sensors, etc. fits in well with the student’s world.

2.8.3 Use of and Contribution to Knowledge about STEM Education: The importance of experiential learning in STEM education is well known as evidenced by the success of cooperative education programs, internships and senior capstone courses. The HARP system encourages the use of hands-on, real life learning in the classroom.

2.8.4 STEM Education Community-Building: It is expected that the formation of an informal community of STEM educators who use the HARP system in the classroom will occur. The workshops will be a natural time for networking to occur. This will build on the networking that Taylor has already started with DePauw, Cedarville, Valparaiso, Stanford, University of Illinois, etc. In addition, the website will be a place to share data, results, ideas, best practices, etc.

Within Taylor University, a collaboration between Physics and Psychology is taking place through this proposal by coupling the HARP system expertise in the Physics department with the assessment expertise in the Psychology department through Dr. Steve Snyder.

2.8.5 Objectives, Approach and Expected Measurable Outcomes: Table 5 shows the objectives for the proposal, including the associated approaches and expected measurable outcomes.

Table 5. Objectives, Approach and Measurable Outcomes of the Proposal

Objectives	Approach	Expected Measurable Outcomes
20+ universities (predominantly in the Midwest U.S.) who have implemented HARP in their STEM curriculum.	<ol style="list-style-type: none"> <li>Four workshops for faculty and instructors at other institutions.</li> <li>Taylor assistance for 1<sup>st</sup> on-site HARP launch on workshop participants’ campus</li> </ol>	<ol style="list-style-type: none"> <li>40 institutions attending workshops</li> <li>24 institutions completing their 1<sup>st</sup> on-site launch on their campus</li> <li>12 institutions completing 2<sup>nd</sup> on-site launch</li> <li>4 institutions completing 3<sup>rd</sup> on-site launch</li> <li>2 institutions completing 4<sup>th</sup> on-site launch</li> <li>20+ institutions reporting plans to make HARP experiments a regular part of one STEM course</li> </ol>

Obtain data showing the impact of HARP and the learning cycle on undergraduate STEM learning.	Design and execute assessment study which includes all institutions which have completed at least one on-site launch.	Completed report including data and conclusions from assessment study.
Make documentation of HARP system and experiments available publicly for any institution.	<ol style="list-style-type: none"> <li>1. Document HARP system</li> <li>2. Document suite of experiments</li> <li>3. Website development</li> </ol>	Website available with documentation of HARP system and suite of experiments on it.
Formation of informal network of faculty and instructors who use HARP system in their curriculum.	<ol style="list-style-type: none"> <li>1. Networking at workshops</li> <li>2. Website for sharing data, results, ideas and best practices</li> </ol>	<ol style="list-style-type: none"> <li>1. 40 institutions attending workshops.</li> <li>2. 20+ institutions sharing information on the website</li> </ol>

### 2.8.6 Project Evaluation Plan:

The Formative Evaluation Plan is as follows:

1. Monitor number of workshop attendees. The expectation is that there will be on average 10 institutions attending per workshop.
2. Monitor number of 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> on-site launches on institution's campus.
3. Website should be available before 1<sup>st</sup> workshop with documentation of HARP system, and suite of experiments.
4. Monitor number of institutions sharing information on the website.

Summative Evaluation Plan is as follows:

1. Number of total workshop attendees
2. Number of 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> on-site launches on institution's campus
3. Number of institutions reporting plans to make HARP experiments a regular part of one STEM course.
4. Completed report including data and conclusions from assessment study.
5. Website available with documentation of HARP system and suite of experiments
6. Number of institutions sharing information on the website

**2.9 Future Work** Future work includes the following efforts to continue to institutionalize the HARP system in undergraduate STEM curricula at colleges and universities.

1. Continue workshops and assistance with 1<sup>st</sup> on-site launches at institutions' campuses. This would include extension of the workshops and assessment tools (student learning and faculty development) so that other institutions besides Taylor can perform these.
2. Continued encouragement of network of institutions by keeping the website updated and initiating a periodic conference for users of the HARP system.
3. Assessment results from this proposal may be used to generate specific instructional research questions to develop an empirically based model of instruction on how to effectively teach undergraduates STEM concepts within a cognitive apprenticeship framework. We would like to explore what teaching pedagogy facilitates intrinsic motivation like contextualization, curiosity, challenge, control, and cooperation. We are interested in how to effectively integrate metacognitive knowledge and processing within the instruction of the HARP program because of the key role it plays in the transference of cognitive skills to future academic and professional settings. The assessment of this program through multiple measurement methodologies will provide the foundation we need to generate questions and develop measurement tools to begin to answer these motivational and metacognitive research questions.

## 1.0 Project Summary

For this NSF CCLI Phase 2 proposal we seek to promote and disseminate high-quality STEM education using in part a novel and proven High-Altitude Research Platform (HARP) to develop faculty expertise, to implement educational innovations, and to assess learning.

**Broader Impact:** The learning cycle (theory, research, instrumentation, operations, data analysis, and presentation) is a significant pedagogical building block that stimulates and retains students (especially female and disability) and prepares them well for thesis work and professional careers. Students obtain a personal ownership of their education when they engage in state-of-the-art balloon launch capability into the "unknown" with real-time data (100 Kb) and command interaction. The scientific method comes alive with creativity, problem solving, fun, and multidisciplinary hands-on team work in a relatively unexplored region of our atmosphere. The potential for significant novel discovery is opened up even at the undergraduate level. The nation will gain more students in basic science (and liberal arts) with an awareness of the environment, atmosphere, space, and heavens by direct probing and remote sensing from "New Heights" (over 98% of atmosphere at 33 km altitude).

We propose dissemination over three years by means of four faculty staff workshops, compiling teaching materials, developing and maintaining a website network, assisting university HARP start-ups, and publishing initial assessments. The physics department at Taylor has grown about 20% (now ~60 students with high ETS/GRE scores) in the past 4 years, in part, with this type of challenging, real, and hands-on research with recent graduates in the top tier at U of Illinois, MIT, and other STEM graduate programs. We expect at least 20 universities will implement a HARP program into their curricula. Workshops will be established that include DePauw University, University of Illinois, Cedarville University, Purdue, Stanford, Valparaiso, U. of Wisconsin, and others (see endorsement letters).

The workshop consortium will help inspire a new generation of undergraduate students through exciting hands-on projects, retaining and preparing students for graduate school and advanced careers. Documentation, web site database network, assessment, and publication of HARP know-how will help to improve and multiply STEM education to other universities and institutions. Correct training in FAA safety procedures and FCC wireless links will be taught under supervised conditions. The HARP learning assessment results may be used to generate specific instructional research questions to develop an empirically based model of instruction on how to effectively teach undergraduates STEM concepts within a cognitive apprenticeship (situated learning) framework.

**Intellectual Merit:** The proposed New Heights program has the potential for advancing knowledge and understanding across disciplines by giving students and faculty rapid and low-cost access to earth/ecology remote sensing from high altitude, *insitu* and limb atmospheric measurements, near-space stratosphere measurements, and IR/UV/cosmic ray access to the heavens. This new capability is possible by exposing students to recent advances in MEMS technology, nanotechnology, wireless/telecommunication systems, GPS, DSPs and other microchip miniaturizations to build < 4 kg payloads. This brings the power of technology to synergistically enhance all STEM fields. With now forty successful launches (100% recovery) the HARP system has been refined, resources are in place, and robust for commercialization (Voss et. al., 2006). The proposed program is based on recommendations of recent STEM education database studies and building a community of learning through collective action. The proposed program provides an engaging laboratory, gives challenging field experiences, reaches students from diverse backgrounds, collaborates with science faculty, and assesses the learning outcomes with feedback. The proposed program is at a high Technical Readiness Level (TRL). The PI, CoPI, and proposed team are highly qualified, experienced, and have the manpower to carry out the New Heights Phase 2 program through dissemination, through workshops, to safely complete and operate this new development project, and document, assess, and publish the initial results.