A New Strategy for Stem Education and Innovative Engineering Problem Solving

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Introduction

There are hundreds of programs currently funded by NASA, DOD, Industry, NSF, etc. to encourage STEM education, interest in STEM subjects and the pursuit of STEM-related careers. The current proposal is both similar in some respects to several of the ongoing and proposed future programs but different in seemingly subtle, yet key aspects. The methodology and strategy of the current proposed program is a result of over 37 years solving complex engineering problems at NASA and four years of experience teaching and field testing at the young practicing engineer, graduate student, undergraduate student and high-school student levels. The current proposal involves a methodology, called Innovative Conceptual Engineering Design (ICED), which is centered on the solution of “real” and very critical multidisciplinary problems which are science-, engineering-, and/or technology-based and related to a critical need or mission. The program draws upon a very diverse group of students to explore an open-ended design space and exercise the analytical/logical/structured side of their brain (the left hemisphere) and associated skills as well as the artistic/creative/innovative right hemisphere to conceive and develop innovative solutions. The primary purpose is to: attract and inspire students to the joy of solving “real” and very interesting engineering problems; maintain that interest and passion with age-appropriate lessons in each of the necessary STEM subject areas; and link the mastered STEM skills by applying them in solving real and relevant problems of interest.

The methodology relies on problem-based learning and uses a very collaborative environment which emphasizes teamwork, team learning, rapid prototyping, collaboration, cooperation, and communication. It also relies on a virtual platform to link students to mentors, technical experts, and resources from around the world (Academia, Industry, and government) to effectively provide mentorship at age-appropriate educational levels and to accelerate problem solution and concept maturation. The value propositions of such a program for all participants will be shown to facilitate self sustaining communities which can effectively solve several issues currently facing the nation and the economy: 1) inspiring the next generation of scientists, engineers and mathematicians by creating the spark that ignites a passion for problem solving which is infused with the joy of the creative process/experience; 2) creating an “open” community which integrates the learning process, creates and shares tools for education and provides tools for continuous mentorship from middle school to graduate school; 3) links
universities to real problems to conceive novel ideas which can then serve as a basis for future research and funding; 4) creates a collaborative network to link departments within a university as well as with other universities, the government and industry to accelerate the innovative process and help identify rewarding areas for technology application; 5) enables industry and the government access to a very large reservoir of very creative and innovative ideas; and 6) allows academia, industry, and the government direct access to a community of the best and brightest students for future internships, grants, and career opportunities.

The current proposal will discuss the methodology used for instruction, critical thinking and creative problem solving; lessons learned from previous course offerings; the virtual platform and environment for communication, collaboration, innovation and evaluation; the metrics used to measure performance; and the business plan and associated program phases which will ensure the evolution of a national outreach program which, it is hoped, can be completely self-sustainable in three years.

**ICED Methodology**

The Innovative Conceptual Engineering Design Methodology (ICED) is one of several design methodologies which addresses the engineering design process (refs. 1 and 2). This particular methodology for design focuses on the very early “conceptual design” stage of the process where rules regarding the level of rigor involved in the analysis, design, and test phases of the development cycle are relaxed to some degree in order to rapidly conceive, prototype, and evaluate as many ideas using an intelligent strategy to obviate potential failure mechanisms early in the design process. The methodology proposed in the current program was developed over many years while working on multiple NASA programs involving the research, design, analysis, and testing of very complex vehicles/systems for hypersonic flight. Most recently, the idea for teaching and utilizing this methodology for critical thinking, problem solving, project-based learning and STEM outreach was inspired by work to identify the cause of the Space Shuttle Columbia accident and to develop technologies to predict critical damage and to repair the vehicle in the event of a subsequent debris strike and resulting damage to the vehicle (refs. 1 and 2). Ideas which were actually developed and matured using this methodology were shown to be feasible and actually flown on the Return-to-Flight Space Shuttle mission following the Columbia tragedy (ref. 1).

The framework for the methodology is illustrated in Figure 1 and centers around a “Grand” or “Epic” challenge or problem which has very special qualities which spark the imagination, create the passion and maintain the interest of a diverse community which are dedicated toward the development of creative solutions. An example of a fairly recent “Epic” challenge,
the repair of a Shuttle wing leading edge by spacewalking astronauts on orbit is shown in figure 2. As mentioned above, this problem inspired the current program and is discussed in more detail in references 1 and 2.

Some of the attributes which constitute an “Epic” challenge are: 1) it is very complex – preferably without an existing or known solution, 2) it is multi-disciplinary and involves the expertise of multiple disciplines for solution, 3) it is time critical or has some sense of urgency which helps impart a healthy tension, 4) it is of grave importance to the interests of the Agency, company, nation or world, 5) has a real or perceived competitive adversary (ref. 3), 6) it is of a “design” nature (open ended and, thus stimulating to the imaginative/creative side of the brain), and 7) the solution of such a problem would have far reaching benefits for the quality of life on earth, the exploration and better understanding of the unknown, etc.

Figure 1. - Schematic diagram of a framework for the Innovative Conceptual Engineering Design (ICED) process.
A Recent “Epic Challenge”

How to repair a damaged wing leading edge on orbit?

Small Unofficial RCC Repair Team Results

Figure 2. - Example of a fairly recent “Epic” challenge proposed by the Shuttle Program following the Columbia Tragedy on February 1, 2003.

The next phase is the total immersion of all students and team members into the problem. It is imperative that there is a clear, overarching mission or goal with direct and clear links to the problem statement so the students can visualize the end goal/product from the “one-hundred-thousand-foot level” and recognize the importance of all the critical disciplines involved in the solution as well as the “systems” nature of the problem and its interdependencies and coupled nature. The Grand or Epic Challenge is at the “Mission-Level” and provides the technological “pull” which drives the solution process and the necessary technology development and maturation.

Total immersion involves the rigorous background searches of past, related and/or analogous problems and their solutions, lectures by key experts to explain the current state of the art, videos, links, test results, data, lessons learned, etc. This immersion phase will help to capture lessons learned and prior knowledge and will be stored and shared on a virtual platform for peer review and to be referenced by a virtual community of students, experts, facilitators and interested participants. This phase is not intended to constrain the design space or initial concepts, but rather to serve as an initial starting point or frame of reference. The student teams will be selected to ensure a diversity of thought, capability/skill, experience, culture,
outside interests, etc. to maximize the creativity and innovation the team’s contributions to the solution process. A survey was developed (fig. 3) and used to evaluate participant’s learning and thinking styles (refs. 4-6); creative ability and roles most preferred in the creative process; academic and acquired skills; hobbies; leadership and teamwork ability; as well as individual passions. Virtual communities will be established which will link age-/skill-appropriate student teams to mentors, experts, and resources (e.g., learning modules; hardware; modeling, analysis, simulation and design software; test facilities; etc.) to facilitate team development and leadership and to allocate roles and responsibilities. Learning modules will be developed which will allow self instruction and mastery of essential skills similar to the Khan Academy (ref. 7), enhanced simulation and modeling tools similar to reference 8 (e.g., to teach aerodynamics to middle school through graduate school), and eventually customization of the learning modules based on individual thinking and learning styles of the student (ref. 9). These communities will have clearly defined rules which will govern: engagement, information sharing, security, privacy, permission, and intellectual property rights (ref. 10). The foundation for the program resides with a system of university Hubs from which the academic instruction, leadership and mentorship will emanate. The organization and structure of the network of University Hubs, local High School Hubs, and high-school/middle-school satellite programs as well as the associated roles and responsibilities will be explained in more detail in a later section.

Techniques for lateral thinking, creativity enhancement and concept ideation will be taught and utilized by the communities and include but not be limited to methods such as brainstorming, SCAMPER, Fishbone Diagrams, 6-3-5 Method, Biologically Inspired Design (BID), and TRIZ (refs. 11-15). The program will focus on the generation of unique ideas at the conceptual design stage and the rapid analysis, design, prototyping, fabrication, testing, exploration and discovery.
Designing surveys to ensure optimum team success

Figure 3. – Typical survey used to help quantify student skills, interest, learning and creativity styles and select team members.

Although the program will focus on the early stage innovation phase, the rapid development strategy for technology verification, validation, and maturation will be firmly based on rigorous engineering procedures whereby analysis is correlated to experiment in a building-block fashion which grows in form, function and complexity with time and problem understanding. The projected speed and diversity of this process will enable the rapid evaluation of numerous creativity-rich ideas and potential solutions simultaneously and thus enable more intelligent design decisions earlier in the programmatic cycle, when it will have the largest impact on positive outcome.

The program is designed to inspire students to pursue science, engineering and/or math majors by tapping into the innate human tendency to solve challenging and relevant problems. It will hopefully maintain student continuous interest and help prevent them from opting out of reality and a world replete with real “Epic” challenges and into a virtual world of “games” (ref. 16). This is accomplished by proposing a real “Epic” challenge and then clearly mapping out and teaching the necessary skills to conceive innovative concepts; pose solutions; and analyze, design, test, discover and mature those ideas. The complex problem will first be deconstructed into its many elemental sub-systems and STEM disciplines and will include all the necessary interactions and requirements using a visual schematic representation (Concept
Maps (Cmaps), Object Process Methodology (OPM), Object Process Analysis (OPA), etc. (refs. 17 and 18))

The conceptual design process exposes the more junior students to the fun of scientific inquiry and the art and joy of the creative expression of their own ideas. Ideas are generated which can be explored and developed through maturation and culminating in capstone design projects in their junior and senior years. The communities necessary for research and mentorship will be formed at the SME/graduate-student level and will serve to support the students, Teacher-Coaches, and advisors throughout the program.

Students today are digital natives and very adept at using open communities to self learn and gain knowledge and insight. We will provide an online platform to help motivate the students to continue to learn and master necessary skills in STEM by providing intrinsic rewards for recognized accomplishments, online internships within the government and industry, research opportunities, etc. In certain cases, “Endgame” rewards will be awarded based on pre-determined algorithms which recognize behaviors that are determine important (e.g., elements of teamwork/collaboration, creativity, the number of newly acquired/mastered skills (rewarding diversity and breadth as well as depth) and not necessarily the final grade achieved!

It is precisely the intrinsic rewards that are most important for motivation as stated by Prof. Teresa Amabile (ref. 19): “In fact, in our creativity research, my students, colleagues, and I have found so much evidence in favor of intrinsic motivation that we have articulated what we call the Intrinsic Motivation Principle of Creativity: people will be most creative when they feel motivated primarily by interest, satisfaction, and challenge of the work itself – and not by external pressures.” And as expressed by noted author on creativity, Mihaly Csikszentmihalyi (ref. 20), it is this joy in exercising the “creative” side of our brains that is most rewarding: “Creativity is a central source of meaning in our lives ... most of the things that are interesting, important, and human are the results of creativity... [and] when we are involved in it, we feel that we are living more fully than during the rest of life.”
Experiences, Results, and Lessons Learned

Experience with the current methodology as a mechanism for instruction and STEM education and outreach has been gained over the past four years (2008 – 2011) and has involved student experience and grade levels ranging from young practicing NASA engineers (with approximately 5-10 years experience from 7 NASA Centers); tenured and associate-professor faculty at NYU-Poly; graduate students (MIT and NYU-Poly); undergraduate students (NYU-Poly, Penn State, MIT, Ga. Tech, and Carnegie Mellon); and high-school students (over 40 schools in NY/NJ area) and is summarized in figure 4 below. We have also gained experience with rollout of our Mars Spacesuit Design program at the Solomon Schechter Middle School in New Jersey.

Connecting students with "real” problems

Problems Worked by Students

- 30 young NASA Engineers
- 7 different NASA Centers
- 5 day course at Penn State
- 15+ students from Penn State and MIT

Digging and Drilling on the Surface of the Moon (2009)
- 1 Graduate
- 20 Undergraduates
- 10 High School students
- 2 High Schools, 2 Universities

Design of a Space Suit for Mars (2010)
- 44 students
- 31 High Schools in NY/NJ

Figure 3. - Example of Innovative Conceptual Engineering Design (ICED) student projects.

A brief summary of the experiences, results, lessons learned, and value propositions/metrics from the four case histories are listed below, detailed summaries can be found in the Appendix A. The metrics or value propositions which were used to measure the effectiveness of the program were categorized according to:

1. Creativity or Innovation – based on the quantity, quality, novelty, and uniqueness of ideas. A rich set of diverse ideas or combination/recombination of new or prior ideas obtained from either the same domain or analogous solutions from other domains.
2. Pipeline – Effectiveness in creating a pipeline of continuous mentorship from middle school to graduate school students and subject matter experts.
3. **Sustainability** – Steadily reduce the reliance on grants and government funding while simultaneously increasing reliance on commercial sponsorship and student/parent fee-based membership.

4. **Continuity** – Measure the participation of individuals with time, number of challenges, return membership, etc.

5. **Scalability** – Ability of the program to easily replicate and grow/expand in diverse markets and regions (urban, rural, etc.).

### Summary of Lessons Learned

1. Students highly motivated to solve real problems that are relevant.
2. Students enjoy working collaboratively on teams.
3. Unique, creative ideas were conceived and shown to be feasible solutions to critical problems rapidly and for minimal cost.
4. Senior students were natural mentors for more junior students.
5. Existing resources can be shared to minimize costs (“Stone Soup”).
6. Design challenges can easily transition to formal as well as informal educational experiences in multiple areas of engineering, science and math.
7. A combination of online/virtual learning modules and in-classroom instruction can help reduce program costs and enable the program to successfully scale.
Organizational Framework of Proposed Program

The ICED Problem Solving and Educational Outreach Program relies on a complex, multidisciplinary problem or “Epic” challenge which has the vested interest of the program “Underwriters” or sponsors. NASA and the Air Force Research Labs (AFRL) have partnered in Phase I of our proposal and mutually agreed upon challenges to kickoff Phase I in the summer of 2011 (see Fig. 4). A “Cohort Group” of 5-7 points of contact (POCs), one for each of the university “Hubs”, was selected to help guide the selection of the “Grand Challenges” with NASA and Air Force subject matter experts (SMEs) and form the top-level mentorship platform from which the flow of curricula, age-appropriate learning modules, mentors, etc. would emanate. The Executive Advisory Board consists of key educators (from middle, high-school, and university levels), technical experts, virtual platform builders/engineers, and administrators and assists in the development and oversight of the program.

Figure 4. - Organizational structure of ICED Problem Solving and Education Outreach Program.

The “Grand or “Epic” Challenges” flow to the university Hubs and a network of graduate student leaders from each university will be formed which will create the basis for a network which will address each individual Grand Challenge (GC). Each GC will form a separate network or virtual community. These individual problem-based networks or communities will grow and shrink in size according to the needs of the particular challenge using a “flexible critical mass” approach as described in reference 26. The virtual platform will be a very important part for both the formal and informal educational programs; for linking students and enabling effective communication and collaboration; and for providing an environment which encourages innovation, rapid learning and critical thinking. For example, just as problem 1 (see Appendix A)
(Contingency Land Landing of the Orion Capsule) led to several formal “Capstone Design” projects for several Penn State Teams and the for-credit interdisciplinary design course of problem 2 (Digging and Drilling on the Surface of the Moon) as well as the informal summer program of problem 3 (Design of a Space Suit for Mars) and problem 4 (Design of an autonomous system to Explore Lava Tubes on Mars). It is easy to see how the undergraduate student design teams could easily serve as technical assistants (TAs) and mentors for the high-school teams both virtually and locally (centered at each university Hub). Phase I attempted to enlist 5 local High-School Hubs for each University Hub with a high-school teacher coach chosen to be the local mentor at each high school. Programs to train undergraduate, high school, and middle school mentors and teacher coaches will be in place to ensure the overall engineering principles, and ICED methodology are reinforced and practiced at each educational level. Learning modules will be developed at each level of instruction and shared uniformly by the respective virtual communities and will also be open to all educators and students. A unified method for peer review of all learning modules will be in place and adhered to as a way to help monitor and evaluate all modules developed.

**ICED Problem Solving and Educational Outreach Program**

**Summer and School-Year Programs**

The process of engagement for the proposed program emanates from the challenge sponsors/underwriters to the local university and high school hubs as follows:

Step 1 – Select an “Epic” Challenge

The underwriting organization(s) select(s) an appropriate challenge as outlined above meeting specific criteria guidelines (e.g., refs. 3 and 16); develop(s) a strategy for developing and posing the challenge; advertising it; and set(s) the rules and guidelines for running the challenge.

Step 2 – Select University, High School and Middle School Hubs

Once the challenge is selected, identify which disciplines/domains are of critical importance and identify key universities with expertise and interest that might want to either lead or participate in the collaborative challenge. Advertise challenge and solicit the interest of local high schools to serve as high-school Hubs based on expertise, interest, resources and agreement to share all content, lessons, curricula, and hands-on-learning modules publicly. For example, universities of interest must have resources to design, analyze, prototype and test (hands-on/project-based interdisciplinary curricula) and high-school hubs might similarly have necessary resources whereby they can serve as local hubs for students of other schools to meet, learn, build, and share ideas in formal classes or extra-curricular programs (e.g., Project Lead-the-Way (PLTW) and science magnate schools).
Step 3 – Advertise, survey, and select 15 NASA engineers to participate as full course members for one-year

Select a relatively small set of key NASA personnel who have the requisite discipline expertise and passion and who agree and have supervisory permission to devote not more than 15% of their time at work on the proposed challenge. Selected engineers will complete all the assignments and agree to mentor, facilitate, collaborate and help conceive, develop and mature solution ideas/concepts. In addition, NASA participants will help develop educational outreach tools within their region/community as well as on-line.

Step 4 – Select the team of subject matter experts (SMEs), teacher-coaches/mentors, and student-coaches/mentors

Select a relatively small set of key SMEs to introduce the problem and develop an initial set of content to immerse the students in the problem and provide sufficient background information. The SME team should have expert skills in each of the key disciplines necessary for successful problem solution. Using a “Flexible Critical Mass” approach (ref. 26), keep the teams of experts small enough to ensure rapid assimilation of key information yet large enough to ensure diversity of thought and breadth of skills. SMEs should include “systems-level” thinkers with technical breadth in addition to SMEs with technical depth in critical areas as necessary.

Step 5 – Problem Functional Decomposition

Decompose/deconstruct the selected complex multidisciplinary engineering challenge into its component pieces with respect to function, form, engineering discipline, appropriate math and science skill level, etc. (e.g., using functional decomposition methods such as Object Process Methodology (OPM)). Using a “systems engineering/thinking” approach, identify all the areas of interaction and necessary inputs and outputs using a “Concept-map-like” strategy for outlining the knowledge capture, learning and problem solving process. The Concept Maps developed in this step will serve to link necessary courses, lectures, skills, etc. necessary to solve the problem together with the interaction of necessary disciplines and knowledge as appropriate to capture the inherent “coupling” of these disciplines. These Concept Maps will also help to develop the courses and curricula for high-school and middle-school programs.

Step 6 – Develop educational roadmap which links STEM subjects and overlays educational requirements onto the proposed challenge

Create the educational roadmap/framework which links STEM subjects and learning objectives together with engineering disciplines and maps this framework onto the proposed challenge. Faculty, students, and Teacher-Coaches will create links to online learning tools such as The Khan Academy and MITx for students to master necessary skills at their own pace and be rewarded accordingly upon demonstrated mastery.
Step 7 – Identify Roles and Responsibilities of each of the participating universities and high schools

Identify the roles and responsibilities of each of the participating university and high school hubs, their faculty, Teacher-Coaches and student mentors. Curriculum development, hands-on-learning activities and learning modules will be sub-divided based on interest and expertise and once developed and certified, will be made available for public use (See Appendix B).

Step 8 – Plan/organize summer workshops and follow-on school-year programs.

**Summer Program:**

1. Each challenge will be kicked-off by a one-week workshop which will immerse the Teacher-Coaches, SMEs; graduate and undergraduate students in the ICED methodology and the problem-based learning methods such as CDIO which will be taught become the foundation for challenge solution.

2. Following the initial workshop, high school teams, together with undergraduate and graduate student mentors will be immersed in the challenge and will follow a 5-6 week curriculum of instruction by faculty, SMEs and Teacher-Coaches consisting of 1-2 weeks on campus at the University Hub and 3-4 weeks of online learning and concept development at local high-school hubs.

3. Academic institution identifies local high schools to engage in its summer outreach program and classify each school into Tier 1, Tier 2 and Tier 3 targets.

4. The Executive Advisory Board and Cohort Groups will develop participant surveys which will be used to select and place students within teams.

5. Academic institution conducts research to determine the point(s) of contact within the high school administration or District Office for all Tiers.

6. Academic institution presents the summer outreach program to the Tier 1 High School point of contact(s) to offer a limited number of spots available for their top students including a program cost and financial aid policy review.

7. Academic institution sends out formal invitations to the high school point(s) of contact as well as directly to the selected students/parents identifying program details and costs.

8. Academic institutions review student/parent responses, assess financial aid demand and begin to formalize each class.

9. Repeat process for Tier 2 and Tier 3 schools until enrolment is fully subscribed.

10. Close enrolment and begin class orientation with students which should also include the high school point(s) of contact and the parents.

11. Academic institution should keep high school point(s) of contact and parents connected/engaged through the on-line platform.

12. Academic institution shares results with community (HS, parents, and sponsors).
13. Outreach program participants, parents and High School point of contact invited to continue with fall outreach programs.

Step 8 – Plan/organize summer workshops and follow-on school-year programs (Cont’d)

**Summer Program (Cont’d)**

14. Academic institution reviews/re-evaluates summer outreach program based upon metrics captured during course duration.
15. After review of metrics, academic institution considers upwardly adjusting its summer course volume and course selection for the next summer program.
16. Students attain levels of subject mastery by completing individual and team course assignments and by successfully completing additional on-line learning modules such as those outlined in references 7 and 8. Mastery of completed skills are recorded and used to assess student participation in other challenges and to build and maintain individual student skills portfolios! Students will be assessed according to both the number and quantity of skills mastered during each session and this will form a basis for future rewards.
17. Continue to build the community size by challenging the veteran students with new and innovative course choices/challenges while adding new students each semester to the ever refined introductory course selection.
18. Teacher coaches and faculty begin developing course content, hands-on-learning (HOL) activities for both formal and informal/extra curricula programs during the upcoming school year!

**Fall and Spring Programs:**

**University Programs:**

1. Promising ideas/concepts conceived and developed in the summer program will be used in conjunction with additionally proposed ideas and form the basis by which the Government/Industry/academic team will select Capstone Design Projects to be worked collaboratively among university Hub undergraduate students.
2. Promising research ideas may be funded as MS or PhD topics and receive partial or full funding to be decided by sponsoring agency/company.
3. The graduate and undergraduate student teams will form the top tier of student led virtual and physical mentorship team for the Teacher-Coaches and high school teams during formal and informal programs. They will also help develop the modeling and simulation tools and experiments to be developed and used during the high-school programs.
4. Formal classes will be developed based on a “Problem-Based” focus with a series of online and in-class instruction and course content based on satisfying national standards (e.g., problem-based/CDIO standards, ABET Criteria, etc.). Lesson planning will be designed such that each lesson plan will be mapped and evaluated with regard to the
above mentioned criteria using Bloom’s Taxonomy to overall curriculum guidelines for each institution.

Fall and Spring Programs (Cont’d):

High-School Programs:
1. Teacher-Coaches, together with faculty, university students and SMEs, develop formal and informal course content; modeling and simulation tools; HOL activities; etc. which will be used during the school year.
2. Students will be selected for program and will select challenges for formal and/or informal programs. Student roles will be determined based on past skills mastery, interest/passion, overall portfolio subjects mastered and program curriculum desired (e.g., aerospace, mechanical, robotics, computer science, etc.).

Middle-School Programs:
1. Similar in format to above-mentioned high-school program with high-school Teacher Coaches working with middle school counterparts and high-school students serving as mentors for middle school students.

Roles and responsibilities of each of the participants and/or participating organizations are discussed further in Appendix B.
Virtual Platform to Connect, Collaborate, and Communicate

The underlying backbone or spine the program relies upon is a virtual platform for connectivity, communication, collaboration, and problem solving called iQ4 (fig. 5). After exploring the use of three separate types of platforms for collaboration and communication (Wiki pages, Blackboard, and MyPort80 (IntroNetworks-based), etc. (see Appendix A)), it was decided to develop a customized platform based on the program needs and the feedback of students and faculty from the prior three programs. iQ4 developed a platform which was used during the 2011 summer session program which was led by The Stevens Institute (Appendix A). The platform system architecture for iQ4 is shown in figure 5.

IQ4 Architecture

![IQ4 Architecture Diagram]

Figure 5. – iQ4 virtual platform system architecture.

iQ4 is a Software as a Service (SAAS) business social platform hosted by Amazon. iQ4 is built on the Google Web Technology (GWT) platform for a rich front-end user interface (UI). The back-end is built using Grails/Groovy middleware, Java and Solr for our open search engine. iQ4 can be utilized through hosted services or installed within the customers fire wall. In addition, iQ4 has implemented the product using a Service Oriented Architecture. Customers can implement iQ4 components, such as “Connect”, within the customer application (such as support desk).

iQ4 was built to address the market demand for a simple and unified way to find people skills, information, communicate and collaborate on important projects and initiatives... a combination of email, LinkedIn and Facebook for professionals. IQ is a virtual social software platform that connects people resources, information and organizes how they work. Our ability to retain and find shared information is critical to leveraging intellectual capital over time (similar to a smart Google search for
project information). This unique combination of technology, content and an innovation process methodology provides organizations, an opportunity to solve problems and work projects by outsourcing challenges to university, high school and middle school students/teachers and faculty.

**Connect**- provides users the ability to search and find specific people skills, documents, discussions, groups and projects that are pertinent to their work. iQ4 uses an open source search engine that utilizes “indexed” and “data attribute” based content. Results are displayed either by dropdown or visual options.

**Collaborate**- iQ4 has designed communities, groups and projects around how people work and share information. Features include project-based process focused on aligning workgroups and nested groups in order to provide sub-discussion groups working on a project. Each community, group and project has access to a variety of tools “work items” such as discussions, tasks, assignments, resources, writeboards, member communications and process steps. iQ4 provides links to external products such as Linkedin (for loading profiles) and Sharepoint for accessing documents.

**Communicate**- a key component of iQ4 is to provide “Cross-Community” access to information. This enables users to search internally and externally for information (assuming communities provide certain access). This powerful architecture allows intellectual capital (shared information), that would normally be lost in email, to be accessible over time decreasing the time it takes to solve problems. Various forms of communications are provided: email and SMS for external communications and chat and discussion threads for on-line communications. iQ4 was designed and built for Wall Street and provides for the security, access control communications and privacy required.

Figure 6 is an example of one of iQ4’s data visualization tools where a member of iQ4 has initiated a search based on specific search criteria (in this case expertise and interest) in “their world”, including all the communities and groups they belong too, projects they are working, people they work with and information / documents shared. Today members can visualize search results based on their personal selection criteria or based on the community, group or project. The custom search engine uses indexed based search on any descriptive content available in iQ4 and then uses a “refined” data-base attribute search for fine tuning the search. An example would be searching for certain skills (mechanical engineering, drawing and cad background) and then attribute search ( number of years experience, availability, college junior, living in NYC) to refine my search. The same type of search is available for groups, projects, discussions, tasks and documents.

We also plan to include a “matching” engine that would make it easier for organizations to quickly identify and link skills and resources of participating members and organizations.
Figure 6. - iQ4 connectivity, communication, collaboration, and problem solving network.

An example of how the platform was used during a Beta trial with the last summer program at Stevens institute is shown in figure 7. In the course group entitled: “Autonomous Vehicles for Extreme Environments” under the “Lessons Tab” is a list of linked course notes and video learning modules for class Day Two. Lectures by 7 NASA SMEs and two university faculty from Ga. Tech and Penn State on Mars exploration, robotics, biologically inspired design, and creativity are stored for access by the community/group.
Figure 7. - Example of multiple lessons recorded (live videos with question and answer period) and posted with lecture notes and slides by NASA subject matter experts (SMEs) for autonomous vehicle project (Case 4, Appendix A).
Concluding Remarks

This paper presents a strategy for STEM education which is based on an Innovative Conceptual Engineering Design (ICED) methodology for problem solving and which focuses on the solution of real, complex engineering challenges. The paper proposes a framework to integrate multiple levels of the education environment from middle school to graduate school to form a continuous line of mentorship and instruction within the problem solution process. Each education level is responsible for developing the age-/skill- appropriate learning modules which include conventional as well as hands-on-learning activities and which are directly applied to the solution of the challenge. The program includes classroom experiences as well as virtual/on-line learning and problem-based team and individual exercises. Multiple university hubs will collaborate with each other and also regional and national high-school hubs. Informal, after school programs, as well as formal programs of study are proposed. Over the past four years, this program has been successfully field-tested over a wide variety of participant experience levels, ranging from the high school student, through to the young practicing engineer. Past problems addressed include contingency land-landing systems for NASA’s next generation spacecraft, lunar digging and drilling systems, Martian space suit designs, and Martian lava tube exploration robots. Results of these previous programs have resulted in novel ideas which were developed to varying degrees of maturity. One study resulted in a “Personal Airbag” solution to an Orion capsule land landing problem which was shown to be feasible through analysis and test and which continues to confound the current space community.
Appendix A

Case Studies, Experiences, and Lessons Learned


The methodology was initially taught as a formal summer short course as part of the NESC Academy Program in July 2008 to help instruct young NASA engineers in the art and science of innovative engineering design (ref. 2); a skill which was the hallmark of NACA (the National Advisory Committee on Aeronautics), the predecessor to NASA, as well as the early years of NASA during Apollo which were renown for creative engineering design solutions and technical as well as operational and programmatic innovation. A team of university professors from MIT, Penn State, and Georgia Tech were teamed with landing dynamics, human physiology, controls, creativity and innovation; and landing load attenuation experts from NASA to create the course content (see Table 1). Working together with training specialists from Ciber Corporation and the National Institute for Astronautics (NIA), the leadership team created all the workbooks, teaching and learning modules and tools; computer models, etc. which were used during the 5-day class. A diverse group of 30, mostly junior, NASA engineers and scientists were selected from 7 of the 10 NASA field centers across the country to attend the course which was held at Penn State University.
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Penn State was chosen to host the NESC Academy Innovative Engineering Design course for several reasons: the location provided an aesthetically beautiful and isolated setting so students could focus on the problem; the Penn Stater Hotel and Conference Center provided well equipped conference facilities complete with large breakout spaces/rooms for teams to interact; the university provided computer design classrooms for CAD instruction and background content searching; and the resources of the “Learning Factory” (Fig. A1) provided a work environment where students could rapidly prototype, manufacture and test ideas/concepts. There were numerous areas where students could socialize and relax during breaks and in the evenings. All meals and snacks were included in the package so students could spend maximum time mingling with teammates, faculty and other students both formally in class and informally, at meals and later in more relaxed settings.

Figure A1. Penn State Learning Factory.

There were numerous ideas identified by the student teams during the week-long class which was likened to an innovation “boot camp” and which drew the attention of several of the technical experts and program managers present (Fig. A2) because of their creativity and possible utility. One idea which showed promise employed “person airbags” and was inspired by a biological system for protection of seeds; another idea investigated extending the entry heat shield and used collapsible strut dampers to absorb the energy of impact. Dr. Joe Pellicciotti, NESC Tech Fellow for Mechanisms, was so impressed with the personal airbag idea that he secured NASA funding to continue a collaborative research program with MIT and Penn State for further study.
Proof the Methodology Works
Alternate Land Landing of the Orion Capsule

30 young NASA engineers and students from MIT and Penn State

Figure A2. Some of the ideas which were analyzed and prototyped by students during class.

The follow-on collaborative two-year design program, included over 15 students, two faculty advisors from Penn State and MIT, and several NASA mentors and resulted in three conference papers, one journal article, one MS degree/Thesis (refs. 19 – 22), a proposed patent application, three capstone design projects (one capstone senior design project at Penn State won first prize out of a total of about 70 student teams) and cost the government a total of only $135K (Fig. A3).

Real NASA problem inspires many and provides timely results... for little cost

Figure A3. Penn State/MIT collaborative design project using air bags to mitigate impact loads on crew for the Orion space capsule in addition to active strut damper Senior Capstone winning project.
The Students designed, manufactured, analyzed and tested their ideas in a rigorous building-block process described earlier and were able to fail, learn and evolve their ideas very rapidly. They developed simple analytical models which they correlated by tests and which could have been used as learning-modules for high-school teams and/or other university teams. **Results of the study indicated that, indeed, an airbag system could potentially result in the safety of the crew in a contingency land landing and, thus, provide a feasible solution (ref. 23).** Not only was the solution feasible, it reduced mass by 265 lbs. and increased habitable volume by 26%!

The university program lasted for two years and has provided a continuous learning and growth experience for undergraduate team members. It has evolved several alternate ideas and other unrelated potential solutions, several of which were explored by the Penn State Senior Capstone Design teams. The program leveraged expertise and resources from NASA, Penn State, and MIT to keep costs to a minimum (ala Stone Soup ref. 20). For example, an expensive instrumented crash test dummy was loaned by NASA and mechanical engineering expertise of key individuals provided timely and very focused guidance (Dr. Pellicciotti estimated his total time spent mentoring would have amounted to only 0.03 FTE (Full-Time Equivalents)). Professor Oli de Weck of MIT was also able to leverage $10K from an existing program to support testing.

**Lessons Learned:** This pilot project validated several premises originally identified at the beginning of the program: 1) many students are truly motivated to solve “real” problems which are complex and which, if solved, can have very substantial positive outcomes to very meaningful programs; 2) students enjoy working and collaborating in teams with students from either their own university or with students from other universities on integrated projects; 3) the “Stone Soup” (ref. 19) of expertise, resources, and existing funds of other ongoing programs can significantly minimize total program costs; 4) faculty/student teams can conceive innovative solutions to real problems relatively quickly, 5) useful analytical solutions to real, complex problems can be generated to explore the complete design space and offer insights to other useful applications of the technology and serve as learning modules for other university/high-school and even industry teams, and 6) Senior students are ideal mentors for junior classmates! The graduate student who remained with the project provided direct mentorship and inspiration for the underclassmen that helped with the test setup and operation which also helped satisfy requirements for other formal classes.

What was used in the above-mentioned program was a Wiki website for communication; data transfer, collaboration, and file sharing. It must be recognized, that for graduate student development and formal course applications of such a program, it is important to remember that a clearly defined curriculum must be established which addresses very specific learning objectives, schedules, and goals and must be included in the development of the program. This
may determine the project direction and may not result in maximum programmatic efficiency but may result in a compromise of education and program objectives. It is hoped that a scaled-up version of such a program will result in a multitude of “original” ideas and concepts which can be matured to a level where intelligent evaluation and down selection can greatly benefit the front end of the innovative design process!

**Value Propositions:**

1. **Innovation:** NASA and academia have access to a much larger reservoir of creative ideas. In addition, several ideas were evaluated and matured simultaneously throughout the course of the project.
   a. **One of the concepts from that reservoir was designed, analyzed, tested and developed in only two years and at a cost of $135K and proven to be feasible (could provide a safe land landing capability for the Orion Crew Exploration Vehicle (CEV)).** A highly sought after capability the US human spaceflight program has been seeking since the Apollo Program!
   b. Proves the premise that in a very short time (only one week) numerous, new and innovative ideas can be conceived; that these concepts can be matured in a rapid fashion and at a much reduced cost to the program.

2. **Pipeline:** In this project we experienced a mentorship pipeline from NASA engineers and university faculty to graduate students and finally to undergraduate students, however, it is apparent that this continuum of mentorship could flow from undergraduates to high school students (see next project) and even from high school to middle school.

3. **Sustainability:** For only $135K investment and 0.03 FTE (Full-Time Equivalents):
   a. Touched the lives of over 15 undergraduate and supported one graduate student
   b. Resulted in 3 conference papers, one journal paper and supported 3 Capstone Design Teams (one of which won best project out of 70 teams total) and Ideas, concepts and research relevant to aerospace companies, NASA, automotive companies, etc.
   c. Universities able to leverage existing program directly related to the applied research and technology as well as for educational outreach.

4. **Continuity:** Three years of continuous work by NASA and academia collaborating in two different schools and in two different states.

5. **Scalability:** Easy to see how this program could impact high schools and even middle schools (this was indeed explored with the course). The use of an effective platform for virtual collaboration will also be very useful in helping the scalability of such a program as it will allow numerous schools to benefit from lectures, course content, learning modules, etc.
In the summer of 2009, an interdepartmental/interdisciplinary design, 3-credit course was offered at the Polytechnic Institute of NYU (NYU Poly) which was entitled: “Innovative Conceptual Engineering Design.” The idea for the course initiated with a suggestion by a NYU-Poly faculty member. The final decision to offer the course was made after a group of students in the Civil Engineering Department approached the author and insisted that such a course be offered. The problem/challenge selected for this course was the design of innovative methods for “Digging and/or Drilling on the Surface of the Moon.” The course was offered through four traditional departments at NYU-Poly: Mechanical and Aerospace, Civil, Computer Science and Engineering; and Electrical Engineering. It should be noted that for universities which do not have a Systems Engineering or Interdisciplinary Studies Department or recognize the importance of such courses it makes the offering of such studies more difficult. The class totaled 31 students with 19 undergraduates from one of the four departments from NYU-Poly and one CS undergraduate from Carnegie Mellon; one management of technology graduate student from NYU-Poly and 10 high-school students from either Brooklyn Tech or Archbishop Molloy (two NY high schools). The course lasted six weeks and included individual as well as team assignments (projects and presentations) with one final team presentation at the end of the class which was attended by guests from the NYU Poly and the two high schools and included a team of judges from industry and academia.

This was the first course which utilized the ICED methodology which included a virtual platform for student, faculty, and technical expert collaboration. “Blackboard” was the platform which was utilized to collect individual and team home works/projects; post grade assignments; course logistics; enable course/subject content posting and sharing; individual and team collaboration; differentiate between individual and team contributions; and to monitor individual and team performance to enable appropriate intervention and guidance.

Since the ICED summer-session course was a pilot course, it was offered at a much reduced rate to the students ($300 per student). The course linked the students to a very innovative robotics company in NYC, Honeybee Robotics, which agreed to participate in the program together with NASA experts and key faculty from NYU-Poly, Ga. Tech., and Penn State, who helped to develop the initial ICED program for junior NASA engineers (ref. 2). All participants agreed to check the Blackboard website at least once or twice a week and reply to students’ questions. The course integrated material and lectures from NASA experts on the then proposed Lunar Mission (including reasons for going to the moon, strategy, key technologies, environment, in-situ
resource utilization, etc.); subject matter experts on conventional civil engineering methods and soil mechanics from NYU-Poly; lectures on analogous design methods and concepts using biologically inspired design (BID) from Ga. Tech. and other creative design methods from Penn State; and historical and current methods for digging and drilling in extreme environments from experts at Honeybee Robotics. We decided to allow participation from two high schools, Archbishop Molloy in Queens and Brooklyn Technical High School in Brooklyn. We partnered with Brooklyn Tech for several reasons: it was physically located within walking distance of NYU-Poly and offered resources for rapid prototyping, fabrication, machining and instruction thereof not available at NYU-Poly which we traded by allowing their students to enroll at no cost. The tuition was sufficient to cover materials and the travel expenses of guest lecturers.

The students were divided into six teams of 5-6 students based on a pre-course survey to ensure team diversity (gender, culture, experience, skill, artistic talent, hands-on fabrication experience, etc.) for optimum creativity and performance. Course content was uploaded to the website throughout the course and included over a hundred technical papers, links to videos and pertinent websites, course material (e.g., copies of lectures, notes, handouts, and assignments), team group sites; blogs, threads, and discussions; links to experts for general questions and answers; contact information; individual student idea journals (to help gauge individual participation and understanding) and homework assignments. Grades were based on individual and team performance (50%/50%) including: class participation, virtual collaboration, communication, creativity, analysis, critical thinking skills, presentations and written projects/assignments. The course included hands-on exercises and experiments, drawing, computer-aided-design, prototyping, analysis and testing.

Some of the design ideas and concepts proposed by the students can be seen in figure A4.

![Biologically Inspired Design](image)

**Biologically Inspired Design**

Mole Rat + Mud
Lobster Inspired

**Excavation Prototypes: CAD Models**

![Excavation Prototypes](image)

Figure A4. Two team concepts: one inspired by biological systems, the other by a NYC street sweeper.
Some of the student teams were very impressed with the lectures on Biologically Inspired Design (BID) by Dr. Jeannette Yen (Director of the center for BID at Georgia Tech.) as shown in figure 7a where the shape of the skeletal skull and jaw of a mole rat was combined with the anchoring methods of a mud lobster to provide a structurally efficient scoop and system for vehicle stability in the $1/6^{th}$ gravity of the moon. One member of “Team Awesome” was inspired by the large steel brushes of a conventional NYC street sweeper which resulted in a very simple and efficient method to collect lunar regolith for processing. This particular concept had not been investigated and was very intriguing to robotic drilling and excavating expert, Dr. Kris Zacny of Honeybee Robotics. Dr. Zacny provided a comprehensive lecture on digging and drilling in extreme environments and served as one of the judges of student team final presentations. All teams conducted some level of analysis, modeling, computer-aided design, prototype fabrication and testing. Several NYU-Poly students were later provided internships at Honeybee Robotics, a very innovative robotics company who has developed components and mechanisms for the Mars Rovers. A team of NYU-Poly students were able to draw from their experiences and content from this course and carry it forward to help them design a vehicle for the NASA Lunabotics Competition in 2011, conduct educational outreach to local high schools in the NY metropolitan area, fielded a team to compete in 2012 Lunabotics competition; and have taught and mentored undergraduate students at NYU-Poly and high-school students at Stevens Institute (see 4 below).

**Lessons Learned:** Although the students were told of the importance of communication and virtual collaboration, there was not as much activity noticed in the individual student journals or team web pages and blogs/threads as expected. This was not totally unexpected based on results of a previous class in which students were opposed to using the “Blackboard” platform for collaboration and instead used other sources for collaboration including: e-mail, AOL instant messaging (AIM), Google Wave, etc. Apparently the students of this class determined that class meeting times (three times a week) and other, more conventional, sources for collaboration would be sufficient. This result provided insight as to the shortcomings of Blackboard as a platform for collaboration and virtual team problem solving and for use as a “social media” or collaboration platform. Even though Blackboard offers a comprehensive collection of tools which you would expect would facilitate team-based problem solving and collaboration, some of the responses from the students included: it was not user friendly, too cumbersome to accomplish very simple tasks, discussion board was too “messy”, and very difficult to search website for content. Since we believe the virtual platform for communication and collaboration is critically important to creative problem solving as are social media and crowd sourcing, we chose to experiment with other virtual platforms for our next course offering. This was the first ICED formal course for college credit and one in which we experimented with a mixed class of high-school and undergraduate students (there was also one NYU-Poly Technology Management graduate student from Honeybee Robotics also taking the class). We divided up
the 10 high-school students evenly with the other students to form the six class teams. A survey for the class to evaluate course content, guest speakers, individual lectures, etc. resulted in very high favorable ratings with minimal negative comments. The mix of high-school students with undergraduates was looked on very favorably from students of both grade levels, in fact, one team was led by one of the high-school female students and their performance was exceptional. It was initially considered that a mix of high-school teachers could be interspersed within individual teams to instruct them as teacher-coaches and get feedback from them to help develop age-appropriate lessons for the high school. This idea was not considered for this phase due to a lack of time and also funding. The major complaint from several of the students was that there was not enough time to design, fabricate, and build their prototypes. The students loved the hands-on activities and asked for additional class time to complete their respective projects prior to their final class presentation.

**Value Propositions:**

1. **Innovation:** Students identified several novel ways to design drilling and excavating systems for lunar exploration. Several ideas were recognized by the CEO of Honeybee robotics for their creativity and utility.
2. **Pipeline:** In this project we experienced a mentorship pipeline from NASA engineers, industry SMEs and university faculty to graduate student, undergraduate students, and high school students.
3. **Sustainability:** For only $300 per student:
   a. Touched the lives of over 20 undergraduate one graduate student and 10 high school students
   b. Ideas, concepts and research relevant to NASA
   c. Opportunities for internships with Honeybee Robotics and NASA
   d. Inspired student design competition with NASA (Lunabotics) which was able to utilize tremendous course content from this course for the 2011 NYU-Poly Team.
   e. Universities able to leverage existing program directly related to the applied research and technology as well as for educational outreach (NYU Poly students mentored local high school students).
4. **Continuity:** Lead to NASA’s Lunabotics design competition with NYU-Poly graduate student leading an undergraduate team with Poly faculty and a network of experts from NASA and Honeybee Robotics. Senior and graduate students from original course mentored junior classmates in Lunabotics competition at NYU-Poly and high-school students at Stevens Institute (see 4 below).
5. **Scalability:** Easy to see how this program could impact high schools and even middle schools. The use of a more effective platform for virtual collaboration will also be very

Due to the very favorable responses from the students who attended the NYU-Poly ICED program the previous summer (2009), a decision was made late in the spring semester of 2009 to offer a similar design course exclusively for high-school students in the summer of 2010. Because of the lateness of the decision to proceed, there was not a high expectation we would have a sufficient student response to offer such a course. However, within less than one week of posting, the NYU-Poly admissions office had received over twice the number of positive responses of students necessary who wanted to take the summer course (over 90 responses from the top high school students in the NY/NJ area). We selected a total of 44 students from 31 different high schools in the NY/NJ area. Some of the students had to commute over 2 hours by train and bus to attend class which met twice a week for four hours each day for seven weeks on the Brooklyn Campus of NYU-Poly. Because the class met only twice a week for seven weeks, it was essential that we utilize a better platform for communication and collaboration which would allow ease of posting and sharing documents and the ability to search content for key words or phrases. Following a similar format and methodology of previous classes, Dr. Lawrence Kuznetz was selected to co-teach this class because of his expertise in spacesuit analysis and design from an engineering and life sciences background and because this course was very similar to prior classes Dr. Kuznetz offered and The University of California, Berkeley to undergraduate and graduate students. The Berkeley spacesuit design course, which was offered for a total of four years, also recognized the importance of student collaboration and the use of a virtual platform to help solve such multidisciplinary problems. There were guest lectures on the innovative design process, the Mars environment, spacesuit systems and subsystems, thermal analysis, and structural analysis with hands-on demonstrations of spacesuit hardware by industry experts from Hamilton Sundstrand, and experiments on heat transfer and structures. There were also demonstrations by scientists and designers from MIT and private industry on very novel spacesuit design ideas. The students also went on a field trip to MIT to tour their spacesuit design laboratory and test facilities and to talk to Prof. Dava Newman and graduate and undergraduate students there. The class was offered at $500 per student which was sufficient to cover the cost of all guest lectures and the field trip to MIT. The course received an overwhelmingly positive response by the students. Some of the relatively few negative responses mentioned the desire for “more time” (even though we added an extra
week and one extra day for a hands-on spacesuit hardware demonstration) so that the students could spend on their prototype fabrication and demonstration. There were also several comments which highlighted some of the shortcomings of IntroNetworks platform which was used for collaboration and communication called myPort80: they liked the ease of posting and sharing files, content, and data, however, there was no simple way to form sub-groups focused on project activity. Many team members felt that a virtual platform was definitely needed to complete the project assignments by their expected deadline. In fact, one of their assignments was to develop a communication plan and strategy which each team felt comfortable with, in addition to myPort80 (communication and collaboration system utilizing the IntroNetworks platform), in order to maximize team performance.

The students presented their final results to a panel of judges with their parents, faculty members and guests on the last evening of class. The entire video of the student presentations can be viewed at the following link: http://www.vimeo.com/14285084. Some of the creative ideas which were presented are shown in figure A5.

![Exoskeleton](image1.png)  ![Thermal Regulation](image2.png)

a) Exoskeleton b) Thermal regulation using nano-tubes

Figure A5. Two team concepts: one an exoskeleton to offload the mass of the spacesuit and the other using the thermal properties of polar bear using modern carbon nano-tube fabrication technology.

As shown in figure A5a, one team explored minimizing the effect of the mass and bulk of a Mars spacesuit (effective gravity is 0.38 g on the surface of Mars as compared to 1/6th g on the surface of the moon) by using a powered exoskeleton design. Another idea used biologically inspired design and the thermal efficiency of hollow polar bear hair which could be manufactured using carbon nano-tube technology to provide a more efficient thermal insulation. Five NYU-Poly undergraduate technical assistants (TAs) provided close mentorship for each of the high-school teams. The teams worked very well together and very early on it
was evident that there was much more virtual collaboration using myPort80 that the previous class which used the Blackboard platform. Teams posted blogs, threads, commented on ideas, and lead teammates to links to other content. From an instructor’s viewpoint, it was readily apparent which students were natural leaders within the individual teams. It was also quite evident which teams needed help and when it was necessary to intervene for guidance, direction, and team support. The students also noted that while they enjoy “team” projects, their teachers do not like to assign them because it is very difficult to ascertain each individual’s contributions and, thus assign a fair grade. Using, a virtual platform for collaboration, however, made it easier to differentiate individual participation and performance. Instructors, guest lecturers, subject matter experts (SMEs), etc. were provided a separate group to allow questions and answers for all teams to see and comments and provide guidance individually as needed and were also provided access to team pages to help guide and mentor.

Lessons Learned: The students commented favorably on using the myPort80 platform for collaboration together with other tools such as AIM, e-mail, Google Wave, etc. The student activity for this class was noticeably higher using myPort80 and the IntroNetworks platform then for all previous courses. High-school students are really motivated by hands-on exercises and experiments and enjoy building, fabricating and testing. The environment encouraged very mild levels of competition but stressed that all teams share ideas and acknowledge and reference where the ideas originated. Several of the students who did not consider engineering as a career have changed their minds after this course and other students who did not consider NYU-Poly as a choice have now reconsidered and have and accepted and will be attending NYU-Poly next fall. These types of responses are encouraging for using such a program at a national level to help attract top students to careers in engineering and as a recruiting tool for admissions departments. Many of the students still communicate and have created a website to do so. This is very encouraging and indicates how such a program could not only help maintain continuity of students and interest level but also create a pipeline of students at all age and experience levels (middle school to graduate school). In fact, some of the students that have since graduated and are freshmen in college participated in the follow-on program this past summer at Stevens Institute. Students can stay connected via the virtual platform and have access to all content generated during and after the class. In addition, students could monitor progress of other communities and can change areas of interest according to individual interests and yet still maintain focus on a more global area of interest depending on the selected challenge/problem.
**Value Propositions:**

1. **Innovation:** NASA and Academia have access to a much larger reservoir of creative ideas. In this project, several ideas were evaluated simultaneously and evolved throughout the course of the project.

2. **Pipeline:** Undergraduate students to high-school students, however, it is easy to see how this continuum of mentorship could flow from high-school students to middle-school students. A pilot middle-school program using the “Design of a Spacesuit for Mars” theme was initiated in the fall of 2011 at the Solomon Schechter Middle School in New Jersey.

3. **Sustainability:** All costs were covered by the $500 tuition charge. Costs for two instructors were covered by NASA:
   a. Touched the lives of 44 high-school students
   b. Resulted in inspiring several students to pursue careers in engineering and in considering NYU-Poly in their list of college applications (when prior to this course, Poly was not a consideration!)
   c. Ideas, concepts and research relevant to aerospace companies, NASA, etc.

4. **Continuity:** Too soon to tell. Rolling out national program to expand ideas and reach.

5. **Scalability:** Easy to see how this program could impact even middle schools (this was indeed explored with the course).

The summer 2011 program elicited the interest of the US Air Force (Tech Edge Program at the Wright Brothers Institute) and five universities (Stevens Institute, Wright State, Texas A&M, MIT and Penn State) as shown in figure A6. A university/government Cohort Group was used to select a challenge to pose as part of the summer challenge. The “Epic” challenge selected was one proposed by Dr. Rob Ambrose, Division Chief of NASA JSC’s Automation, Robotics, and Simulation Division and agreed upon by our University “Cohort Group” comprised of a team of faculty points of contact (POC) and graduate students from each of the five collaborating universities: Stevens Institute, Texas A&M, MIT, Penn State and Wright State; our Air Force Partners at Wright Patterson AFB, and the Wright Brothers Institute (see figure A6).

![Organizational Framework](image)

Figure A6. Organizational structure of the Collaboratory for Innovative Conceptual Engineering Design to develop autonomous vehicles for extreme environments, 2011.

A total of 78 students attended the 2011 summer sessions from some of the top high schools in the NY/NJ metropolitan area. Three students from the 2010 summer classes re-enrolled in the 2011 summer session challenge. The cost of the program was $1000 for a six-week program which was divided into a two-week segment located on campus at Stevens Institute (7-hrs. per
day five days a week) and a four-week virtual experience with team assignments leading toward a final team presentation. Full- and part-scholarships were awarded to over 50% of the students on a needs-based determination, hence, ensuring a broad range of diversity in the student population and individual teams. The two-week on-campus experience was phased sequentially between two equally-divided groups of students; 5-6 member student teams were formed based on student skills and interests as determined by the pre-course survey shown in figure 3. As shown in figure A6, we approached some of the top high schools in the Metropolitan NY/NJ area and asked them if they would like to act as local High School Hubs and support a pipeline of students interested in the STEM subjects and the application of those subjects to solve “real” problems of extreme interest to the nation and the community. Each of the schools shown in figure A6 were extremely interested and expressed a desire to participate and advertised the program within their individual high schools.

In order to achieve sustainability, we experimented with the development of on-line learning elements for certain components of the program. For example, the problem immersion phase was video recorded live during the first session summer class and posted on the autonomous vehicle for extreme environments group page as shown in figure 7. Seven NASA experts on Mars exploration from 3 different NASA Centers (JPL, JSC, and KSC) lectured on robotic challenges; Mars geology, history and lava tube formation; autonomous vehicle design; mobility; communication; etc. These lectures were posted and used during summer session two lectures and were available for repeated access throughout the program. Capturing and posting such learning modules would allow students who join the challenge during the school year to rapidly catch up to the rest of the class and immediately begin contributing. The use of such modules would also greatly lower the overall expense and drive costs and overhead to within sustainable limits. On-campus student classes included lectures on: innovation by Dr. Sven Bilen of Penn State; biologically inspired design by Dr. Jeannette Yen (Director of the Center for Biologically inspired Design at Georgia Tech.); the importance of failure by Dr. Jack Matson (Prof. Emeritus Penn State); the ICED program methodology, engineering methods and ethics, the design process, etc. (Dr. Charles Camarda); computer-aided design and rapid prototyping by Prof. Jan Nazelowicz (The Stevens Institute); and systems engineering and robotics by Prof. Joe Miles (The Stevens Institute); and rapid prototyping by Mr. Jack Poon (NYU-Poly student and student from first class taught at NYU-Poly (problem 2 above: “Digging and Drilling on the Surface of the Moon”).

Lessons Learned: The students had mixed reviews regarding the iQ4 virtual platform; although it served nicely as a repository for much of the course content and learning modules, much of the social networking features were still at the Beta stage of development and others were not quite ready at the time of the course rollout. We learned also that although the students were
told that failure and risk taking were encouraged during the class, many of the students did not like the idea of sharing early ideas and thoughts on a public platform where course instructors had open access. Hence many of the team members chose to communicate using other available social media platforms such as Facebook, AIM (AOL Instant Messaging), e-mail, Google Wave, etc. The student activity for this class was noticeably higher using iQ4 from previous class using myPort80. High-school students are really motivated by hands-on exercises and experiments and enjoy building, fabricating and testing. Once again, there was not enough time to coordinate responsibilities between NASA lecturers and University partners. This was due in part to the enormous amount of time spent to sell the program and develop the necessary buy-in for the program. A recommended solution proposed for this year’s program is a clearly defined set of roles and responsibilities in the form of an agreement which all parties agree to prior to the launch of the program. Hence we are starting very early in the school year and limiting the number of university hubs and cities and ensuring we have complete agreement on objectives and projected outcomes. While initially hoping to have support of 5 university and high school hubs, we eventually resulted with one university and two high school hubs and partial collaboration with the Air Force team at Tech Edge.

**Value Propositions:**

1. **Innovation:** Many of the student’s ideas were innovative combinations of prior/existing concepts and in some instances were totally revolutionary and unique. Many were inspired by biological systems and some students were very successful using TRIZ principles to either conceive ideas or improve ideas.
2. **Pipeline:** Several prior graduates returned to either take the class again or to help with instruction and mentorship.
3. **Sustainability:** Total program tuition of $1000 with reduced costs and full scholarships for needs-based students:
   a. Touched the lives of 78 high-school students
   b. Resulted in inspiring several students to pursue careers in engineering and in considering NYU-Poly in their list of college applications (when prior to this course, Poly was not a consideration!)
   c. Ideas, concepts and research relevant to aerospace companies, NASA, etc.
4. **Continuity:** Graduates from prior courses (see 3 above) enrolled in the current course and filled leadership roles on current teams and graduate students from the NYU-Poly
course (see 2 above) lectured and mentored students on computer-aided design (CAD) and rapid prototyping.

5. **Scalability**: Easy to see how this program could impact even middle schools.
Appendix B

Roles and Responsibilities

Government and/or Industry Sponsors:

The government and/or industry sponsors will act as challenge underwriters and have the prime responsibility for selecting and posing the challenge and share in the financial support of graduate students and undergraduate capstone design teams at participating University Hubs. They will provide a network of key subject matter experts (SMEs) to help facilitate the challenge solution process and to guide student teams. Sponsors will assist in the selection of university hubs and regional high-school hubs which will collaborate throughout the summer and school-year program and provide membership to support the Advisory Board and university and high-school Cohort Teams. Sponsors will also help identify potential resources within their organizations which may be used to help facilitate the primary goals of the challenge (e.g., hardware, test facilities, instrumentation, people, etc.). SMEs will help develop course content, provide lectures, and assist faculty and high-school Teacher-Coaches to develop age-appropriate, challenge-based curricula. Sponsors will support the program administration, advertisement, participant/student survey development, and will establish metrics to monitor performance (both individual and team). Sponsors will also help coordinate bi-annual challenge expositions, team presentations, events; and individual and team awards.

Subject-Matter-Experts (SMEs):

The SME members will provide in-depth discipline expertise in the form of lectures, online mentorship, course content, and help facilitate development of modeling and simulation tools and resources to support problem solution.

University Hubs:

Universities interested in collaborating on particular challenges will be evaluated based on their interest, expertise, and potential for in-kind support. They will be responsible for recruiting and selecting graduate students and undergraduate students with appropriate interest and expertise and submit a proposal based on an interdisciplinary, multi-year program which integrates specific research interests with capstone design projects focused on the solution of the selected challenge(s) and which is directly tied to a formal and/or informal course of study. University hubs will help select regional high-school hubs which will serve as centers for high-
school student teams to receive instruction and educational support; meet to develop and mature ideas; and analyze, design, build, test, and mature concepts. University Hub faculty, graduate, and undergraduate students will provide mentorship and guidance for high-school Teacher Coaches and students (e.g., bi-monthly visits, lectures, and online course content development). One University Hub will be selected each year to host a one-week challenge workshop to help instruct incoming graduate and undergraduate students, SMEs, and high-school teacher coaches in program curriculum, instructional methodology, online collaboration, and schedule of events and milestones. University Hubs will also be responsible for instituting and monitoring online educational tools (e.g., Khan Academy, MITx, etc.) and participant performance (students, Teacher-Coaches, SMEs, etc.) and in awarding mastery-of-skills badges/certificates based upon successful completion and demonstration of individual and team skills by students. Graduate and undergraduate program participants will also assist in the development of modeling and simulation tools; educational outreach and content, analysis and presentation.

**Graduate Students:**
Graduate students will collaborate with other university participants; assist in mentorship of undergraduates and capstone design projects, lead student teams in problem solution and identify key areas of current and future research areas. They will help develop modeling and simulation tools useful for problem resolution and also educational outreach for high-school programs.

**Undergraduate Students:**
Undergraduate students will collaborate with other university participants; identify capstone design projects for senior-year design programs, mentor high-school student teams and provide educational outreach and assistance.

**High-School Hubs:**
High schools interested in becoming High-School Hubs can apply annually prior to initiation of the summer workshop and will be evaluated based on academic excellence, expertise; analysis, design, build, and test resources, teacher competence, and commitment. Selected High-School Hubs will be responsible for: 1) nominating and providing Teacher Coaches to help develop and teach formal classes as well as informal (after-school) classes which will allow participation by students from other schools; 2) provide local facilities for after-school or weekend and 3) team/student facilitators and mentors.
**Teacher Coaches:**
Teacher Coaches will work with University Hubs and students; SMEs, sponsor engineers and scientists; and university faculty to help develop formal and in-formal curricula focused on solving program challenge and provide age-/skill-appropriate hands-on-learning experiences for high-school students and teams. Courses of study will be designed to meet rigorous agreed-upon core standards. They will help develop the evaluation tools and metrics which will be used to measure and award specific certificates of accomplishment which will be used to monitor student performance.
References

7. www.khanacademy.org

References (Cont’d.)
