

Hands On, 24/7 – Virginia Tech’s Joseph F. Ware, Jr. Advanced Engineering Laboratory

Odis Hayden Griffin, Jr.
Professor and Head, Department of Engineering Education
Director, Joseph F. Ware, Jr. Advanced Engineering Laboratory
Virginia Polytechnic Institute & State University
Blacksburg, Virginia 24061

Abstract

This paper details the design, renovation, and approximately six years of operation of a hands-on undergraduate student projects laboratory with approximately 400 undergraduate students authorized to use the lab during a given semester. Approximately 10,000 square feet of open space was converted into a machine shop, welding shop, CAD lab, and individual project work bays. Problems encountered during renovation, rules for operation, problems encountered, cost of operation, and staffing of the laboratory are discussed. Discussion is presented of what might have been done differently, and advice for those who would create such a lab is included.

Background and Introduction

The Virginia Tech College of Engineering has sponsored student teams in national design competitions for approximately 20 years. Beginning with the SAE Mini Baja®, progressing to Formula SAE®, Steel Bridge, Future Car, Future Truck, AIAA Team Aircraft Design, Autonomous Vehicle, Solar Decathlon, underwater autonomous vehicles, and most recently DARPA Grand Challenge, teams have been formed, supported, and have done very well in national and international competitions. The philosophy behind sponsorship of these teams has been that to be properly trained for the engineering workplace students must have not only theoretical knowledge but also the experience that goes along with realization of designs, plus the associated testing and inevitable redesign and retesting. Young engineers with only theoretical backgrounds, no matter how strong that theoretical background may be, are not as easily assimilated into the workplace without some “hands on” design realization experiences.

Those with experience sponsoring and/or guiding student realization projects know these projects are very resource intensive. The resources required span a wide range of people, including faculty, technicians and graduate students, space, equipment, and money. All of those items are scarce resources at all universities. At Virginia Tech we have been fortunate to have adequate funding, administrative support, bright students who were interested, and faculty with the desire to both work with students and to participate in the design and realization of these projects. From the early 1980’s until the late 1990’s, however, space was a continuing problem. Teams worked wherever shop space could be found. Often the space was not well-suited for the purpose, but it was available and was therefore used. Machine shop space was even more at a

premium, since for various valid reasons it was concluded that students would not be allowed to use the machine shops owned by several of the departments. In some cases, departmental machine shops assisted in fabrication. In other cases, departments believed there was educational value in the students doing their own machining, welding, and assembly. In those cases, departments used available space to create makeshift machine shops with old, sometimes castoff, machine tools. Sometimes the machine shop space was in proximity to the work areas for the various teams, and sometimes it was not. In several cases, families of local team members loaned shop space to the teams. The outcome, however, was that the work got done, the students learned, and Virginia Tech teams have been recognized as strong contenders in these competitions for many years.

The College of Engineering had long desired to consolidate a number of projects, especially those projects representing the “Car Factory,” into a common area. However, the space required for such an effort was too large to be accommodated by any available area. Also, the anticipated cost of renovation and relocation was very high. Simultaneously, the university had given the college control of approximately 10,000 square feet of contiguous space that had previously housed an on-campus laundry. The space was not, however, in good shape, with large trenches in the floor from drains, no air conditioning, and insufficient power for most uses. Numerous uses were proposed for the space, but for various reasons, including allowable floor loading, drainage, noise, ceiling height, and power availability, the space had not been found suitable for a number of research-oriented efforts. In 1995, the university made \$600,000 available to the college for renovation of the space. Dean Bill Stephenson gave the approval to convert the space into a student project laboratory and tasked the author, who was at the time an associate dean and the faculty advisor of the Mini Baja Team, with leading the effort to create the laboratory.

Facility Design

The initial design team included the author, Jerry Lucas, who had been working with student design teams for approximately 15 years and had much experience with building and renovation of facilities, Associate Dean Mike Vorster, and Dr. Charles Reinholtz. Both Drs. Vorster and Reinholtz had considerable experience with student design teams. Also involved in advisory roles were Dean Stephenson and Dr. Robert Comparin. Dr. Comparin is the former head of the Mechanical Engineering Department and was responsible for the initial creation and support of the student design teams. He also created the “Car Factory,” and was the former advisor of the Formula SAE® Team. The group went through several iterations of the design over a period of several months.

Design of the lab began based on the funding provided by the university. With that funding and 10,000 square feet of basically open space, we determined that we would be able to make the space habitable, build partitions for a machine shop, welding shop, CAD Lab, and possibly put up some temporary partitions for project work areas. There would be little, if any, money left for furnishing the labs and shops, so the plan was to use the current old machine tools, plus whatever CAD equipment could be scrounged, to furnish the lab. Since there was a fixed amount of space, we deliberately made the machine shop and welding shop somewhat small, but large enough to accommodate the number of machines required to support the projects that would occupy the remaining space. We were constantly aware that shop space took away from project space, and

vice versa. We also wanted to have a classroom/conference room in the building for student presentations. The college has enjoyed good support from a number of companies over the years, and the conference room appeared to be not only a good place to hold discussions with corporate sponsors, but also a place for the students to make presentations during their projects.

As the design process began, Dean Stephenson made the creation of the centralized student project facility one of his top priorities. It was at that time that Joe and Jenna Ware decided to make a significant gift to the college. The Ware gift made the creation of a first-class centralized student project lab a reality. The final design included a showroom at the entrance to the lab, some new machine tools, new CAD stations, and new equipment for the welding shop. In September 1998, the newly renovated facility was dedicated as the Joseph F. Ware, Jr. Advanced Engineering Laboratory. The Wares desired that the laboratory would be primarily for the use of undergraduate students, and that is indeed the case. It is noteworthy that Joe Ware is a 1937 graduate of the VPI Mechanical Engineering Department, having been a member of the first class to receive degrees in "Aeronautical Engineering." He subsequently spent his career as a Flight Test Engineer at the Lockheed "Skunk Works," working on every major project, including the F-104 Starfighter, U-2, and SR-71 Blackbird. Arthur Klages, a 1942 Industrial Engineering graduate who was the founder of the Burlington Handbag Company and the inventor of a number of mechanical devices used in the garment industry, also made a significant gift of machine shop equipment, including a lathe, mill, drill press, and bins full of bits and tooling.

All shop spaces were designed under the assumption that all areas except the manager's office and the tool room would be accessible by undergraduate students and that the students would do the bulk of the fabrication, as had been done in the past. To meet building codes, the shops were designed with adequate power, lighting, fire protection, and ventilation, with extra ventilation in the welding shop. The CAD Lab was located next door to the machine shop so that once direct CAD to machine NC programming was available the two areas would be readily accessible to each other and any wiring required would be minimal. The university contracted with an architectural firm for the detailed design and to create the actual demolition and renovation plans. All aspects of the design, including power, ventilation, fire sprinklers, and access meet current public and University building codes. The overall layout of the lab is shown in Figure 1.

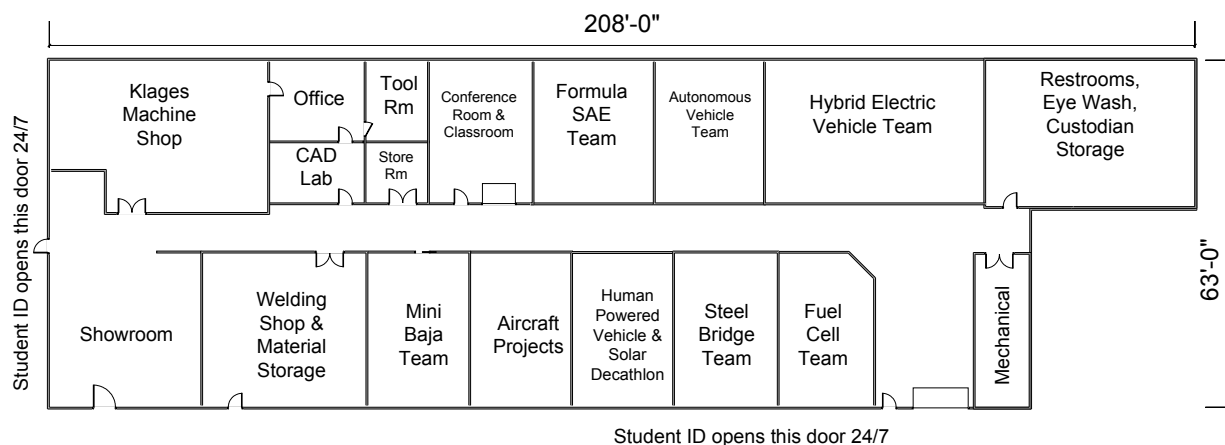


Figure 1. General layout of Ware Lab

Once we designed the rigid partitions for the shops, showroom, and conference room, the remainder of the space was available for student project shops. Two options seemed reasonable: to leave the space open and allow the various teams to share space, or to create some sort of partitions so that each team had its own work area. Being astute students of literature, we recalled “Good fences make good neighbors” and decided to subdivide the area into distinct work areas, each with its own walls, doors, and lock. In all honesty, that decision was also the product of having seen the discord that arose when several teams had been required to share a common space in the old shops. Since we wanted the overall space to remain as reconfigurable as possible, we decided not to build more partitions but rather to use wire cage materials.

Each work bay is equipped with compressed air and a large number of 110 volt outlets. There is a fire extinguisher and a first aid kit in each bay. A drill press is the only machine tool allowed in any of the bays. We have received requests to allow small mills and lathes in the work bays, but our policy has been that the machine shop is available and that such tools in the work bays would result in safety problems.

Renovation

Anyone who has dealt with renovations knows that there are a multitude of problems that arise, and this project was no exception. Although the architects did a reasonably good job of facility design, there were several instances when their opinions differed from ours. One example is that since many of the projects were automotive, the architects wanted to put some lamps that looked like streetlights along the central hallway, along with some creative, but seemingly frivolous, helical stripes on some of the interior columns. In the end, we did agree to a yellow dashed line down the center of the hallway, simulating a roadway, as shown in Figure 2.



Figure 2: View of hallway with work bays on either side

Other complications during the renovation involved having classrooms on the floor above, which meant that we had to pay overtime for noisy work that could not be done during the day. Fortunately that work was minimal and did not have a large effect on the overall renovation budget. There were also problems with design of the electrical system, when we found that during the design the power had been stepped up from 220V to 440V at one end of the building and then stepped down to 220V at the other end, with no need for 440V anywhere. There was also a very expensive door with a window purchased for the custodian's supply closet. We were fortunate that Jerry Lucas was involved with oversight of the renovation on a daily basis and was able to identify many of the problems before they happened, eventually saving a large amount of money on the renovation.

One of the bays, designed for the Hybrid Electric Vehicle Team (which is currently involved in the Future Truck Competition) required a lift for their vehicle. Due to the concentrated loads caused by the lift and the weight of the vehicles, additional support had to be added on the floor below the shop.

In the end, the renovation of 10,000 square feet cost approximately \$800,000, not including new machine shop and welding shop equipment. We used a portion of the Ware gift to purchase some new machine tools and welding shop equipment, as well as cover renovation expenses that were not covered by the university funds.

Outcome of the renovation

The resulting space, with the industrial cage material used for bay walls, has proven to be quite functional. Although it is possible to climb over the cage from one bay to another, we have no evidence that this has happened. Students tend to respect the space of the other groups as they would have their own space respected. We decided to install double wide sliding doors on all of the work bays to allow moving relatively large objects in and out of the bays. One of the work bays is shown in Figure 3.



Figure 3: Typical work bay

The concrete floors in the Lab have been somewhat problematic. As was previously mentioned, the floors initially had trenches for drains, and those had to be filled. As a result, there are seams throughout the facility and the concrete is not uniform. In order to make the floors look right, we decided to have them sealed and painted with an epoxy paint. Before long, we found that brake fluid, and several other fluids in use, removed epoxy paint from concrete. The problem is not severe, however, so the only effect is cosmetic.

Operational Information

In addition to creation of the Ware Lab, Dean Stephenson also provided financial support for two technicians, a Laboratory Manager and a Machinist, and the college continues to provide that support, along with an operating budget of approximately \$10,000 per year. The Lab Manager, Jerry Lucas, oversees the daily operation of the Lab, serves as the enforcer of the rules, and also creates and oversees all student certification procedures. The Machinist, Derwin Stafford, assists with the certifications and also provides assistance to students as they have questions about the machining and/or welding operations associated with fabrication of their projects. These two individuals work from 8:00 am to 5:00 pm weekdays, although they have been persuaded to assist in the evenings and on weekends as competition time nears.

The Ware Lab operates under a fairly simple set of rules. Before space was allocated initially, department heads and faculty advisors had to agree to the basic ground rules, that projects were to be of multiple year lifetime, teams were to be composed primarily of undergraduate students, each team is required to have a faculty advisor who is frequently present, and the project must be financially supported. Team members had to agree to some rules as well, including: the health and safety of persons working in the lab is paramount, safety glasses are worn constantly, nobody is allowed to work alone, hearing protection is worn as necessary, music cannot be loud or offensive, engines are not to be run inside, there is to be no painting inside, and bays are to be locked when no team members are present. Students are required to clean machines and the floor in the shops as soon as their work there is done.

The lab manager is the self-appointed cleanliness enforcer of the lab, with the complete support of the lab director and the dean. He has the authority, and the inclination, to lock down any shop or work bay he believes is so untidy that the health or safety of the students is at risk. It is amazing to see how clean a shop can get in a short period of time when students are a few days away from their competition and their shop is in danger of being locked down for lack of cleanliness. It is not a popular thing for the lab manager to do, but it does occasionally happen. It is always effective in getting the area cleaned up, often with the help of students from other teams who were not involved in making the mess.

To have access to the building, students must be registered with the lab manager, who arranges for their student ID cards to open the outside doors. This access is 24 hours a day, seven days a week and allows access to the work bays and the CAD Lab. Separate electronic locks on the machine shop and welding shop allow access between 8:00 am and 11:00 pm to the subset of students authorized to use those shops. Students are allowed access to the machine shop if they have taken a course entitled "Manufacturing Processes Laboratory," and have subsequently passed a certification test administered by the lab manager. The certification test involves

machining one part using a lathe and another part using a vertical mill. Parts must be machined within specified tolerances. The test normally takes approximately two hours to complete. Students are allowed access to the welding shop if they have taken and received a grade of B or better in a course entitled “Advanced Welding Technology,” in which the students learn gas, arc, MIG, TIG, and plastic welding techniques, along with gas and plasma cutting. Students are allowed in the CAD Lab if they have attended an orientation and agreed to the rules of the CAD Lab, which include appropriate use of information systems, no hacking, no attempts to repair hardware, and so on. The CAD Lab is supported through the ME Department CAD Lab, which serves some resources from its primary location in another building via a high-speed network.

The former shop areas had operated with a minimum of rules, generally remaining open 24 hours a day, seven days a week. What we noticed, however, was that much of what was fabricated in the early hours of the morning was scrap, and that students who were very tired had no business operating machine shop equipment. As a result, we made the decision to allow 24 hour access to the overall building, and thus to the individual project areas, but to close the machine shop and the welding shop between 11:00 pm and 8:00 am. Adverse student reaction to the curtailed hours was immediate, loud, and of approximately two years duration. After approximately two years, however, the students who had worked in the old shops were gone, and the newer groups realized that first-rate shop space was worth the effort of abiding by a few simple rules, including somewhat limited hours. The rule has been that if students really need to “pull an allnighter” in the machine shop, the faculty advisor must pull an allnighter with them. In my years of advising the Mini Baja Team, the students were never able to convince me to pull an allnighter with them, and the existing machine shop and welding shop hours were found to be sufficient. We have installed security cameras and a webcam which can be checked remotely, and if students are found in the shops after hours they are asked to leave. This has happened, but it is rare.

When projects end, or possibly move on to other space due to special needs, a call is put out for proposals for occupancy of the vacant space to all department heads, who pass the call along to interested faculty. Approximately four proposals are received for each available space, and the decision is ultimately made by a committee formed of the director, associate director, manager, and faculty representatives from the departments that have projects in the Lab. The decisions have not been disputed up to this point.

Current projects in the Ware Lab include Formula SAE®, SAE Mini Baja®, Autonomous Vehicle, Human-Powered Submarine, Hybrid Electric Vehicle (Future Truck), Fuel Cell Team, Steel Bridge Team, several airplane projects, Human Powered Vehicle, Solar Decathlon, Autonomous Underwater Vehicle Team, and the Grand Challenge Team. All of those projects participate in the national competitions annually (with the exception of Solar Decathlon, which is on a longer cycle and Grand Challenge, which is new). “Alumni” projects include the Personal Electric Rapid Transit System (PERTS), which needed larger space for prototype testing, and the Hokie SAT satellite group, which moved into a clean room for final assembly of the microsatellite. Additional details of the Ware Lab and the current projects are available online at <http://www.eng.vt.edu/warelab/>.

Funding

Personnel costs are the largest item requiring continuing funding. However, operation of a facility of the nature of the Ware Lab requires full-time oversight by faculty and staff. Even with qualified staff members present, students sometimes damage machine shop and welding shop equipment due to inexperience and/or carelessness. Without supervision, equipment damage and student injuries would increase. One must realize that creation of such a facility imposes continuing funding requirements.

The other significant funding requirement is for repair and replacement of equipment and tools. This expenditure can either be covered by funding directly in the lab budget or by making project teams responsible for their own tooling, such as bits and clamps. Project teams purchase their own materials, with the exception of a relatively small quantity of material that has been purchased through surplus agencies. The project teams are responsible for their own hand tools. Corporate donations of air tools and electric drills have allowed us to equip each work bay with those items at small cost to the teams.

The method of obtaining funding for the project costs varies from project to project. Sources include departmental funds, funds solicited by students, funds donated by corporate sponsors, and funds donated by alumni. In reality, almost all projects are a mixture of those sources. Some departments choose to fund the entire project cost, some choose to have the students obtain part of the funding. Requiring the students to obtain part of the funding results in closer attention to the budget and increased student efforts to make designs cost effective. Travel to competitions is also a significant expense. Travel for a team of 20 students to a week-long competition results in large hotel bills. Students are typically required to purchase most of their food on these trips, with hotel costs coming from other sources.

Experience and lessons learned

At this time, the Ware Lab has been in full operation for over five years. It has become one of the primary tour stops on campus for visitors, whether they are scientists, engineers, company recruiters, politicians, or prospective students and parents. The lab is always open on graduation day so that the new graduates can show their parents the project that constitutes the capstone experience of their curriculum. In almost all cases, the students who work on the projects are the exciting part of the tour. By simply asking a student to speak for a few minutes about their project, the visitor is usually entertained for as long as they will listen, complete with offers to sit in the vehicle, crawl under it, or review pictures of the previous competitions. Students always include details of the theory, design, fabrication, and testing. The students learn to be what all employers want – engineers who speak enthusiastically and extemporaneously about their projects. The graduates of these programs are highly sought after and are employed in some jobs that most engineers would only dream of – with all major auto manufacturers, aerospace companies, racing teams, energy companies, and the list goes on. Educationally, the Ware Lab has been a great success.

Operationally, after five years of operation of the facility, it looks as good as it did when it was dedicated in September 1998, as the pictures show. Given a first-class laboratory, students

believe that it gives them a leg up on the competition, which it does. They are also willing to put in the time to keep it looking first class. As alumni, they are successful in convincing their employers to donate materials and components, and they also occasionally send donations. When they come back to campus as recruiters for their companies, they always want to talk to the students in the lab, and those students are often the first to receive offers, because employers know that they not only understand the theory of engineering, but that they can also put it into practice. Figure 4, the showroom with the trophy case and a project or two on display, is the normal entry into the lab for visitors, so they see from the outset that performance, along with the required engineering and documentation, is important.



Figure 4: Showroom with trophy case and project display

In terms of students using the facility, the number of students with approved access to the Ware Lab is typically about 400 at any given time. Of those students, approximately 250 are seniors. The others are students of all academic levels. Some are receiving course credit for participating, while others participate as volunteers for a variety of reasons. Access to the machine shop is typically approximately 30 students, with approximately 20 students who are allowed to use the welding shop.

One of the lessons we learned was that the open space design did not allow for work that was dusty or smelly. We were faced with the need to accommodate those projects that required a facility to perform that work, which includes fabrication of fiber-reinforced polymeric materials and fabrication of components requiring considerable sanding. We were fortunate to obtain

approximately 1,000 square feet of additional space downstairs in the same building to meet that need. The university facilities department designed this laboratory to have considerably more ventilation than the main facility to make it safe for conducting work that was dusty and/or smelly. Students are required to wear whatever protective gear (gloves, respirators, etc) is appropriate when performing work in the downstairs area. Cleanliness rules are also in effect in that lab, where buildup of dust of various kinds could pose considerable health hazards. The renovation of that space cost approximately \$60,000, which the dean provided. The downstairs laboratory is shown in Figure 5.



Figure 5: Shop for dusty/smelly project work

Conclusions, recommendations, and advice

The Ware Lab has proven to be a significant facility and an integral part of our educational programs, and we believe it is unique. Students who participate in the design realization projects housed in the Ware Lab are highly recruited and have no difficulty in becoming contributors in real-world hardware projects. In addition to the project experience, the large number of tours through the Ware Lab, typically several per week, offers the students numerous opportunities to make short presentations on their projects, thus developing their speaking and presentation skills.

Those of us involved closely with the Ware Lab frequently wonder how we could have been so fortunate as to have been assigned over 11,000 square feet of space and given over one million dollars to create a project laboratory for undergraduate students. Development of this facility has been the opportunity of a lifetime. It is paying large rewards for our undergraduate students, our educational programs, and for the college and university as well. It is a publicity tool of significant magnitude and has been written up in almost every campus publication. Recently, it has become a tour stop when the local economic development people conduct visits for companies considering relocating to our area. We have standing offers of gifts in kind from several companies if we are in need of their products.

We have been asked what we would do differently if we were to set out to do it again and what advice we would give to others developing such a facility. I do not believe we would do much differently if we were to do it again. However, recall that one of our goals was for the space to remain as reconfigurable as possible. If that was not a requirement, possibly solid partitions would have been used for each work area. As shown in Figures 6 and 7, there is no extra room in the machine shop, and the welding shop has become somewhat crowded after we added a material storage rack to allow the teams to put some materials there to unclutter their work bays. However, larger shops would have resulted in less project space. The lack of a facility for painting is a continuing problem. However, considering current environmental regulations related to painting, the cost of such a capability in our current space is prohibitive, and the aesthetics of any exterior additions are strictly controlled by the University Architect. Those with space in other configurations or less strict exterior modification regulations might not have this limitation.

The addition of the showroom, although it did not seem completely justified during the design process, was a good decision. With several tours per week, it gives the person conducting the tour a place to meet the visitors and give them an overview of the lab and a look at whatever projects are displayed in the showroom at that time. Anyone considering development of such a facility should consider its value as a showplace and resource for recruiting both students and faculty.

Do not attempt to begin a laboratory such as this with less space than you need. Space is precious, and contiguous space is practically nonexistent. No matter how much space you have, it is not really enough. Even if you do have enough space, it will become filled with projects from previous years and other assorted things of great importance that must eventually be scrapped. The management of the lab needs to have the authority and the will to get rid of things that are no longer needed in order to keep the facility from becoming a storage building.

The final piece of advice is that you absolutely must have strong support from the dean and the heads of the associated departments for such a facility. Without that support from the administration, the facility will probably not survive, and even if it does survive there will be a constant struggle to maintain even a minimal capability.

Additional photographs

Below are a few additional photographs of parts of the Ware Lab.



Figure 6: Partial view of the machine shop



Figure 7: Half of the welding shop



Figure 8: View from lobby to machine shop



Figure 9: CADD Lab

Acknowledgements

The Ware Lab could not have become a reality without the vision and support of former Dean Bill Stephenson, and subsequently Interim Deans Malcolm McPherson and Ed Henneke. Dean Hassan Aref, who joined VPI&SU in March 2003, has become a strong supporter of the Ware Lab as well and has coined the phrase “Hands on, minds on” to characterize our approach to undergraduate education. Former University Provost Peggy Meszaros was instrumental in providing the initial renovation funding from the university. Obviously, without the generosity of Joe and Jenna Ware the facility would be a shell, and there would probably be no new equipment in the machine shop or welding shop. Without the machine shop tools donated by Arthur Klages, the machine shop would be minimal. The design team (Griffin, Lucas, Vorster, and Reinholtz) gave many hours over the course of approximately two years before the facility opened, and Jerry Lucas has done an excellent job of managing the facility. Dr. Walter O’Brien, head of the Mechanical Engineering Department, has been consistently strongly supportive. Also, we cannot forget the contributions of Dr. Bob Comparin, who conceived the facility in the current space,

stormed into my office sometime in 1994 and said, “I need a million bucks,” and then proceeded to tell me the basic concept that became the Ware Lab. We will also all remember Bob’s praise for the design team when he first saw the initial plans for the lab – “You guys didn’t screw this up nearly as bad as I thought you would.” Susan Sink, the former Director of Development of the College of Engineering, worked very hard with great success to assist with funding for a number of efforts. There are too many corporate sponsors to name, and to begin a list would guarantee leaving someone out. Since our contacts at most of those companies are our alumni, they have given back to the university in large measure, and we are grateful.

Author information

HAYDEN GRIFFIN has been the director of the Ware Lab since its inception. He is currently professor and head of the Department of Engineering Education (formerly the Division of Engineering Fundamentals) at VPI&SU. He holds BSME and MSME degrees from Texas Tech University and a Ph.D. in Engineering Mechanics from VPI&SU. He had 13 years of experience industry and government laboratories prior to joining VPI&SU in 1985.