Mentoring Students in a Capstone Design Experience

Timothy Dewhurst, Gerald Brown

Department of Engineering and Computer Science, Cedarville University, Cedarville, Ohio, USA

Email: dewhurst@cedarville.edu, gbrown@cedarville.edu

Abstract

The Cedarville University Mechanical Engineering Program requires a capstone design experience for each of its students. Many of these projects are focused on intermural competitions, while others involve biomedical, industrial, or societal goals. The authors advise Cedarville's Solar Boat Team; Dr. Dewhurst is a mechanical engineering faculty member, while Dr. Brown is an electrical engineering faculty member; all of the students in the capstone experience are mechanical engineers. The solar boat project has been highly successful due in large part to the mentoring relationship the advisers have established with the students. The advisers have tried to achieve a balance between providing project management, technical expertise, and manual labor. What has resulted has been a program that we describe almost as an apprenticeship, where the students and faculty work side-by-side throughout the life of the project. Each faculty member approaches the role of adviser differently, and the adviser role varies from student to student. This paper discusses the nuances of the adviser-student role and how development of a proper balance has been the key to the boat team's success.

Keywords: mentor; adviser; apprentice.

1 Introduction

The faculty-student relationship plays an important role in the success of project-based engineering education, but the manner in which advisers interact with students varies significantly from person to person and project to project. The authors are project advisers to the highly successful Solar Boat Team of Cedarville University, which has won 6 Solar Splash World Championships over the past 9 years, and was the top university in the Netherlands' 2012 DONG Energy Solar Challenge. The relationship between the faculty and students has been a key factor in this success. In this paper, we focus on the faculty-student relationship, but first we describe the nature of the competitions and how they are integral to the mechanical engineering program at Cedarville University.

1.1 The Competitions

There are two competitions in which the solar boat team has participated: Solar Splash (USA) and the DONG Energy Solar Challenge (DSC) in the Netherlands. In each competition the teams enter an electrically-powered, piloted craft; the energy is provided by solar panels. Solar Splash is a multi-event competition combining high speed, short distance events (50 km/hr, 300 m) with slower, long races (12 km/hr, 50 km). The DSC is a 5 day race following the *Elfstedentocht* course of 220 km with sustained speeds of 15-20 km/hr. The *Elfstedentocht* (Eleven City Tour) is a famous Dutch skating race that circumnavigates the canals and lakes of the Province of Friesland. Solar Splash is open only to universities around the world, while the DSC is open to both academic and industrial teams. Important elements of a successful boat are the solar panels, maximum power point tracker (MPPT), batteries, motor controller and motor, drive train, propeller, hull, and energy management system. The electrical system is more than 50% of the overall project and involves basic circuits, control systems, microcontrollers, printed circuit boards, data acquisition, and power electronics.

1.2 The Senior Design Course – Project-Based Engineering Education

The mechanical engineering program at Cedarville University requires a "capstone design experience" which involves the design, manufacture, and testing of a device. This course includes two 3-credit courses; one in the fall semester, one in the spring semester of the senior year. The requirement to iterate through the engineering design process and produce a workable product defines Cedarville's approach to Project-Based Engineering Education. Using these products to compete against other universities provides the ultimate test of the quality of the product and the efficacy of the educational methods used in this process.

Each year the solar boat team is primarily comprised of students in this course who choose to work on a competition team, and as such, the team is almost entirely composed of mechanical engineering seniors who have not worked on the project in any of their previous undergraduate years.

Cedarville provides a sound, fundamental mechanical engineering program, but these students have no specific coursework in the design of hulls, propellers, or solar arrays. Being mechanical engineers, they have no training in microcontrollers or printed circuit boards; they do have coursework in circuits, electrical machines, automatic controls, and digital logic design. Thus, the design of almost every component of the boat is outside of the normal training the students receive during their standard coursework. For competition teams, each student is expected to work on the project approximately 15 hours/week over 30 weeks, committing 450 total hours to the project. In reality, student members of a successful boat team will contribute far more hours than this.

Two faculty advisers work with these students. Dr. Tim Dewhurst is a mechanical engineer with a focus in solid mechanics, while Dr. Gerry Brown is an electrical engineer with a focus in power electronics. The advisers hold weekly meetings with the entire team or sub-teams. However, it is the informal faculty-student interaction in the office, advising in the laboratory, or working side-by-side in the shop where the most effective education takes place. The relationship between the faculty and student is critical to the success of the project and is the subject of this paper.

2 Background Research – Teaching Models

There are many ways to classify the faculty-student relationship in project-based engineering education. The traditional role has the faculty member playing the role of teacher, imparting knowledge to the student. However, in a project, there are other types of relationship models that might better exemplify how the students learn.

2.1 Teacher-Student Model

In the traditional model, the faculty member is the teacher and the possessor of the knowledge. It is the expected role of the faculty to teach the student out of a wealth of knowledge. Typically, efforts to improve this educational model focus on the faculty member's ability to teach and the teacher's mastery of the information. Improved teaching techniques often focus on the mode of delivery and lectures are often used to convey the information to the student. Thus, the teaching skills emphasized are lecture organization, daily objectives, outline of the information and presentation skills such as delivery, visual aids, etc. When a lecture format is used in engineering education, it is usually accompanied with "homework" equation problems to help the students develop a certain skill set.

Umbach and Wawrzynski (2004) concluded that faculty play a huge role in student learning, but indeed this learning is more effective when "faculty members use active and collaborative learning techniques, engage students in experiences, emphasize higher-order cognitive activities in the classroom, interact with students, challenge students academically, and value enriching educational experiences" (p. 2). The use of project-based engineering education is consistent with their conclusion.

This traditional model of faculty-student relationship has serious deficiencies when carried over to a design project such as the solar boat. The scope of the project is so large and multidisciplinary in tasks that it is a rare project adviser who could be the "holder of all knowledge" or the "resident expert" with all the answers. Successful completion of the project often requires work in areas where the adviser has very little experience and the traditional faculty-student relationship seriously jeopardizes the success of the project.

2.2 Manager-Engineer Model

In industry, the manager of an engineering group may or may not be the "holder of all knowledge" or the "resident expert." Good managers are those who can guide their engineers and help them achieve the group's objectives. Often, the manager has a significant level of expertise, but not all good engineers make good managers. Just as often, the manager may not be the best engineer in the group. The manager has many responsibilities, chief of which is to ensure that the engineering group meets its objectives, and in achieving these goals, the manager typically does very little engineering work. Instead, the role of the manager is to facilitate the progress of those doing the engineering, holding them accountable as to the quality, quantity, and progress of their work, and interacting with other engineering groups to ensure the company can meet its engineering objectives.

In this role, not only is the manager doing very little, if any, engineering, but the manager does not necessarily know more about the engineering details of the project than individual engineers within the group. To enhance productivity, the company will invest in training the manager to be a better leader of people; it will not focus on improving the manager's engineering capabilities. Thus, training will focus on project management, Gantt charts,

storyboarding, interpersonal skills, conflict resolution, presentation skills, business skills, etc. As a result, the company will be more successful, and will get more production from its engineers, when the manager leads the group well. Improving productivity does not focus on improving the manager's ability to impart knowledge to the engineers. Instead, productivity is enhanced when the manager knows how to better lead the group.

A common drawback to promoting strong engineers to management positions is that many focus on the engineering aspects of the problem instead of focusing upon the people (engineers) (Vallabbaneni, 2002). Engineers as managers are often criticized for "micromanaging," trying to understand every engineering aspect of a large project. However, once an engineer becomes a manager, that engineer can be a good manager by focusing on management issues, of which one of the most important is leadership (McGill, 2007). While some corporations feel that engineers make poor managers because they are unable to understand the world of business, Suhir argues that an engineer "with entrepreneurial skills has a better chance than a business administrator of moving innovations from research into manufacturing and the marketplace." (Suhir, 2011).

2.3 Master-Apprentice Model

A third model for faculty-student relationships in project-based engineering education is that of "apprenticeship." In this practice "novices" learn a specific trade from a "master." While the practice has existed for thousands of years, the apprenticeship model became well established in medieval Europe and was heavily used in the American Colonial period before the rise of the industrial economy. Modern apprenticeship programs began in the USA in 1911 and in 1937 the USA Congress passed the National Apprenticeship Law (the Fitzgerald Act) which formalized apprenticeship programs. The practice continues today among trade unions such as electricians, plumbers, pipefitters, etc. and in our region there is a strong apprenticeship program (Ohio, 2013).

In the Apprenticeship model, novices learn a trade by working side-by-side with masters. Formal programs require a certain number of hours (2,000-10,000) before the novice has completed his training and is able to work alone. Some have drawn parallels between apprenticeship programs and a university education where students achieve different certifications (Bachelors, Master, and Ph.D. degrees) before they are recognized by the academy.

Project-based engineering education has an element that parallels the apprenticeship model. Throughout the course of the project there are numerous times when the student and faculty member work side-by-side on a circuit board, constructing a complex component, or poring over calculations. In the design phase, the two will spend many hours discussing various design options including the manufacturability of those designs. In the building and testing stages they will spend hours working together to bring the project to completion.

3 Cedarville's Approach to Project-Based Engineering Education

In our capstone design sequence, we find that the faculty-student relationship is often a mixture of the three models described above. In many cases, we know the subject matter much better than do the students and so we are the experts and final authority; we are the teachers. However, we must also assume the managerial role as we supervise the team; especially as teams grow in size (leaving less time for individual students), or the students work on aspects of the project about which we faculty know very little. Finally, when a project is very technologically challenging to the students or the work required to be successful becomes excessive, we step in and work side-by-side with the students. At this point we become mentors demonstrating how tasks are to be done; we are also workmates, simple helpers, ensuring that the work is brought to closure. As the project nears completion, and certain tasks must be finished to be competitive, we find ourselves spending a great amount of time working alongside the students.

Before discussing the faculty-student relationship further, we will first give an overview of our capstone design course.

3.1 Project Selection and Scope

We offer students a number of possible projects for their capstone experience. A high percentage of the students choose to work on competition teams (solar boat, Shell Eco-marathon, Formula SAE, SAE Aerodesign, etc.). We also offer non-competition related projects such as bioengineering, wood bicycles, etc. Students indicate their preference for the different projects but the faculty decide the final makeup of the teams.

Projects are reviewed for engineering content including depth of analysis, scope, and manufacturing content. We strongly prefer projects that require that a design be built and tested as it is in these stages that the quality of the design is revealed. The construction stage identifies problems with the manufacturability of the design, while the testing phase shows weaknesses in the performance of the design. Engineering projects that are just "paper designs," neglecting the manufacturing and testing stages, do not provide the same level of engineering education. Projects

associated with intermural competitions provide the ultimate real-world experience as teams are required additionally to subject the design product to the harsh realities of competition.

3.2 Setting Goals and Responsibilities for each Team Member

A major reason for the success of our solar boat team is that each team member is assigned an area of responsibility, and we set performance goals for each member. It is imperative that responsibilities be individual in nature (not group) to hold individuals accountable. We emphasize to the students that in industry they must be able to identify their unique responsibilities and goals. Without these, employers might question their value to the company. In the academic environment individual goals and responsibilities are necessary if individual grades are to be given. Also, there is a high likelihood that unassigned areas of responsibility will not be completed. A more extensive treatise on how goals are set for the team as a whole and for individual members is given elsewhere (Dewhurst and Brown, 2013). Setting reasonable and sufficient goals is a critical part of the success of the team.

3.3 Areas of Responsibility are usually Outside of any Classroom Training

During this assignment of responsibilities we find students reluctant to accept work in an area for which they have no direct training (e.g. hull & propeller design, electronics, microcontrollers, etc.). However, if the team is to be successful, then work must be done in each of these areas. As a result, students are regularly assigned work for which they have insufficient knowledge. This is not a negative; this is a major educational opportunity when handled correctly. One student (Ronco, 2013) gives further information on the benefit of working on a cross-discipline project.

The main advantage of providing such challenging opportunities is to teach students how to approach a problem for which they have little or no training. When our students start working in industry and are approached by a manager with a task that is unfamiliar to them, we want them to be able to accept the assignment with a confidence based on their knowledge of how to approach a project for which they have little training. To get students to this level of confidence we, as project advisers, have to train them how to approach an engineering task.

How closely we work with individual students, and what faculty-student model we adopt, often depends upon how well their education background matches their area of responsibility on the project. We assume the Teacher-Student relationship where there is general knowledge that must be imparted to a large number of team members. We assume the managerial role for a large team or if members are working in areas for which we have little expertise. Finally, we use the apprenticeship model if the students need very detailed guidance to accomplish their tasks. While we use a combination of all three models, the apprenticeship model imparts the most knowledge, and it is the most time consuming for the faculty adviser.

4 The Faculty-Student Relationship – Cedarville's Solar Boat Team

As outlined above, we have identified three faculty-student teaching models that are commonly used in project-based engineering education: the Teacher-Student, Manager-Engineer, and the Master-Apprentice models.

4.1 The Traditional Teacher-Student Relationship

The traditional teacher role plays a very small part in project-based engineering education. On the solar boat team we rarely, if ever, conduct sessions that exhibit the traditional teacher-student relationship of lecturing and note taking.

4.2 The Manager-Engineer Relationship

Throughout the project we attempt to better prepare students for industry by interacting with them in the same way that their managers will interact with them. As a result, the Manager-Engineer model most closely matches how we as advisers interact with the students.

We are responsible for the overall completion of the project but the students are primarily responsible for doing the engineering work. We focus on setting reasonable goals, helping to provide whatever is needed to accomplish these goals (materials, finances, time, etc., or guidance to procure these resources) and hold the students accountable (i.e. ensure that they are making adequate progress toward their goals). There are other important managerial duties of the faculty adviser, such as project financing and logistics, but we will not discuss them in this paper.

We implement the Manager-Engineer model, as found in industry practice, in two primary ways. Firstly, we have regular team meetings where we meet with the whole team (10-12 students) or with smaller sub-teams (3-4); we hold these meetings on a weekly basis. Secondly, we have one-on-one meetings in the adviser's office that are typically

unscheduled, but provide a welcome forum whenever a student feels a need to provide an update or discuss how to approach a particular problem.

In our team meetings, each student is required to give an informal account for work accomplished that week. The adviser asks appropriate questions to assess the quality and quantity of the work accomplished and to determine whether or not the student is on-track. Technical details must be concise and are usually kept to a minimum so that everyone has time to report on progress. Team meetings keep everyone apprised of the overall project status as well as the progress of individual members. They help keep individuals accountable to the team and members can see how their work affects other aspects of the project.

In industry, individual engineering groups regularly interact with other engineering groups. When one group encounters a problem and needs to make a change in a system that negatively affects other groups, the two groups must work out a compromise that allows the team to reach its overall objectives.

A clear example of this type of interaction concerns our motor and propeller. Our motor was designed to run efficiently at 4000 rpm which, with a 5:1 gear ratio, gave a propeller speed of 800 rpm. However, our propeller designer found that the propeller would be 4% more efficient if it were slowed to 600 rpm. In our team meeting, the motor group evaluated the negative impact of the speed change and ascertained that reducing the motor speed to 3000 rpm (propeller speed to 600 rpm) would reduce the motor efficiency by only 2%. Thus, decreasing the motor speed would yield a gain in overall system efficiency of 2%. This is the type of interaction that is produced in good team meetings.

The second type of faculty-student interaction that occurs under the Manager-Engineer model is the one-on-one conversation. Engineers must be in constant communication with their managers to keep the managers appraised of their work and to work out more complex details of a project. We have found that in graduate school, industry, and project-based engineering education, it is essential that there be consistent one-on-one conversations between a manager and engineer. We often tell our students that if we only see them at weekly team meetings, and rarely outside that time, then in all likelihood, they are not making adequate progress. Students who are wrestling with tough issues need to talk with their advisers and seek guidance. We may often not know the answer to their problems, but as good managers of our projects, we can talk through the problem with them and develop a plan of approach.

Teaching students how to properly conduct themselves in team meetings and how to interact with their managers on a regular basis are key tools that we provide the students in preparing them for industry.

4.3 The Master (Mentor)-Apprentice Relationship

The one-on-one meetings that typically occur in the Manager-Engineer model sometimes end up being much more involved and result in a time of intense mentoring or one-on-one training. This transition is not common in industry, but one-on-one training significantly enhances the educational process and improves the success of project-based engineering education. These interactions are best described as a Master-Apprentice relationship where the faculty member is the Master, or mentor, and the student is the apprentice.

There are two types of situations where the Master-Apprentice description is appropriate. For our team, we have many mechanical engineering students doing complex electric circuit design which could include printed circuit board layout, microcontroller integration, and programming. As these skills are outside the scope of the ME curriculum, the EE team adviser spends a large amount of time working side-by-side with individual students. A second situation in which the faculty work very closely with the students occurs as the project approaches the ultimate deadline, a competition.

Whereas in the Manager-Engineer model students are given guidance on how to approach a problem and sent off to wrestle with it alone, there are other circumstances where they cannot make progress and need significant help to proceed. Here, an adviser with expertise can make a tremendous difference in the outcome of the project. This is the Master-Apprentice relationship that we so readily employ. We now present two examples of our Master-Apprentice relationship model.

In 2012, one mechanical engineering student, Tim Ronco, accepted the responsibility to design and build a Maximum Point Power Tracker (MPPT) for the boat. The key components of an MPPT are a microcontroller and a printed circuit board with many sophisticated, high-frequency, power circuits and surface-mounted analogue components. Ronco describes how he approached the problem and the benefits he gained from working on a cross-discipline project (Ronco, 2013), but he does not fully describe the in-depth mentoring instruction he received from Dr. Brown, the EE project adviser for the boat.

The Master-Apprentice relationship is most evident in the amount of time the two worked together to solve the problem. The first stage of this work involved many hours of going through the circuit schematic diagram of previous designs, identifying each component and explaining its purpose and function. This was followed by a thorough review of accompanying spreadsheets with detailed calculations that modelled the circuit function. Ronco thoroughly mastered many of the analogue design calculations and devised user-friendly spreadsheet-based calculation tools to simplify the circuit optimization. The last step of the preliminary stage involved hours upon hours in the lab testing individual components in the circuit. The overall circuit developed previously did not work, so the effort in the lab focused on identifying whether or not individual components worked, then whether or not small sections of the circuit performed properly, and then finally, investigation of the circuit as a whole.

This entire process is simply overwhelming to a mechanical engineering student. Thus, to ensure success required a Master-Apprentice relationship where Dr. Brown (the Master/Mentor) spent uncounted hours working side-by-side with Ronco (the Apprentice), until Ronco had developed a sufficient understanding of the circuit. As the competition date approached and the MPPT still didn't work, Brown searched for a commercial device to use instead. With his expertise, he was able to identify a unit that could work if appropriately modified. Brown and Ronco patched the commercial unit into their design, creating a hybrid device that could perform the required functions. The complexity of the hybrid MPPT and the elusiveness of a robust design haunted Brown and Ronco right up to the competition, and required a tremendous ability to work patiently, together, for hours on end.

It is fair to ask if the educational benefit of such a project is worth the hundreds of hours invested. What is the value if the Master-Apprentice relation becomes one where just the Master does the work while the Apprentice observes? There are no easy answers to the second question, and the answers vary from case to case. We can answer the first question, however, based upon what happened at competition.

Although the MPPT system initially worked in the lab, it did not work reliably right before competition and during the first few days of racing. A crippling failure could severely limit the vessel's performance. The benefit of the long hours spent together in the Master-Apprentice relationship became evident as Ronco took the lead in troubleshooting the problem and coming up with the solution. Ronco was now acting as the engineer, with his detailed knowledge of the system, while Brown resumed the role of manager, asking questions and helping Ronco devise a solution. Each night after racing, Ronco could be seen sitting in the boat with flashlight and multimeter or under an umbrella (Figure 1). Each night he got closer to a solution until, on the third day, he found it. In the process, the apprentice had achieved a level of self-sufficiency and confidence to attack the problem with minimal faculty oversight. This is a major goal of project-based engineering education, that students can tackle real-world problems with skill and confidence.

Figure 1: The Apprentice Becomes the Engineer; Tim Ronco (left) working on the MPPT (right) at the race site

A very similar story demonstrating the Master-Apprentice relationship concerned the construction of the hull. In many ways, boat construction is an art and is often taught as such. Many boatbuilding schools exist that follow the Master-Apprentice model, and we incorporate a similar approach for the boat team. During the actual construction of the boat, those of us who have significant boatbuilding experience work side-by-side with the students to ensure that the hull is constructed properly. This, again, is a very time-consuming task, but overall project success is dependent upon a well-constructed lightweight hull. Beginners could never construct a "world-class" hull on their own, but an "apprentice" can be part of a team that does. This, too, has tremendous educational value.

Many of these manufacturing tasks could be sent out for manufacture saving significant time. However, the more the students manufacture in-house, the more they learn about the whole process and the need to consider

manufacturability when designing a product. Long hours of labour build a deep appreciation for the value of the finished product and the character required to keep at it when quitting would be far easier. This is another benefit of Cedarville's approach to project-based engineering education.

In a Master-Apprentice relationship, we find that working side-by-side with the students does more than teach and impart knowledge. Working together, for long hours on end, develops a close relationship between faculty and student; it also encourages the students to persevere when they realize that you are doing some of the menial work. Performing simple but tedious tasks that they can easily do (e.g. sanding, cleaning up, soldering, etc.) encourages the students who are then more willing to persevere and to see the project through to completion.

A final look at the Master-Apprentice model concerns the end-of-project phase. In order to participate in a competition, the design, construction, and testing phases must all be brought to completion. It is at this stage that the minute details of the project and the vast number of the infamous "little things" become increasingly apparent and increasingly overwhelming. Again, we, as faculty advisers, step in once more and the Master-Apprentice model reappears. Students must learn how to conduct themselves in high-stress situations. They must learn to develop solutions quickly to unforeseen problems. They must learn to think of everything that is required to make a project successful. They must learn to persevere when the work seems impossible to complete.

Here, an experienced adviser working alongside the student team can guide them through these problems and demonstrate the clear thinking, hard work, and perseverance necessary to ensure success (Figure 2). We have found that this is the most physically demanding time of the project; work hours are long, tensions are high, everybody is exhausted, tempers are short, morale is declining, and success is slowly slipping from the grasp of the once hopeful team. Without experience, the team is unlikely to succeed at this point. If some of the students had been through this in prior years then these students can assist in the leadership role. Unfortunately, almost everybody is new to the team and has virtually no experience in these pressure situations. So again, it is imperative for us as advisers to step in and model behaviour that will lead to successful completion of the project.

Figure 2: The Last Hours before Competition, Faculty and Students Working Side-by-Side to Bring the Project to Completion

5 Conclusion – Bridging the Gap Between Education and Industry

In our project-based engineering education, where our teams are heavily involved in intermural competitions, we have found that the Faculty-Student interaction mirrors various types of relationships seen in industry. As such, the experience we provide the students better prepares them for industry. Our main goal in these projects is to teach them how to successfully approach a task, even if it is somewhat outside of their discipline.

The main models of Faculty-Student relationships that we have pursued are the Teacher-Student, Manager-Engineer, and Master-Apprentice models. We have now minimized use of the Teacher-Student model and have mostly adhered to the other two; we have found that the Master-Apprentice model has been instrumental to our success. With this model, we find that we are able to bring the students to a much better understanding of the project as they learn how to approach a task by working alongside a faculty member. Also, as the project nears completion, it is imperative for the faculty member to once again work directly with the students to guide the project to a successful close.

The Master-Apprentice model is extremely demanding on the part of the faculty. It requires them to be very knowledgeable about the task at hand and it requires an inordinate amount of time. However, our teams have been very successful (Figure 3), and the students that go through this type of training are significantly better prepared for

industry (Ronco, 2013). As such, they can confidently approach problems outside their discipline, they know what it takes to bring a project to completion, and they know how to work alongside others in tense situations.

Figure 3: In the Netherlands; maneuvering through a narrow canal (top), and a successful team with an award (bottom)

References

Dewhurst, T., & Brown, G. (accepted for publication). The Preliminary Design Phase – The Key to Achieving Project Objectives. In N. van Hattum-Janssen, R.M. Lima and D. Carvalho (Eds.), Proceedings of the Fifth International Symposium on Project Approaches in Engineering Education PAEE 2013, Eindhoven, the Netherlands.

McGill, R. (2007). Leaders Lead, Engineering & Technology, 2(2), 44 – 47.

Ohio Department of Job and Family Services, Ohio State Apprenticeship Council (2013, April 6). Apprenticeship History. Retrieved from: http://www.daytonapprenticeships.org/

Ronco, T., Brown, G., Dewhurst, T. (accepted for publication). Cross-Discipline Projects Prepare Students for Industry, In N. van Hattum-Janssen, R.M. Lima and D. Carvalho (Eds.), Proceedings of the Fifth International Symposium on Project Approaches in Engineering Education PAEE 2013, Eindhoven, the Netherlands.

Suhir, E. (2011) Inventive Leadership. American Society of Mechanical Engineers. Retrieved from URL: http://www.asme.org/kb/news---articles/articles/entrepreneurship/inventive-leadership-for-engineering-entrepreneur

Umbach, P.D., & Wawrzynski, M.R. (2004, June). Faculty Do Matter: The Role of College Faculty in Student Learning and Engagement. Paper presented at the annual forum of the Association for Institutional Research, Boston.

Vallabbaneni, S.R. (2002). Do great engineers make good managers? Engineering Management Journal, 12(4), 146-146, URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1029461&isnumber=22115