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Michael McGrath, University of Colorado-Boulder

Mr. McGrath is the Engineering Director at the Laboratory for Atmospheric an Space Physics, and Professor Adjunct in Aerospace Engineering Sciences at the University of Colorado -- Boulder.

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The NAE report on the Engineer of 2020 describes the growing separation between the needs of industry and the focus of academia, and cites the desire to close this growing gap. At the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado at Boulder, students are employed in hands-on engineering work in space instrument design, in addition to their academic program. LASP's projects routinely involve undergraduate and graduate students in instrument and spacecraft engineering, as well as mission operations. Students are paid to work a maximum of 20 hours per week during the fall and spring academic semesters, and full time during the summer. Students are given significant roles and responsibilities in the engineering phase along side professional engineers, and it is not unusual for a student with demonstrated abilities to take a lead responsibility in a design. Students graduating from CU with experience from LASP are sought after by industry, and quickly move into positions of responsibility. This paper compares the student involvement in three NASA funded missions over two decades: the Solar Mesosphere Explorer, the Student Nitric Oxide Explorer and the New Horizon's Student Dust Counter. It describes the challenges of working with students in a professional team, compares the successes and failures within each of these programs, and recommends approaches to take with student teams to enhance the probability of program success. The paper suggests that creating this kind of significant hands-on experience parallel to academic study may be an appropriate way to bridge the industry-academia gap.

LASP is an institute of the graduate school at the University of Colorado at Boulder, and is focused on space science. LASP is a mix of academic, professional and student staff who work toward the common goal of space science. LASP-designed instruments have flown to each planet on NASA missions, most recently to Saturn on Cassini, with two instruments currently enroute to Mercury and Pluto. Most of LASP's funding comes from NASA, and work is done to support NASA's goals. LASP was formed about the same time as NASA, and many of the processes and approaches developed by NASA are evident in the engineering environment at LASP today. LASP has historically involved students in engineering and mission operations – at times in significant numbers. Traditionally LASP has worked with CU's School of Engineering, but more recently has broadening out opportunities to students in business and the liberal arts. LASP is unique in that it has an academic component and undertakes education and training as would be expected in a university environment, and as an organization devoted to the pursuit of scientific knowledge, it has a business element as would be seen in industry.

The NAE study on the engineer of 2020 points out the accelerating "disconnect between the system of engineering education and the practice of engineering"[1]. The study cites reasons for this including the explosion of knowledge, the complexity and interdependence of societal problems, and the global economy. In addition to the challenges discussed previously, one of the more recent issues arising from the general complexity of business is the fact that time spent training a student takes away from time a professional can spend on his/her own work. With downsizing, and demand for increased productivity, the time available to train entry level people is very limited. It's important that a student work well as part of a team, but also important that a student be able to work independently within the team. Students who come to LASP having gained experience working on teams in the academic environment have shown a high degree of independence, and have quickly become productive within the team.[2] It used to be the case that our professional staff had time to put into training students, but this is no longer the case. We, like industry, expect that students will quickly become productive with design tools, and that they can be counted on to produce results. The same issues facing LASP are the same issues facing industry. These challenges exist today, and it is reasonable to expect current trends to continue: the engineer of 2020 will need to be able to work independently, and still effectively interface with the team.

The design and construction of equipment for space is a focused, niche business, and it's beneficial for a student to be immersed into the business to best understand it. Mentoring is a valued method of knowledge transfer within the space hardware industry, and it's common that a company's space construction practices are passed down from more experienced staff to those with less experience. Much of the information is proprietary, and companies in this business protect their corporate knowledge. While one might expect high levels of innovation and design to be inherent in the practice of space hardware development, the opposite is true: innovation is considered high risk. Heritage designs that are based on past successful performance are highly valued by the industry, and much of today's hardware and software design has its roots in a previously-flown successful design. Replicating a heritage design is a challenge in itself, and depends heavily on the documentation created for the previous design. At LASP we've found that replicating a design is often more challenging than designing and building the first unit due to knowledge being retained by the original build team. Thus the mentoring environment is an effective way to transfer this knowledge.

It can take a career to become competent in the design of space hardware, and it's not unusual to find specialists in large companies who have done so, many with a very narrow focus. Engineers who understand lubricants, bearings, motors, materials, fasteners, etc. are highly valued, and carry much of the knowledge of space practices. It is this knowledge and experience that needs to be transferred to students. Twenty years ago NASA used their sounding rocket program to train future scientists and engineers. On a sounding rocket program[3] one could quickly gain a realistic experience flying hardware into space. These rockets only provide a short observing time (5 minutes) above the atmosphere, but the value comes from replicating every phase of a space project -- most importantly the propulsion event inherent in the launch environment. Scientists and engineers who successfully fly these rockets gain the necessary management and design experience to move on to larger missions. Not surprisingly, through, the cost of launch vehicles has increased, creating fewer sounding rocket opportunities. The space shuttle and space station programs were once thought to replace sounding rockets as a way to gain flight experience, but few opportunities are available owing to a limited number of flights, and the additional work required to assure safety when humans are in the launch vehicle. This leaves few opportunities for training new employees to move into the business.

Despite the absence of a well-defined path for young engineers to gain space hardware design experience, companies involved with the development of space hardware are placing increased expectations for new engineering hires to quickly engage in the design/development process. Tighter budgets, shorter schedules and increased oversight from customers are challenging the most experienced groups in the space business, and the trend to higher levels of productivity is expected to continue. For a new hire entering the space business this can be a daunting proposition: companies are looking for students who they can count on to produce. When you couple in the challenges to U.S. leadership in space from advances in space technology in the international markets, along with the growing international competition for space in emerging countries[4], its easy to understand the challenges to educating today's space engineers. It is also easy to understand the NAE's view that "current complexities are so daunting that tinkering at the edges – reforming one course, one program, one department at a time – is no longer a viable response if we are to build the kind of robust programs in research and education now needed to strengthen the U.S. engineering community by 2020"[5]

For a number of reasons it is difficult for academia alone to provide the necessary breadth of education and training for young professionals to enter the space business. Experience with training students at LASP has had positive results, and the combination of education at the university, and the training at LASP, has been well received from industry. This combination of education and training may be part of the solution to better match the student's skills with the expectations of industry in other discipline areas.

The NAE study points to needs in several elements of the engineering education system. One of these is the area of "curricula, laboratories, instructional technologies and other tools for teaching and learning"[6]. One consideration here is the role of training in academia, and how this is integrated with a university's role as an educator. LASP's experience has shown that the combination of education with training enables the student to more quickly become productive in the design and problem solving experience. A student coming to us with specific trained skills relevant to design almost immediately integrates into our process. It is also the case that training acquired from outside of the university experience is relevant, either through a hobby, interaction with a parent, or a high school experience. The NAE study notes that attempts to change the basic engineering curriculum to include features like additional training "have not resulted in systematic change, but rather only in isolated instances of success in individual programs"[7]. It's clear that academia's focus on education will probably continue, but training is vital to completing the educational process.

One aspect of training cannot be replicated: training almost always involves the trial-and-error learning process, with failure being an element of the learning process. Through the process of training, the student experiences failure, and is encouraged to move past early failures, ultimately to success and eventual mastery. Accommodating failure is one of the most significant challenges to an entry level engineer, as their expectation, in large part based on their experience in school, is that they will be successful in their work. The ability to experience failure, accept it and move on, is a key part of the engineering process, and it's important for entry level engineers to understand that failure in not only a routine outcome, but that it is neither right nor wrong, but just part of the process. In contrast, education generally refers to a failure as the wrong answer – resulting in a penalty in the form of lower score. Learning to accept and master failure is paramount to designing hardware for space. At LASP all hardware designed to go into space is thoroughly tested in an environment simulating space, before final assembly. Sorting out failure modes is not only encouraged, it's vital: testing is key to diagnosing problems and correcting errors before launch.

Independent and productive students at LASP generally share a common experience: At some point in the design process they experience failure, recognize and accept the limits of their own knowledge, and then actively seek out support from more knowledgeable staff to help with the problem. Vygotsky describes the "Zone of Proximal Development"[8] where learning can be enhanced by the addition of a more knowledgeable person who can scaffold and encourage the individual to move beyond where he could be on his own. Failure presents a unique opportunity to teach, and if the student is open to this experience, the channel for communication between the professional and student can be unimpeded. Knowledge can be effectively transferred, and the student can gain valuable experience in the design process.

We have found this interpersonal transaction to be important in developing students, and our most experienced professional staff are skilled in mentoring students in this way. Not surprisingly, when the student understands that failure is both inevitable, as well as an opportunity to gain experience, they feel accepted as a part of the team, and they feel valued. This type of interaction creates an effective teaching opportunity that comes close to satisfying Glasser's[9] ideal classroom, where the opportunity to fail, and the subsequent interaction between professional and student, encourages the student to put the experience of learning into their "quality world" as something that they would like to repeat. When students are supported in this way they quickly gain experience and confidence and their performance improves.

LASP has three examples of programs having significant student involvement. All three have been highly success from the perspectives of operating successfully on orbit and returning high quality science observations from space to the ground for analysis. These programs include

NASA's Solar Mesosphere Explorer (SME), the Student Nitric Oxide Explorer (SNOE) and the New Horizon's Student Dust Counter (SDC) experiment. Each of these programs involved students in slightly different ways.

The SME satellite[10] which gathered data on ozone and solar radiation variability from 1981 to 1988, was the first satellite to be controlled by a university, using primarily students in mission operations. This spacecraft had a suite of instruments designed and developed by LASP engineers with some support in the design process from students, but with significant involvement of students in mission operations. SME opened the door for students to contribute, and set a precedent for increasing student involvement in later missions. Students who supported the design activities were primarily drafters, and they worked with the design engineers in detailing parts for fabrication. One student was dedicated to a professional, and productivity of the two was highly dependent on the relationship between them. In cases where the professional committed time to mentor, results were positive. Student support for mission operations was handled differently. A group of students were hired and trained together, and as a group they supported the operations aspect of the mission under supervision of a group of professional mentors. This model of training proved to be very successful. The students, in general, performed better, and there was a higher level of camaraderie within the group.

The SNOE satellite[11] was launched a decade later in early 1998 and operated for 6 years – significantly beyond its 81 day design lifetime. SNOE was an implementation of an idea developed by NASA and the Universities Space Research Association (USRA) for a university to demonstrate the feasibility of designing and building small, relatively low-cost ($5M) spacecraft that could accomplish beneficial science and include significant student participation. The SNOE satellite with 3 onboard science instruments was designed and built by CU-Boulder students, faculty and engineers. The design and construction phase involved about 110 students, including high school, CU undergrads and graduate students. This project used lessons learned from the previous SME mission, including the use of a professional project manager and systems engineer, with professionals leading teams of students in each of the subsystems. Student teams were responsible for the detailed designs in each of the spacecraft subsystem areas, for the integration of the instruments and satellite, and for performing most of the detailed testing. The small group of professionals who were involved in the project had demonstrated abilities in teaching and mentoring students. The students fused into a focused team over the course of the project. They brought enthusiasm and new perspectives. They worked productively, and in many areas provided innovative solutions to technical problems. The cost constrained facet of the project required novel approaches to accomplish the work, and many of approaches taken for SNOE have become the processes we rely on today. The impact to LASP was significant in an unexpected way: the teamwork that developed between the students and professionals invigorated the organization in a way that hadn't been experienced before.

More recently a student team at LASP completed the construction the Student Dust Counter (SDC) instrument currently enroute to the planet Pluto on the New Horizons spacecraft. SDC is the first student instrument to fly on a NASA interplanetary mission. SDC was proposed as an all-student program, with a minimum of professional oversight. This was done for two reasons: 1) to have students responsible for all aspects of the instrument design, and 2) to work within the constrained budget. In retrospect this approach worked to a degree, but both the project and the students would have benefited significantly had more funding been available to involve professionals in the process.

All three projects worked well with student involvement. SME was the pathfinder to involving students in the development of a space mission, and positive results were obtained by training a group of students who were under the oversight of professional mentors. SNOE took this model and expanded it, resulting in a significant scientific success involving a breadth of training for students. SDC went beyond both programs in increasing the level of responsibility for students. While successful this model is not preferable to the SNOE model. In looking to the future we intend to continue to use the SNOE model for student involvement in projects, and will build in the necessary resources to support a professional mentor group where student training is required.

To understand the 'engineer of 2020' we can remind ourselves that the 'engineer of yesterday' helped create the vastly different world of today. It's important to recognize academia's contribution of excellence to the historic transitions that have taken place, and the roles that teachers at all institutions have played in this process. Thomas Akins[12] sees many models for engineering education in the future, and notes that "cooperative education opens a myriad of possibilities". He notes that "there is no substitute for blending practical application with theory learned in the classroom".

Academia is being challenged to keep up with the changes, and opportunities in cooperative learning seem to be one option to assure that this happens. The practical experience that students gain at LASP strongly complements the theory learned in the University of Colorado's School of Engineering. Students need both education and training. Students benefit from both, and industry is demanding it. The transition from academia to industry needs better bridges, and institutes (like LASP) at universities can help play this role, but academia cannot build the bridges alone. Industry can be a partner by helping to better identify their needs, and where possible to professionally and financially support this evolutionary process.

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