

AC 2009-1469: INSIDE THE DESIGN CHALLENGE: MOTIVATING STUDENTS THROUGH THE DESIGN PROCESS

Debbie Mullins, Texas Space Grant Consortium

Debbie Mullins has been a Higher Education Program Coordinator for the Texas Space Grant Consortium (TSGC) since 1999. She was instrumental in designing the features of TSGC's flagship higher education program: The TSGC Design Challenge Program in 2002 and has been responsible for managing the program since its inception.

Wallace Fowler, University of Texas, Austin

Wallace Fowler is the Paul D. & Betty Robertson Meek Centennial Professor in Engineering and Distinguished Teaching Professor at the University of Texas at Austin. He was the 2000-2001 President of ASEE. His teaching and research focus on space mission planning and spacecraft design. He is co-author of Statics and Dynamics textbooks with Dr. Anthony Bedford.

INSIDE THE NASA/ TEXAS SPACE GRANT CONSORTIUM DESIGN CHALLENGE PROGRAM: Motivating Students Through the Design Process

Introduction:

A paper entitled *The NASA/Texas Space Grant Consortium Design Challenge Program: A Systems Engineering Educational Program*¹ was presented at the 2008 ASEE meeting in Pittsburgh, which provided a general overview of Texas Space Grant Consortium's (TSGC) flagship higher education program. The Program model was developed by the authors in an effort to improve student design team accountability while at the same time encouraging a higher level of motivation among the Design Challenge (TDC) participants. This paper will focus on the methods used by the Program to motivate students through the design process that at the same time provide a level of accountability to program administrators. Anecdotal comments provided via program evaluations and surveys have provided the basis for the conclusions presented in this paper.

Background:

Sponsored as a NASA Workforce Development Initiative since 2002, the Design Challenge Program (TDC) remains a unique academic experience that exposes undergraduate students to space-related problems and careers as they work toward solving a NASA mission-relevant design objective. Participating students work as part of an engineering design team under the guidance of a faculty advisor and alongside a dedicated workplace mentor to solve a "real-world" problem identified and provided by NASA. Over the course of one or two semesters, each team simultaneously secures funding for their individual project and satisfies course credit required for graduation.

The opportunity to engage in substantive student research is the hallmark of the program's effort to encourage and prolong student interest in STEM (science, technology, engineering and math) related academic studies and careers. A measure of success is assured for all participants using TDC methods that guide and motivate student teams through each phase of project development.

The program accomplishes this by providing resources that are directly tied to the successful completion of required milestones called "Levels" and optional opportunities called "Option Areas." Guidelines and awards attached to milestone deliverables provide schedule structure, motivation, instruction, and funding to the team as design projects mature from the preliminary idea-stage to a sound design solution. Graduate student peer reviews complement academic and technical guidance provided by both faculty and project mentors/customers. The semester culminates with a professional-style conference, called the Design Challenge Showcase, which provides each team with a platform for presenting their work to an audience of peers, NASA mentors and members of the academic community.

Monetary resources earned by the student teams are minimal by most funding standards, but adequate to allow for project supply procurement and model building. Supplemental grants support off-campus travel and collaboration opportunities within the community-at-large, provide funds to support more advanced second-semester model or prototype construction, and

provide incentive to teams that compete national design team competitions. Merit based awards and scholarships recognize individual team accomplishments in a variety of program-related areas – not just the overall “best.” Based upon the anecdotal comments provided by students, faculty, mentors and reviewers, as well as the successful outcomes observed since TDC’s inception; the Program’s methods serve to engage students in a well-rounded real-world engineering experience that successfully motivates and whets individual appetites for additional space-related research, design and careers. As one student aptly put it,

“Participation in this program has continued to improve my impression of both NASA and the TSGC. I have worked on other NASA related projects before, but this project is in a very different field than my previous experience. I have enjoyed learning about the additional challenges that engineers face in providing for human space exploration. I would like to combine my future career interests with the space sector due to my involvement in this program.” Student participant, Fall 2008.

Participation:

Since Fall 2002 when the TDC pilot program launched, 146 teams have successfully participated and completed the Design Challenge via the milestone model. Although evaluation comments returned by team members confess that combining both classroom and TDC requirements results in more work than what they might have bargained for; 100% of program evaluation respondents say they value participation enough to do it again and would recommend it to other students. Motivating factors cited most often on student evaluations include: the opportunity for involvement in real world projects and collaboration, program structure and management, funding and scholarship opportunities, and the experience of conference presentation. As one Fall 08 - Spring 09 participant commented:

“I would describe the Design Challenge as a supplement to our current senior design class, totaling about 1.5-1.75x the work that might ordinarily have to be completed. I would say that it helps students expand their minds and develop their problem solving skills. It also encourages students to work in groups and learn to collaborate with one another. It is an amazing developmental experience and I encourage it to all.”

Real World versus Theoretical Project Assignments:

At the beginning of each academic semester, researchers and scientists housed at NASA’s Johnson Space Center are invited to provide design project topics for student design team use. Over 200 projects have been submitted directly to the Design Challenge to date; not including those contributed on a national level by NASA’s Exploration Systems Mission Directorate. Project interest areas cover a wide range of space-related/space-application topics, including future plans to explore the Moon or Mars, current plans to upgrade International Space Station (ISS) facilities or Shuttle capabilities, Crew Exploration Vehicle (CEV) design development, and human / biological challenges associated with space exploration.

NASA-related projects can appeal to a wide range of students enrolled in STEM-related disciplines, but garner the most interest among engineering majors where capstone design course completion is a requirement for graduation. Teams from all major engineering disciplines have participated in the program, suggesting that many engineering students respond with interest

when offered an opportunity to work on a NASA project. NASA association, however, is not the primary contributing factor to student involvement. Students most often cite the opportunity for real-world engineering relevance (versus theoretical) as most meaningful, coupled with the potential for contributing some useful to society.

“Real-world engineering has played a role in motivating me”, commented one recent participant. “I have always wanted to gain experience in doing a project that could impact people in a positive way.” Fall 2008-Spring 2009 Team Member.

When asked for a “public service announcement point” they would use to attract students to Design Challenge participation, the number one “hook” cited is the opportunity to apply concepts learned in the classroom to a real-world engineering problem. By placing students in a project setting requiring team-directed development, the program gives students a pre-graduation glimpse of what it is like to pool the talents and expertise from a wide range of team members. As one faculty advisor put it:

“The Program is a wonderful opportunity to experience the “real world” (conferences, symposia, design reviews) under controlled conditions . . . This is a natural aspect of engineering work. The student learning in this aspect is immeasurable and as a faculty advisor, the load is off me and onto them. Unlike homework, quizzes and exams, the project deliverables are a (relatively) long-term commitment for the team. This is very important and a great thing for the team to get exposed to prior to entering the professional community regardless of which engineering discipline or sub discipline that they have chosen.” Dr. Harley Myler, Chairman, Department of Electrical Engineering, Lamar University, Beaumont, Texas

This view was shared by a participating student who described learning “*how much time should be given in designing, prototyping and then testing a device through the schedule of deliverables. In other words, I learned how to manage my time when it comes to finishing a project. This experience should be valuable to me when I go into industry in the future.*” Fall 2008-Spring 2009 Team Member.

One of our graduate student reviewers agrees:

“the experience that the teams gain through this program definitely would help them in understanding how things work in an industrial or research type environment, moving much beyond what they learn in the classroom. It also provides them with valuable team skills, the ability to liaison with external agencies, and communicate scientific information effectively – all of which will go a long way when they begin their careers after graduation.” Ganesh Krishnamoorthy, Graduate Student, Department of Mechanical Engineering, University of Texas at Austin.

Practical Collaborations:

Collaborations are required of all teams and most often include faculty advisors, workplace engineers, project mentors, graduate student reviewers, and members of the community.

Collaboration is cited on evaluations as an unexpected and valuable skill gained by participation in the Design Challenge as student teams explore resources outside the academic unit.

Each student team is managed by a faculty advisor who is responsible for overseeing and assessing the team's progress for a course grade. Although oftentimes the academic department is rife with experts willing to aid the design team with answers to questions about the project, the program requires that each team seek outside collaborators that can add to the scope and experience readily available to the team. As a result, academic associations are expanded to include faculty outside the home department, graduate student assistants, university lab technicians; and often include out-of-institution or out-of-state academic collaborations. One recent team member observed that *"this requirement helped us learn to communicate our product to a group and increase our team-working ability."*

Working and retired NASA employees serve as both the "customers" and designated mentors to student teams, setting the specifications and standards for each project. This workplace-based partnership helps to broaden the purely academic view by exposing the students to the dynamic of the workplace engineer and the methods they use in identifying solutions to problems. As teams are invited to visit the workplace and present their design solutions they have an opportunity to engage in meaningful dialogue and gain valuable feedback from a NASA workgroup in its "natural setting." After a visit to the mentor's workplace at the Johnson Space Center, one team commented, *"When we visited NASA, the reality and scope of the project really hit us!"*

Typical mentor motivation is characterized by of our most experienced NASA mentors:

My main motivation is in being part of the team and process in getting students excited about engineering through hands-on design projects. Getting to know the students and seeing them work as a team is personally rewarding. The team benefits by knowing that they are working on real problems and are getting real world experience. Robert Trevino, NASA EVA Technology Development Group, Crew & Thermal Systems Division and NASA Administrator's Fellow

Many teams build upon their NASA associations by venturing into the community-at-large to seek expertise. These associations have included local business partners, researchers within private industry, individuals involved in peripheral professions - all which may add substance to the development and design of the project. Come semester's end, students applaud the extended learning opportunity gained from these "extended community mentors" and cite this requirement as being one of the most "eye opening" of the participation experience. One recent TDC participant described the collaboration requirement as *"a great opportunity to discover resources."*

The TSGC community includes the program manager, graduate student reviewers and NASA-affiliated employees - all who offer review comments and counsel to teams at every submission interval. Reviews are directed toward paper presentation and formatting, technical details, and suggestions for improvement. Teams address reviewer comments with each subsequent submission. Most graduate student reviewers participate for the duration of their own academic

experience. A doctoral candidate at the University of Texas at Austin and TDC reviewer since 2003 was motivated to volunteer as a Design Challenge reviewer because of his own undergraduate experience. He states:

“I had to complete a senior design project in robotics without any formal coursework or review from peers or graduate students. I would have loved to get some help from a graduate student during that time. Therefore, it is my pleasure to give my technical feedback (in whatever modest form or amount) to upcoming engineers such as the Design Challenge participants.” Dinesh Rabindran, Doctoral Candidate, Department of Mechanical Engineering, University of Texas.

Student participants agree that receiving peer reviews motivate them through the design process. As one student team member recently commented:

“The reviewer comments were extremely helpful. The more honest the comments, the more helpful they were. It is sometimes difficult to know if you are effectively communicating your design to the reader; and the reviewer comments allowed us to incorporate the perspective and suggestions of various reviewers. I always learn something from the reviewer comments that I did not know before.”

Program Management:

Key to the continuity and evolution of the program is the dedicated attention of a long time program manager who is responsible for the program’s overall design. This Space Grant representative has been in place since the program’s inception in 2002 when the method of milestone based funding awards was envisioned as a way to increase accountability and student motivation. Structuring the program guidelines and periods of performance in an effort to gain the maximum amount of participation from the student teams continues to be a focal point. Experience, results and evaluation comments garnered after the conclusion of each program semester allow for modification and change wherever needed; with new features, requirements and funding continually adapted to meet the needs of an ever-changing participant and audience base.

“The Design Challenge program manager facilitated the entire design process . . . was always responsive and available to answer questions or resolve any issues that arose. She also provided the team with a number of opportunities to receive feedback from NASA staff.” Student Participant, Fall 2008-Spring 2009.

Direct association throughout the semester is maintained via a weekly status updates called Tuesday Tag Ups. A copy of each team’s weekly status update is submitted to the program manager, mentor, and faculty advisor. Although teams find the status updates a tedious requirement at times, this requirement is cited as a key element in maintaining a welcome and constant dialogue with TSGC. Tag Ups also provide student team leaders with opportunities to gauge their team’s productivity, to voice team-related concerns, and to ask questions about program guidelines. A recent team leader remarked:

“the Tuesday Tag Ups were an effective way of keeping the team accountable. The team was able to monitor its own progress and weekly input to the project via the Tuesday Tag Up memos submitted to Ms. Mullins.” Student Participant, Fall 2008-Spring 2009.

Guidelines, Structure and Milestones:

The program is structured so that as the team progresses through the semester, the work attached to each deliverable will build upon each previous submission and culminate in the final design. An extensive program website⁸ and Design Team Notebook⁹ provide a ready reference to teams on all aspects of participation from Team Organization and Budget Management to Guidelines for Writing the Final Report. Both Project and Scholarship earnings are associated with milestone completion as a way to give the team a sense of ownership in the manner in which they address the project as a whole.

Four required milestones are laid out and paired with specific sets of deliverables; the submission of which aligns directly with earnings that are used to support the team’s project. Each team must satisfactorily address these required milestones in order for participation and funding level to be considered complete. Although the amount of funding is low by most support standards, students and faculty report that the challenge and incremental success of completing each milestones to secure project funds plays an important role in maintaining the enthusiasm and motivation of the Design Challenge teams. One team member writes:

“The monetary rewards for the completion of each level requirement were a motivating factor in our team’s participation. Instead of getting a lump sum of funds at the beginning it felt as though we had accomplished something with each report or presentation submitted ... fostering a sense of accomplishment”. Team Member Fall 2008 – Spring 2009.

“I think the model parallels somewhat the competitive nature of federal research funding and the stages that a grant typically has.” Dr. Harley Myler, Chairman, Department of Electrical Engineering, Lamar University, Beaumont, Texas.

Required Milestones: Design Brief Submission, Levels I, II and III:

There are two categories of teams in the program, those with one-semester design courses (designated Semester I teams) and those with two semester design courses (designated Semester II teams). The milestones described below apply to both categories of teams, but the timing is different for the two categories. The milestones are described below.

- **Design Brief.** The submission of the Design Brief at the start of the semester introduces the team to TSGC and provides details about each of the team members, the primary faculty advisor and the team’s initial thoughts on how to address the design problem. Although no earnings are attached to this initial submission, acceptance into the program is set on a first come first served basis based upon availability of funding and projects.
- **Level I.** Both Semester I and Semester II teams are required to submit a written report as the primary deliverable during Level I. Submissions are circulated to two peer reviewers in addition to the program manager, faculty advisor and mentor for feedback with comments

provided to the team within one week of submission. The smallest amount of earnings is attached to Level I (currently \$75.00).

- Semester I teams submit a full proposal to clearly present the design background, objective and goal. Evidence is supplied to indicate an acceptable level of research has begun, the mentor (customer) has been contacted and project specifications and requirements received and understood. Consideration of collaboration opportunities must be included along with project timeline and budget constraints.
 - Semester II teams (those that are continuing project design for a second culminating semester) have the option of submitting a Summary of Work in Progress (SOW) in lieu of a full proposal in order to allow continuing teams to focus less on “paperwork” and more on fabrication. Teams submitting a SOW must reference the team’s Final Technical Report submitted the previous semester and provide enough information so that the objective and goals for continuation are clear.
- **Level II.** Deliverables associated with Level II are submitted three to four weeks after Level I is completed. Papers are circulated for peer review once again, and comments returned to the team within one week. A medium level of funding is provided at the completion of this Level (currently \$125.00).
 - Semester I teams are expected to submit a midterm report that demonstrates that they have expanded on the initial ideas presented in the Level I submission, and settled on a minimum of three concept variants. A method of down-selection must be included to show how they will determine the best concept of the three. A NASA-styled team mission patch design is submitted along with a draft of a power point presentation the team will offer at the Design Challenge Showcase.
 - Semester II teams once again have the option of submitting a more streamlined report to show that progress is continuing and the design objective is on track. And because they have already demonstrated proficiency in delivering an oral presentation, they may opt out of submitting a power point draft.
- **Level III.** The third Level marks the point when the team presents the final concept selected and developed. Both Semester I and II teams convey the outcome of the semester by submitting a final technical report in addition to presenting the final design in poster, model and oral form at the Design Challenge Showcase held near the NASA Johnson Space Center. The highest level of funding is provided at the completion of this Level (currently \$200).

Dr. Charles Lessard, Department of Biomedical Engineering at Texas A&M University writes that this “*structured program serves to keep the student teams on course . . . it absolutely helps that the teams have to earn the money for the project.*”

Optional Milestones:

Teams have the option of undertaking non-required milestones at any point in the semester to secure additional project funding for the team and earn an associated Scholarship award. Option Areas involve engaging activities that are intended to enhance or round-out the Design Challenge

experience and include: Education and Public Outreach, Professional Meeting Presentation and Website Design. Teams have the option to address one or all three to earn funding. Teams that satisfactorily complete all three Option Areas receive matching Scholarship funds; \$125 each for one or two Option Areas completed and \$400 for all three areas completed. Due to the extra workload and time commitment involved, only about 25% of teams take advantage of Option Area opportunities. In a recent student survey, a current TDC participant described Option Areas as activities he would not normally have been interested in pursuing, but once involved “*found them to be particularly engaging.*”

Supplemental Grants to offset the expense of team travel or second semester model building are available to all teams by application.

Program Milestones, Levels, Options Areas, and Grants are summarized in Table 1 below.

Table 1: Design Challenge Program Timeline and Deliverables

Program Timeline and Deliverables				
Milestone	14 Wk Timeframe	Team Responsibilities	Deliverables	Award
BASE	~2 wks after semester begins	<ul style="list-style-type: none"> Meet Criteria to Participate Form Team / Faculty Advisor Select a Design Topic 	<ul style="list-style-type: none"> Design Brief 	00
Level I	~4 wks after BASE	<ul style="list-style-type: none"> Project Research 	<ul style="list-style-type: none"> Formal Proposal Team Photos 	\$\$
Level II	~4 wks after Level I	<ul style="list-style-type: none"> Develop Concept Variants Site Visit 	<ul style="list-style-type: none"> Midterm Report Draft Oral Presentation Team Mission Patch 	\$\$
Level III	~4 wks after Level II	<ul style="list-style-type: none"> Finalize Design Prepare to Present Design at Showcase 	<ul style="list-style-type: none"> Showcase Attendance Poster, Model, Oral Presentation Final Technical Report Program Evaluation 	\$\$
Option Area I	EPO Activity	<ul style="list-style-type: none"> Present a STEM concept to any audience or community group. 	<ul style="list-style-type: none"> Outreach Report K-12 Lesson Plan Photo Documentation 	\$\$
Option Area II	Meeting Presentation	<ul style="list-style-type: none"> Present project work in a professional setting 	<ul style="list-style-type: none"> Presentation Report Photo Documentation 	\$\$
Option Area III	Team Website Development	<ul style="list-style-type: none"> Design team website 	<ul style="list-style-type: none"> URL 	\$\$
Supplemental Grants by Application	Travel	<ul style="list-style-type: none"> Field trips, site visits, outreach, meeting attendance 	<ul style="list-style-type: none"> Trip Report Photo documentation 	\$\$
	Long Distance Travel Supplement	<ul style="list-style-type: none"> Travel for teams traveling > 300 miles to Showcase 	<ul style="list-style-type: none"> Trip Report Photo documentation 	\$\$
	Semester II Grant	<ul style="list-style-type: none"> Semester II model building 	<ul style="list-style-type: none"> Model Budge Report Photo documentation 	\$\$

Conference, Awards and Recognitions:

Each semester culminates with a professional style conference called the Design Challenge Showcase that provides each team with the opportunity to present the semester’s work to an

audience of peers, academic advisors and NASA employees. NASA judges assess each team's Showcase performance and award top prizes in Poster, Model and Oral Presentation. Additional awards are presented based upon excellence in deliverable submission and include: Best Team Mission Patch, Best Paper, and Best EPO Activity. The semester's Top Design Team award and scholarship recognizes the team that has demonstrated the highest degree of excellence; and Scholarships recognize each award-winning team.

Both faculty and students applaud the opportunity the Showcase offers to TDC participants. Dr. Charles Lessard, Department of Biomedical Engineering at Texas A&M, describes the Showcase as the program's "*Grand Finale which motivates students since it is their conference – an opportunity to show their designs and final products. An atmosphere where all teams are WINNERS!*" Dr. Maria Oden, Department of BioEngineering at Rice University views "*the Showcase is a great chance for me to see what others are teaching and doing. For my students . . . it's a big benefit having the opportunity to present progress in person.*"

Students agree. A current team member and presenter at Showcase 2008 writes that "*the formal presentation of our ideas was just as important to the learning process as the development of the device. These were both important experiences gained from participating in the Design Challenge.*"

Motivation of Teams:

Each semester, information is collected from participating students, faculty members, and mentors concerning which aspects of the program serve as primary motivators for the teams. Evaluation comments compiled since Fall 2002 reveal those TDC aspects that are cited most often as contributing to team motivation.

- Real-World Projects (unique and/or useful projects)
- Associations (NASA, Mentors, & other teams, career exploration)
- Organized Program Participation and friendly competition
- Program Structure (milestones, deliverables, option areas and program manager)
- Design Challenge Showcase (feedback, awards and recognitions)
- Funding (earned funds, travel grants, scholarships)
- Feedback (Tuesday Tag-Ups, reviewer comments, collaborations)

"It's an imperative that NASA motivate the young people of this nation to pursue science and technology as a career choice. The future of our country and our planet depend on it! The Design Challenge provides a fun way to interact with college students on interesting projects which challenge them to exercise the skills that they are developing. The interaction with NASA experts throughout a project benefits all involved. I like the loose structure of the program which allows the team to define its interaction . . . I think the Design Challenge should be continued . . . competition is an excellent motivator and competing teams are what the real world is like." John Zipay, NASA JSC Structural Engineering Division, Team Mentor.

Outcomes:

Thus far 16 Texas institutions of higher learning have participated in the Design Challenge program. Of the 147 teams that have participated, 4 have won National Design Competitions; 10 have applied for or secured a patent; 6 projects have been pursued by NASA for further testing and 1 project is currently in use at the Johnson Space Center. All teams, regardless of their various academic levels or affiliations have succeeded in completing a NASA design project from idea phase to design solution and have presented their work in a conference setting.

Even so, the model is not perfect fit for every institution or every course configuration. The timeline and structure can conflict with what the department or faculty advisor have set in place, the earn-as-you-go funding mechanism can become a hardship for institutions without a means to provide students with funds before the TSGC funds can be transferred, and teams who must travel longer distances to the Showcase may experience schedule conflicts. Each teams level of success depends upon the joint effort and motivation of all involved and how they choose to leverage the opportunities made available through the program.

Conclusion:

By incorporating a system of milestone based funding and award as its structural component, the Design Challenge has succeeded in developing a method for motivating student design teams to become more enthusiastically involved in the process of project design. The continued success of this program is a sound indicator that students respond well and can be motivated toward a successful end when offered the opportunity to step outside the theoretical and into the real-world design project experience. The application of classroom learning in developing solutions to real world problems enhances the educational experience and provides students with a resource for career development.

In addition, collaborations outside the academic arena encourage students to seek ideas and advice from sources that may be outside the mainstream. Feedback from a variety of sources reinforces teams' capabilities and instills a sense that student work has value. Structure and clear specific guidelines foster success; and awards that acknowledge every level of accomplishment reinforce confidence and the potential for delivering a product of value to the community. Opportunities to place ideas in writing, secure funding, maintain a budget and present work to an audience of experts is fundamental training that serves students well as they move beyond the classroom and into the work world.

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