Preparing Engineering Students for Industry

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Abstract

This paper discusses some of the important differences between academia and industry which professors can use to help prepare their students for full time employment in industry. The authors currently work or previously worked full time in industry. Some of them teach part time as adjuncts or full time as professors of practice at various universities. Some are also involved in hiring engineers. The purpose of this paper is to identify some important differences between academia and industry that many students are not aware of nor are prepared for when they enter the workforce. This paper should be of interest to engineering faculty, engineering students preparing to work in industry, and managers in industry who hire new engineering graduates. Engineering faculty can help make the transition from academia to industry smoother for their students by considering these differences and where appropriate alerting their students and modifying their teaching methods as appropriate. Students can learn about and prepare for the differences between academia and industry. Engineering managers can also recognize these differences and prepare accordingly to make the transition as smooth as possible for new engineering hires.

Introduction

There can often be a rude awakening for engineering students transitioning from academia to the work world. Teachers can help make that transition smoother by preparing students for full time employment which is often significantly different than academia in some important ways. Many students believe engineering practice will mirror what they did in school which is typically not the case. While they develop their problem-solving skills in school, they may have the impression that all industry problems have a single answer like their textbook problems. That is rarely the case for industry problems of any significance.

A skill many students have not learned is to check their results to make sure they make sense. This is particularly true for exams where there is a time limit. Students often run out of time and usually cannot go back and check their answers. They do the best they can in the amount of time given. Unfortunately, that does not work in industry as an incorrect answer is of no value. Students may be used to getting partial credit on exams for whatever work they did on a problem even if the answer is wrong. It is particularly embarrassing for new engineers to generate answers to industrial problems that make no sense. In some cases, such as having an efficiency greater than 100%, an invalid answer may be easy to identify. However, in many cases it may not be so easy to see an invalid answer. Students need to learn to consider solution validity before presenting them to colleagues, supervisors, and customers.

Another aspect many students may not be prepared for is working at least 40 hours a week within a defined working time window. Students may also not be prepared for the lack of quantitative performance feedback in industry compared to the constant feedback they get in academia. This paper will look at some of the differences between the theory learned in school compared to actual practice, consider a range of topics related to problem solving, look at some key differences between the industrial work environment and academia, get perspectives from some newer engineering graduates and from instructors with ample industry experience, and finish with some recommendations.

Theory vs. Practice

Some professors spend valuable classroom time deriving formulas that have already been derived in textbooks. This is not a productive use of time because undergraduates will not be asked by their industry supervisors to derive equations that have already been derived. Classroom time would be more productively spent showing examples of how important equations are used so students will be better prepared to use them in industry. Of course, graduate students will often need to study equation derivations.

Another requirement for some classes is memorizing equations. This is not the most productive use of students' time either as they will not be expected to memorize all the equations they will need on the job. Rather, they will have access to reference materials and will be expected to find and use appropriate equations for the problems they need to solve.

Unlike textbook engineering problems that are normally well-defined and have a single correct answer, real world problems are often ill-defined, have numerous constraints, and may not have a single correct answer. These are often referred to as *ill-structured problems* which typically lack definition in some respect (Simon 1973). Those problems have no answer in the back of the book and may lack precise input data. Despite the importance of these real-world problems, Jonassen (2000, p. 63) wrote, "Unfortunately, students are rarely, if ever, required to solve meaningful problems as part of their curriculum." Solving ill-defined problems needs to be taught to students so they will be properly prepared when they enter the workforce. While they may be exposed to this type of problem in their capstone projects, they usually encounter very little of it in their core engineering classes. These ill-defined problems may also be solved using a variety of methods, to arrive at differing answers that still reinforce one another.

Where possible, teachers should give some open-ended assignments where there may be multiple acceptable solutions (Baukal 2017). Students need to determine appropriate boundary conditions and material properties for these "fuzzy" problems. Students must then defend their own solutions as is typically required in industry. This teaches them that many "real" problems do not have a single answer and how to communicate their work to others.

One type of problem that can be used to illustrate ill-defined problems is where iterative calculations are required to determine a solution (Baukal 2016). These are often best handled by computer. Besides reducing computation time, parameters can be dynamically changed to show immediate results with software. Multiple problem formulations can be easily displayed simultaneously. Using high-level commercial software such as Matlab® (or similar alternatives) to formulate and iteratively solve standard calculations in any given industry has a couple of advantages: it helps students develop critical thinking and logic skills and the programming needs only be done once to iteratively solve repeated problems and calculations, such as the sizing of standard industrial components. This method also provides an easy and fast way to look at a range of possible scenarios.

Problem Solving

The ABET (2018) requirements for the 2019-2020 accreditation cycle include several Student Outcomes related to problem solving:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Problem solving is an important skill for professionals (Eraut 1994). Problem solving may be one of the most fundamental processes for engineers (Aldridge 1994). Sheppard et al. (2009, p. 3) wrote, "Engineering practice is, in its essence, problem solving." Jonassen (2014, p. 103) wrote, "Learning to solve workplace problems is an essential learning outcome for any engineering graduate. Every engineer is hired, retained, and rewarded for his or her ability to solve problems." One goal of engineering education is to produce effective problem solvers. Roth and McGinn (1997, p. 18) wrote, "Educating students to become problem solvers has been a goal of education at least since Dewey." Jonassen (2011, p. xvii) argued "the only legitimate cognitive goal of education (formal, informal, or other) in every educational context (public schools, university, and [especially] corporate training) is problem solving."

Engineering students normally learn how to become good problem solvers by the time they graduate. However, those students may not have learned how to assess the validity of their solutions. Engineering educators can facilitate the process of validating solutions by teaching students to constantly assess their results to make sure they pass reality checks. Engineering students at graduation with an undergraduate degree are generally considered novices and do not become experts until they have had considerable experience. A key difference between experts and novices is how each approaches problem solving.

Critical Thinking

An important skill engineering students need to learn is critical thinking (Baukal 2015). Brookfield (2012) defined critical thinking as identifying assumptions, testing their validity, seeing things from different viewpoints, and taking informed action. Here, the concern is testing assumptions about valid solutions. Halpern (1998, p. 450) defined critical thinking as "the deliberate use of skills and strategies that increase the probability of a desired outcome" which is specifically used in problem solving. In this case, the desired outcome is a correct solution. Halpern argued students can become better critical thinkers through appropriate instruction and that enhancing students' critical thinking ability is both challenging and rewarding for instructors. Snyder and Snyder (1995, p. 90) wrote, “Students who are able to think critically are able to solve problems effectively.”

Critical thinking is a key metacognitive activity that should desirably occur during learning and problem solving (Masui and De Corte 1999). Critical thinking and judgment are required for engineering professionals to solve workplace problems (Stevens et al 2014). This includes the ability to critically evaluate solutions. Merely generating an answer does not guarantee the result is credible. In most university engineering courses, problems typically have a single correct answer. Many real-world engineering problems are not that simple and often don’t have a single correct answer. Students must develop the ability to critically assess their solutions for credibility since they will not be able to compare the results of solving real-world problems against an answer in the back of a textbook.

Reality Checks

One important check of the reasonableness of an answer (Moore et al 1979) is its sign. This is a gross error checking process that can be particularly important in certain subjects such as thermodynamics where there is a specific sign convention. Students need to be familiar with the sign convention in a discipline so they can at least make sure their solution is the correct sign or orientation. In these types of problems, students should know even before starting to solve a problem what the sign of the answer should be. Instructors can reinforce this by discussing the sign of the solution before they begin solving these problems. After this has been demonstrated several times, the instructor can then ask students what the sign of the solution should be before the instructor begins to work out an example problem. In some problems there may be intermediate solutions where the instructor can demonstrate this process of checking results for sign appropriateness.

Another reality check is to determine if a solution falls within the correct range. Most calculations have results that should be within a certain range to be valid. While some results can be either positive or negative (e.g., work and heat in thermodynamics), other results can only be positive. For example, calculating a negative mass does not make physical sense. For other types of results, the range is narrower than merely being positive. For example, thermal efficiency ranges between 0 and 100%. In thermodynamics, the quality of a fluid ranges between 0 (all liquid) and 1 (all vapor). Emissivity, absorptivity, transmissivity, and view factor in thermal radiation all must range between 0 and 1. The credible range for certain types of solutions needs to be learned so students can determine if their results are at least plausible. Again, this can be demonstrated by the instructor by discussing possible solutions before solving example problems and eventually asking students to discuss reasonable solution ranges before starting a problem. Final solutions can then be assessed to see if they fall within the valid range.

Determining the appropriate order of magnitude for a result is often the most challenging for a novice. This type of knowledge usually only comes with a considerable amount of experience. The instructor can help students get a feeling for what are “reasonable” answers and what are not. A simple example in fluid flow relates to the difference between laminar and turbulent flow. If the flow is high speed, such as near or above Mach one, the flow will generally be turbulent as determined by calculating the Reynolds number. A common mistake students often make is not using the correct value for viscosity. Often, this is a number in a table multiplied by a small number such as x 10^{-3}. If the student forgets to multiply by that small number, they can get a much smaller Reynolds number since the calculation includes dividing by the viscosity. This produces a result that can be off by orders of magnitude. Instructors should sensitize students to this type of mistake, especially to typical errors instructors commonly see, so students can make sure their results at least pass the order of magnitude check.

While most engineering students are taught early in the curriculum about significant digits, they still seem to struggle with this concept even through graduation. Because calculators and computers can generate many digits does not mean they are all significant. In many cases, only three or four digits may be significant. Failure to recognize this either means students do not understand the concept of significant digits or are not disciplined enough to apply it. Some actually appear to believe the answer is more accurate if they include more significant digits. Significant digits is an important concept that needs to be ingrained before starting full-time employment. A supervisor accustomed to working with real data will view results with too many significant digits as a poor reflection on the employee and potentially on the employee's alma-mater as well.

Students are normally taught about measurement uncertainty, but either fail to understand the concept or forget it when reporting experimental results. Some seem to believe their measurements are much more accurate than they actually are. Where possible, students should determine the estimated uncertainty in their measurements so they can be reported accordingly (Kline and McClintock 1953). Failure to do so can imply the results are much more accurate than they really are. Uncertainty bars on the results provide a dose of reality for students about the potential inaccuracy in measurements. They may also help explain why experimental results sometimes do not follow theoretical predictions.

Documentation

An important aspect of good engineering practice in problem solving is proper documentation. This means showing calculations, listing sources for equations and data, enumerating assumptions, and discussing any simplifications or weaknesses of their analyses.

Engineering students are taught early in their curriculum to work out units to demonstrate they are properly accounted for. Units on the left side of an equation must equal those on the right side. Some equations require conversion factors that are obvious when the units are shown. Unfortunately, many students often neglect to show units and assume they will work themselves out. This is poor practice as it can lead to mistakes that may be difficult to find if the units are not shown. Teachers should make it a point to show units when they work problems and require their students to do the same.

Industrial Work Environment

Many students are used to staying up late at night and waking up late in the morning. Unfortunately, that schedule is usually counter to most industrial workplaces where employees are generally expected to start before 9 am. They are also expected to work at least 40 hours a week. While that part is not usually a problem for engineering students who probably work that many hours between attending classes, doing homework, writing lab reports, and studying for exams, they may not be used to the expected regularity of the workplace.

Another aspect of the workplace that some students may not be prepared for is the importance of meeting deadlines. Some students seem to believe that deadlines are just a target and are not that firm. Even when teachers impose a late penalty, that may not deter some students. However, that attitude will not serve them well in industry where they need to assume deadlines should be met unless they have negotiated something to the contrary with their management. Instructors can help enforce that belief by imposing stiff late penalties or by even rejecting late assignments.

Another difference between academia and industry is that there are generally no grading curves in the latter. Supervisors expect solutions to be correct, where 80% correct may be considered good in academia but unacceptable in industry. Considerable amounts of money may be spent on designs that must be correct. Additionally, many projects on which engineers work deal with the safety of the public. Here, the bar for what is "correct" is even higher. Students must have the mindset that their solutions cannot be just good enough but that they must be correct. They may learn this principle while working on their capstone projects, but it would be better if they learned it much earlier in the curriculum.

University students get feedback on a regular basis from their professors. They receive grades for quizzes, homework, lab reports, exams, and many other types of assignments. However, in industry there are few if any "graded" assignments. They will rarely get regular quantitative feedback from their supervisors. Most employers require at least annual performance reviews. Some employers have more frequent reviews for new employees to make sure they do not get too far off track. However, those relatively infrequent reviews may be the extent of the feedback they get from their industry supervisors. Teachers can warn students not to expect the frequent feedback they get in school when they enter the workplace.

Written and verbal communication skills are very important in most industry engineering positions. While engineering students need to communicate in many of their classes, they will most likely be doing even more communicating and less calculating on the job than they did in school. This is especially the case in some industries where many of the calculations are computerized. Where appropriate, instructors should provide their students opportunities to communicate their results and give them critical feedback to help prepare them for industry.

An important aspect of most industrial work environments is working in teams. ABET (2018) Student Outcome 5 is "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." Instructors should look for opportunities for group projects so students will become more familiar with working on teams. Another important element of industry teams is that employees rarely get to decide what teams they will work on. Teams are normally selected by management. At least some student teams should be determined by instructors rather than letting students always select their friends to be on their school project teams.

Newer Graduate Perspective

An aspect new engineers will have to accept when they graduate from college is that in industry they will not have all the answers, nor are they expected to. In the classroom setting, students pass or fail on their own merit. Even in group projects, professors watch how much each member contributes. While it is true that team members in the professional world are expected to pull their own weight, the engineer is not expected to encompass the whole team. For example, there is a natural relationship between the engineer and the technician: engineers usually deal with the scope of the project and “why” it needs to be done, while technicians typically deal with the more specified details regarding the “how” and “where.” The ability to find balance within the team between different skill sets is a quintessential step for a new engineer’s progression.

Along these same lines, there are rare moments in the college experience where engineering students learn to bring their designs to life or even pass their designs on to someone else to complete. Most classes do not require students to fabricate their own designs or have their designs fabricated at all. Therefore, there is no practice appreciating the work that must be done, the relative timeline to completion, and the amount of money required to complete a project. The back-and-forth communication regarding specifications, questions, and timetables is a critical and normal part of the project life cycle that most new graduates have little knowledge of or practice in prior to starting full time employment.

Another reality that newly hired engineers must face is that they will be mostly an expense before they become an asset. They probably do not bring much inherent value at first because they have not been trained in the company’s specific technologies. The new graduate must first acknowledge this and respond appropriately. The proper response is different than in academia, which usually constitutes digging into a book and reading the required chapters. The response in the professional world includes getting to know the project’s requirements and specifications, familiarizing themselves with the teams of people who collaborate together to take the product from conception to market, understanding the needs of the technicians as they enact the project, getting a grasp on the environment of this new workspace, and so on. A detrimental side-effect of not acknowledging this toxic yet enticing notion is the false belief that the “engineer knows best” solely because of their degree. The harsh reality is that the degree does not equal inherent value addition, but rather that the engineer is qualified to be responsible for the project once adequately trained. This thought process can unfortunately have professional ramifications within the teams of those who have been working on these projects for years prior to the addition of the new graduate. Only after sufficiently partaking in a company-sponsored onboarding process can the new engineer begin creating value for company.

The new graduate will have growing pains as well when it comes to finding resources to complete specified projects. In college, the number of resources is usually limited to notes, books, and faculty. In the professional world there are a multitude of resources needed to complete a project, with varying amounts depending on the project complexity. The new graduate must learn to adhere to industry standards, federal regulations, corporate policy, environmental and safety regulations, and contractual obligations, among others for their baseline design parameters. Then once these have been addressed, they must navigate through less rigid specifications such as best practices, personal preferences, return on investment, innovative techniques, weather conditions, scope, schedule, budget, work permits, management of change, and other legal requirements. All of these can be addressed if the new graduate has a supportive team at the corporation, but this is not taught as an expectation in the classroom. In addition, many of these parameters can change mid-project, thus increasing project complexity for the engineer. Where possible, schools should incorporate nebulous design specifications with evolving expectations to bring the early support the new graduate will need to learn to adapt to the professional world.

Industry supervisors often assign mentors to work with new graduates. Those mentors may provide more feedback to the new graduate than their actual supervisor. Also, a new graduate's colleagues, especially those in their group or on their project teams, may be a good source of feedback. New graduates should actively seek out others in the company who can provide feedback wherever possible so they can find out how they are doing.

Because of the nature of academia where time is broken up into semesters, students are rarely exposed to long term projects except possibly for their capstones. Depending on the company and industry, engineers may work on much longer projects in the workplace. Those longer-term projects also often include large project teams. Goals and team members may change over the course of a project. In college it is a lot of short-term projects so many new graduates are not usually prepared to work on the same project for an extended amount of time. Undergraduates could get some exposure to this by working with professors on their research projects.

A successful engineer in industry requires more than just good problem-solving abilities; they must also possess good judgment. There are many other factors such as cost and delivery that students usually do not need to be concerned with in school, except possibly for their capstone project. They also need to be able to prioritize many competing objectives. For example, it is often possible to speed up delivery on equipment but at some cost. Is that additional cost justified or not? That depends on the criticality of the delivery of that equipment.

Another aspect of industry that may be challenging for new graduates is working with potentially much older and more experienced engineers. In school, most students are at approximately the same age in a given course so there are not usually any significant age barriers to consider. However, in industry they may work on teams with engineers having a wide range of experience. New graduates need to show appropriate respect for their more experienced colleagues without being intimidated as they have projects to complete.

Depending on the industry a new graduate enters, they may work with standards. Students typically get very little exposure to these standards while in school. Their main exposure to them is often in their capstone project. More exposure to at least some of the major standards in a given discipline, such as the ASME standards for mechanical engineers, would better prepare students for using those standards.

Industry Instructor Perspective

Instructors from industry can help introduce students to the dynamics of the industrial workplace that are not typically taught in the classroom. These include how design equations are selected, how much measurement/calculation accuracy is required, secrets of career progression, and the existence of workplace politics.

Not every design equation or model used in industry is derived from first principles. Many are empirical and are only valid over a relatively narrow range of operating conditions. Many students, especially graduate students, struggle switching from a world where all equations are derived from first principles to a world where equations may be purely empirical (and are often simple polynomials). Equation forms are selected purely for their quality of fit of the experimental data. Phenomena that are being modeled in industry are often large, complicated, and coupled systems that do not lend themselves to analytically derived equations.

These are some of the many ways that academia can work with industry to provide opportunities for students to learn more about engineering work after graduation. The key element is for both academia and industry to seek out engagement. Both industry and academia should ensure that the engagement has sufficient depth of purpose and meaning to allow for student learning.

Recommendations

Internships, co-ops, and industry-sponsored capstone projects are invaluable for preparing engineering students to become full-time working engineers. They help to show students that theory is not always realized in actual practice and that problems in industry are often open-ended. Students should be encouraged to participate in internships, co-ops, and industry-sponsored capstone projects wherever possible. As best as they can they should try to understand the differences between academia and industry. Professors can help their students by highlighting some of the key differences. Engineering managers also need to understand the significant differences so they can design an appropriate on-boarding process that may include for example more feedback than they would provide for more experienced engineers.

The purpose of this paper is not to change academia into industry as there are clear and distinct purposes for both. The primary objective of academia should be to develop successful engineering graduates who will be ready when they enter the workforce. This should create a positive impression of the school that could have long term dividends such as possible internships, capstone projects, and industry involvement in the classroom.

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