AC 2009-1233: DETERMINING THE IMPORTANCE OF HANDS-ON ABILITY FOR ENGINEERS

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Introduction

Two challenges facing engineering educators today are: (1) to provide a curriculum that prepares graduates for the work of the twenty-first century; (2) to recruit more students to the field of engineering. A number of reports cite the shortcomings of current curricula[1-4]. For example, the traditional engineering curriculum does not prepare graduates to adapt quickly to new job requirements or to work effectively in the global economy or to solve the large complex problems of alternative energy, environmental protection, and homeland security. Furthermore, the number of students graduating with engineering degrees in the U.S. each year has remained relatively constant in recent decades despite the need for technical solutions to important societal problems and even as the number of degrees awarded in other countries has increased. Outreach to K12 student populations[5] and greater flexibility in the engineering curriculum[6] are recognized as important components of a solution to this problem.

Hands-on ability has an important role in both challenges mentioned above. Although engineering work in the twenty-first century will be increasingly sophisticated, practical ability and intuition about physical phenomenon remain important. In fact, the NAE cites "practical ingenuity" as one of the key attributes of the engineer of 2020[1]. Because students today are less likely to have grown up in rural communities than their predecessors, they have probably had fewer opportunities to tinker. Instead of fixing the family tractor or the hay bailer, the engineering students of today and tomorrow will have lived a cocooned virtual life of video games and online chat forums. While facility with computers is advantageous, our curricula do not provide adequate opportunities for many students to overcome this tinkering deficit. More importantly, there is some evidence that low self-efficacy with respect to tinkering may even turn some students off from engineering[7,8]. We proceed with three premises: that hands-on ability is important for the engineering work of the 21st century; that hands-on ability enhances the enjoyment of and interest in doing engineering; and that hands-on ability can be taught. Regarding the last premise, some may believe that hands-on ability is an innate attribute or talent that differs by gender. Nevertheless, current scientific evidence suggests tool-use and technical ability is a common attribute of our shared lineage [9,10,11]. Moreover, the scientific evidence that inherent talent plays a large role in vocational expertise is actually very weak, whereas, the evidence supporting the role of practice and experience is exceptionally strong[12].

Our work has several goals. The first is to determine whether and why "hands-on ability" is important. Recognizing that "hands-on ability" is more than a motor skill, part of this goal is to understand the cognitive and perceptual abilities that are encompassed by "hands-on ability". Another goal is to determine how hands-on ability affects student motivation, confidence and attitude toward engineering. A third goal is to determine which experiences are most helpful in developing hands-on ability. Finally, we are interested in identifying practices at the undergraduate level that can effectively teach hands-on ability. It should be noted that our work is focusing primarily on mechanical and electrical engineering students. There are several reasons for this: ME and EE are popular majors with large numbers of students; both fields have less gender diversity than engineering as a whole; both fields share features with the highly hands-on work of mechanics and electricians.

Relative Importance of Hands-On Ability

To determine whether hands-on ability is important, we developed and administered a survey for engineering employers. We asked respondents to rate the relative importance of various attributes (including hands-on ability) for new engineering hires. Our list of attributes (shown in Table 1) looks similar to those compiled by various engineering organizations. For example, the NAE recommends that the Engineer of 2020[1] have: strong analytical skills; practical ingenuity; creativity; communication; business and management knowledge; leadership; high ethical standards and professionalism; dynamism, agility, resilience, and flexibility; and the habit of lifelong learning. For each attribute we provided a short description to clarify the attribute for the respondent.

Table 1: Results of industry survey on important skills and experiences for new hires (*N*=54)

	Mean	SD
Communication skill The candidate writes well, is comfortable making oral presentations, and is able to communicate effectively with people that have different job functions.	4.52	0.67
Teaming ability The candidate has done many team projects and works well with others.	4.42	0.69
Hands-on ability The candidate has tinkered with machinery or electronics as a hobby or job, or grew up in an environment where these skills were required (such as a farm).	4.35	0.88
Creative ability The candidate “thinks outside the box”, has worked on inventions, or is involved in artistic pursuits.	4.13	0.70
Leadership ability The candidate has held leadership positions in student organizations or on project teams.	3.90	0.82
Ethical reasoning The candidate had a course in professional ethics and demonstrates an ability to see technological solutions in a broader context.	3.70	1.25
Academic ability The candidate has a high college grade point average.	3.62	0.76
Prior work experience The candidate has engineering intern or co-op experience.	3.59	0.94
Multicultural experience The candidate speaks a foreign language, has lived or worked in another country, or has worked with culturally different people.	2.58	0.83

In October 2008, surveys were distributed to exhibiting companies who hire engineers at a small engineering society conference (22 respondents). In February 2009 they were distributed to companies attending our university's career fair (32 respondents). The respondents' companies hired mainly mechanical (47 of 54 respondents) and electrical engineers (37 of 57 respondents). Other engineering types being hired with multiple responses were materials (19), chemical (19), computer (17), civil (16), environmental (9), and biomedical (5) engineers. Table 1 shows a summary of the results, with the attributes listed in rank order. In the survey respondents were asked to rate the various attributes for an engineer in importance on a 1-5 scale, 5 being very important and 1 being not important. The industry respondents confirmed our observation that hands-on ability is very important (M=4.35). The survey ended with an open-ended question soliciting input on other desirable attributes. Affective traits such as self-confidence, self-motivation, intellectual curiosity, initiative, and passion for the technology were mentioned. Skills such as project management, computer skills, cost analysis, and supervisory experience were also mentioned. Next, we plan to distribute surveys to engineering faculty and students to see how their perspective differs from employers.

Dissecting the Meaning of Hands-On Ability

Given that most engineers spend little time actually doing hands-on work, we wished to determine why that ability is so important. With input from members of a mechanical engineering department external advisory board, we identified a list of reasons that "hands-on ability" is important. A survey was then developed for the purpose of rating each of the reasons. Respondents are asked to rate the various aspects of hands-on ability in importance using a 1-5 scale, 5 being very important and 1 being not important. Thus far, the survey has been distributed to employers at an on-campus career fair in October 2008 and to members of an electrical engineering department advisory board.

Table 2: Results of survey asking respondents to rate the reasons that hands-on ability is important (*N*=41)

	Mean	SD
It allows an engineer to visualize how things go together.	4.33	0.76
It allows an engineer to understand the underlying mechanics of a device.	4.28	0.60
It improves troubleshooting ability.	4.24	0.70
It allows an engineer to understand how things are made.	4.24	0.70
It leads to better designs.	4.17	0.92
It connects the analytical and the physical.	4.02	0.82
It improves communication with technicians.	4.02	0.91
It corresponds to an ability to see multiple possible solutions to a problem.	3.75	0.93

It means the engineer is not afraid to get their hands dirty.	3.73	1.01
It corresponds with an ability to improvise.	3.66	0.88
It gives engineers more confidence.	3.63	1.11
It corresponds with the ability to conduct experiments/tests.	3.54	0.87
It corresponds with good engineering judgment.	3.54	0.98
It improves the engineer's ability to plan.	3.51	1.03
It means the engineer is a fast learner.	2.83	1.14

The top rated responses communicate the concept of an engineer being able to see what is going on inside the black box. Hands-on ability does not seem to be equivalent to getting one's hands dirty although the standard deviation for that response is relatively high. Hands-on ability is associated with a number of desirable traits such as confidence, judgment, and planning, but there was less agreement (higher standard deviation) for these types of characteristics.

Future Work

We plan to collect additional survey data on the importance of hands-on ability. We plan to compare the responses of faculty and students to industry employers. We will also investigate whether there are any differences in responses based on company size or industry. Despite limited sample sizes to date, this preliminary data has confirmed our belief in the importance of hands-on ability and encouraged us to investigate it further. With the ultimate goal of providing learning experiences to better teach the ability, we plan to develop measures for hands-on ability, determine the role of prior experiences in the development of this ability, and determine the effect of this ability on self-efficacy and attitude toward engineering.

Acknowledgments

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