A Tool to Measure Adaptive Expertise in Biomedical Engineering Students

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Abstract

While engineering programs must continue to cover the maximum breadth and depth of content information possible, these programs can also take an active role in encouraging and fostering additional dispositions to help their graduates adapt to their professional career. We define an adaptive expert as an individual who possesses the content knowledge of an expert, but who in addition displays specific cognitive dispositions that augment and enhance their ability to effectively utilize and extend their content knowledge. We have identified four main constructs (multiple perspectives, metacognition, goals and beliefs, and epistemology) which form the foundation of adaptive expertise. We report on a survey developed to measure these qualities of adaptiveness in three target engineering populations (freshmen, senior, and faculty). We also present interview data conducted in conjunction with the survey to provide insight as to how this adaptiveness is manifest in undergraduate engineering students.

Introduction

According to the Accreditation Board for Engineering and Technology (ABET) Engineering Criteria 2000, "engineering programs must be designed to prepare graduates for the practice of engineering at a professional level"[1]. This statement can be interpreted as requiring *more* than simply imparting in students a basic understanding of content knowledge in a particular domain. Indeed, as technology continues to advance rapidly it will become more difficult to equip engineering undergraduates with the knowledge and skills required in the workplace. Thus, while engineering programs must continue to cover as much content knowledge as possible, engineering programs must also take an active role in developing the abilities of their graduates to successfully apply and extend the content knowledge that they have learned in their schooling.

In 1998, the National Science Foundation (NSF) convened focus groups consisting of employers (both technology and non-technology related), students, graduates, and parents to discuss undergraduate education in science, math, engineering, and technology (SME&T)[2]. The NSF found that employers were generally satisfied with the depth of SME&T programs, but typically favored more breadth of coverage. They found that employers were seeking individuals with good problem-solving and leadership skills, who take initiative, and who are capable of independent and self-motivated learning, and they typically found SME&T graduates to be unprepared in these domains. Specifically, employers stressed the importance of employees taking the responsibility to learn what they need to know on their own, because their academic schooling often does not prepare them for what they will do for a living[2]. Because technology and the needs of the workplace change so rapidly, employees must continue to learn and adapt on demand, regardless of the level of expertise attained at graduation[2].

Recent changes in the ABET accreditation process have provided schools with the opportunity to enact creative and radical changes to the engineering curriculum, and documentation of these changes can be found in the engineering education literature[3-6]. At the same time, more emphasis is being placed on student-directed, rather than teacher-directed, learning[7, 8]; a shift of priority that is aligned with the latest research in the field of educational theory[9]. This renewed focus on student-directed learning affords the opportunity to critically address the question of the type of student growth that engineering programs should strive to develop. Related with the question of *what* students should learn is the question of *how* students should learn the material; that is, how can one design the most effective learning environment for this type of intellectual development? Already, the mismatch between the common learning styles of students and the traditional teaching styles of many engineering faculty has been documented[10].

The concept of adaptive expertise offers one lens through which to view the purpose of undergraduate engineering education. While content domain knowledge will continue to be a principle objective of the undergraduate engineering curriculum, it will be valuable (and indeed possible) for schools to foster additional skills and attitudes which will better prepare students for careers as practicing engineers. Other researchers have already recognized the importance of attitude development in undergraduate students. In one particular example, a first-year electronics lab has been developed with the primary goal of "influencing student attitudes rather than imparting cognitive knowledge"[11]. Other researchers have realized the roles that student attitudes can play on student performance, and discuss the utility of studying these changes in students[12]. Ultimately, we feel that it may be possible to introduce learning opportunities in the curriculum (in unit sizes ranging from single assignments, to larger design projects, to perhaps portions of an entire class), with the goal of instilling *both* content knowledge *and* these additional attitudes and cognitive dispositions in students.

The initial focus of our work has been in the field of biomedical engineering, because the interaction among professionals of different backgrounds (engineering, medical, biology) particularly accentuates the need for graduates to be adaptive in the application and extension of their content knowledge. However, we feel that one can readily apply this notion of adaptive expertise to all fields of engineering, and perhaps to a lesser extent to education in the sciences. We should also emphasize that we are interested solely in the *adaptiveness* aspect of the adaptive expert, and have not focused on the level of content knowledge that our subjects may (or may not) be able to demonstrate in their field. With this in mind, the terms adaptiveness and adaptive expertise are used interchangeably throughout the paper.

Adaptive Expertise

By definition, people who have developed expertise in a particular area are able to think effectively about problems in that field[9]. It would seem straightforward to suggest that the purpose of undergraduate education should be, in the least, to initiate the development of expertise within individual undergraduate students. It is commonplace in the literature to see researchers studying expertise in such diverse areas as physics, mathematics, history, and chess. Based on a literature review of such research studies, the following general principles regarding experts have been identified[9]

1. Experts notice features and meaningful patterns of information that are not noticed by novices.
2. Experts have acquired a great deal of content knowledge that is organized in ways that reflect a deep understanding of their subject matter.
3. Experts' knowledge cannot be reduced to sets of isolated facts or prepositions, but instead, reflects contexts of applicability: that is, the knowledge is "conditionalized" on a set of circumstances.
4. Experts are able to flexibly retrieve important aspects of their knowledge with little attentional effort.
5. Though experts know their disciplines thoroughly, this does not guarantee that they are able to teach others.
6. Experts have varying levels of flexibility in their approach to new situations.

Researchers have shown that experts within the same field can utilize and apply their expertise in cognitively different ways[13, 14]. For example, Wineburg provided a detailed description of what it means to be an adaptive expert through an analysis of two historians completing a problem-solving task[13]. In this study, two university-based history experts were asked to form an understanding of Abraham Lincoln's views on race based on a set of related historical documents from the era. Both subjects held the rank of full professor in history departments ranked in the top 25 nationally, and had earned their doctorates from the same history department (one that is consistently ranked in the top three nationally). One of the experts (Expert 1) had spent the majority of his career writing and teaching specifically about Lincoln and the Civil War, whereas the other historian (Expert 2) had a broader expertise in the general field of American history, but was not a specialist of the Civil War period.

What was striking about the results of this study was not the understanding that each historian developed as a result of task, but the *manner* in which each historian completed the task. In his routinized approach to the problem, Expert 1 was described as resembling the stereotypical sure-footed expert. Because of the specific content expertise that he brought into the analysis, Expert 1 immediately defined the key issues related to the task and set forth in a methodical manner to produce a solution. His task progress and analysis were frequently dominated by his prior knowledge, to the point where occasionally his interpretation of various historical documents seemed to be based almost solely on his prior knowledge, rather than freshly evaluating each document on his own merits. (Interestingly, in a longitudinal study of so-called "semi-expert" undergraduate electronics engineering students, researchers also found that they focused exclusively on their initial and satisfactory, albeit sub-optimal, solution approaches rather than investigating alternative choices for the possibility of optimization[15].)

Expert 2, on the other hand, without an extensive foundation of content knowledge, had to employ cognitive strategies different from those of Expert 1. Many of these strategies were positive learning strategies: using of questions, looking for alternative hypotheses, and checking the sources of data for evidence for or against possible alternative hypotheses. Expert 2 was also able to monitor his performance, giving himself feedback both from his own judgements of his understanding and from the text he was using. He evaluated the situation and, finding his initial understanding insufficient, was able to seek out additional information that allowed him to gain new insight, and ultimately solve, the problem. This is an excellent portrayal of adaptive expertise, which has been described as "the ability to apply, adapt, and otherwise stretch knowledge so that it addresses new situations – often situations in which key knowledge is lacking."[13] Despite lacking formal training in the specific area under question, Expert 2 demonstrated "adaptive expertise" and was able to develop an understanding commensurate with Expert 1.

Based on this description and other research efforts in the area, we sought to define exactly what adaptive expertise would entail in the context of engineering. We should emphasize that in this paper we are focusing on the *adaptiveness* aspect of the adaptive expert; there are obviously other attributes which individuals must possess in order to be classified as experts in a given field. We have also assumed that, while adaptiveness is most likely domain specific (individuals may be more adaptive in one domain and less adaptive in another), it is not necessary for individuals to be content experts in a particular domain in order to display these adaptive qualities. Thus, we might consider the adaptiveness of novices, students and other types of non-experts as they function within a particular field. In addition, we argue that adaptiveness is something that can be developed in students, that this adaptiveness leads to positive outcomes in learning and achievement, and that students who are more adaptive will become more successful practicing engineers.

After reviewing the relevant literature, we have identified four primary constructs that together comprise adaptive expertise: (1) multiple perspective, (2) metacognition, (3) goals and beliefs, and (4) epistemology. Each of these categories describes a disposition or mindset with which individuals may approach problems within a specific domain. These four categories constitute a cognitive approach that will assist students in applying content knowledge, in recognizing new situations where a particular set of content knowledge may be applied, and in using their existing knowledge as a springboard for acquiring new knowledge.

Multiple perspectives refers to the willingness of students to use a variety of representations and approaches when working within the domain[16-18]. It is not surprising that professional engineering often requires the use of multiple perspectives[6]. A student who considers multiple perspective realizes that there may be more than one way to analyze, approach, and solve a problem. The student is likely to represent a problem in a variety of ways, and to express an openness to new information that may lead to a better understanding or solution of the problem. In addition, such students show a willingness to try multiple approaches in finding the solution to a problem.

Metacognition refers to the learners' use of various techniques to self-assess and monitor his/her personal understanding and performance[13, 19, 20]. Individuals with high levels of metacognition frequently question their own understanding of a situation, seek feedback from relevant sources (including personal reflection and outside critique), and are able to recognize areas were their knowledge may be incomplete or insufficient. Metacognition can be manifest in many different situations, whether as a traditional student learning new information in a classroom setting, as an engineer responsible for learning new information at work, or as a practitioner applying their knowledge.

The category goals and beliefs describes the views that students have concerning their learning goals and the nature of expertise[21, 22]. Students with this disposition view challenge as an opportunity for growth (rather than a chance for failure), and are able to continue to proceed in the face of uncertainty. Specifically, Dweck and Legget found that learners persistence in the face of adversity can be predicted based on whether the students are "performance orientated" or "learning orientated"[21]. Students who are performance orientated view learning solely as a means of measuring intelligence, and are uncomfortable in learning situations for fear of appearing unknowledgeable. For these students, it is more important to be *judged* as intelligent, rather than participating in actual learning and understanding. On the other hand, students who are learning orientated enjoy the challenge of learning new material, and develop some level of satisfaction as they increase their knowledge base or develop additional skills.

Epistemology refers to how individuals perceive the nature of knowledge[23, 24]. Students with this attribute see knowledge as an evolving entity rather than a static destination, realize the need to continually pursue knowledge (even when one has achieved "expert" status), and appreciate that even experts are liable on occasion to have difficulties within a subject area. These individuals realize the importance of the larger community in pushing forward the envelope of knowledge, and appreciate that others with different backgrounds can provide useful insights and contributions to their work.

Now that we have presented a framework for what constitutes adaptive expertise in the context of engineering, we feel compelled to state what it is not. Adaptive expertise is not of the same as creativity, which one could argue can or cannot be fostered in students. An aspect of adaptive expertise is, however, the ability to recognize situations where creativity is possible (multiple perspectives), and to allow oneself the opportunity to be creative. Nor is adaptive expertise solely a matter of self-confidence, although the learner's confidence may be a factor in why students have certain learning goals and views of learning and knowledge (goals and beliefs). Moreover, adaptive expertise is not solely dependent on maturity or experience, although these may facilitate higher levels of adaptiveness in the individual. Adaptive expertise does not describe how students view teamwork, although it seems reasonable to suggest that teamwork and epistemology may be related. Finally, we distinguish adaptive expertise from the ill-defined notion of life-long learning. While the characteristics of an adaptive expert would certainly assist students in becoming a life-long learners, we have attempted to define adaptive expertise in ways the might be specifically measured.

Survey Development

We began by brainstorming an initial group of survey items. In developing these items, we attempted to "translate" our adaptive expertise constructs into language that would be easily understood by our subjects. We also tried to ensure that the survey items were interpreted in the context of engineering design work, which we felt was the most uniform and authentic experience of the students. In the instructions which accompanied the survey, students were asked to think of the survey items in reference to their design experience; when applicable direct reference to engineering and design are written into the item statement. At this stage of development, we went through numerous iterations of both the survey items and the adaptive expertise constructs, as the process of item generation required us to constantly redefine and hone our construct definitions.

Using a Likert scale, students were asked to read each survey item and to mark on a scale from 1 (strongly disagree) to 6 (strongly agree) the number best corresponding to their reaction. Initially a Likert scale from 1 to 5 was used, but through the development process we found that a scale with even numbered divisions was more informative, as it prevented students from selecting the middle ground and forced them to "take a side". During this development process over 100 items were created, approximately evenly divided between "positive" (where here we would classify "strongly agree" with adaptiveness) and "negative" (where "strongly disagree" would correspond to an adaptive expert) items. The use of both positive and negative items was adopted in this way to prevent users from quickly marking all items the same and to encourage the readers to carefully read the questions. For each of the four adaptive expertise constructs, we calculated a score based on the average of all survey items related to that construct (where scores for negative items were adjusted such that scores of 1 and 6 represented non-adaptive and adaptive answer, respectively). A total adaptive expertise score for each subject was then assigned based on the sum of these four scores.

Once we completed the initial item development process, we administered this first 100-item version of the survey to four biomedical engineering students (two underclassmen, two graduate students). After completing the survey, we interviewed each subject and asked him/her to comment on specific survey items. At this stage of the process, we were particularly interested in the clarity of the individual items and the possibility of social desirability (i.e. “everyone would want to mark it this way” or “everyone would mark it this way”) for individual items. For this latter point, for each question scored a 1 or a 6 the subjects were asked why they marked this particular score, and whether they felt that most other students would mark the item in a similar way. Items that exhibited this social desirability were either carefully rewritten for the next phase of the survey development or discarded.

At this point in the process the number of items was reduced to 84 items. This survey was then concurrently given to a sophomore statistics class comprised predominantly of biomedical engineering (BME) undergraduate students, as well as to a limited number of engineering faculty. The statistics professor encouraged his students to complete the survey as a homework assignment, and offered extra credit as added incentive. The professors were encouraged to provide feedback regarding specific survey items to the development team.

We analyzed the results from each of these two groups in a number of ways to determine the most effective items. We conducted a frequency analysis on each individual item, and eliminated items that showed a preponderance of a particular response. Next we grouped the items according to categories within each adaptive expertise construct, and removed items that were unrelated to other items in that group. In addition, we deleted items that we found to be too similar. Finally, in the interest of brevity, we eliminated a small number of remaining items so that the final items were approximately evenly distributed across the four adaptive expertise constructs.

We administered the final 49-item survey to the three target populations (freshmen, BME seniors, and engineering faculty) in the Spring of 2000. We recruited senior BME students via fliers posted in the BME department at Northwestern, as well as through email messages from the department asking for their participation. We recruited freshmen engineering students via fliers and email messages from the undergraduate engineering department. For both populations, we collected student data via a web implementation of the survey. As an incentive, we entered those students who completed the survey into a random drawing for cash prizes. For both groups, approximately 65% of the applicable students completed the survey. An additional small number of faculty, in addition to those used in the trial phase of the survey, were also recruited at this time. The responses of those faculty who completed the trial survey were edited to include only responses to those items remaining on the final survey.

Based on a statistical analysis of the results of these three subject populations, we reduced the number of items from 49 to 42 in the desire to make the survey as clear and concise as possible. We evaluated this set of items to ensure that the original definitions of the adaptive expertise constructs were maintained given the reduced number of items. Table 1 presents the 42 items making up the final version of the survey, grouped according to the four adaptive expertise constructs. The survey is available on the web at http://www.ils.nwu.edu/fisher/GENsurvey.html.

#	Survey Item
	Multiple Perspectives
1	I create several models of an engineering problem to see which one I like best.
2	When I consider a problem, I like to see how many different ways I can look at it.
3 (*)	Usually there is one correct method in which to represent a problem.
4 (*)	I tend to focus on a particular model in which to solve a problem.
5	I am open to changing my mind when confronted with an alternative viewpoint.
6 (*)	I rarely consider other ideas after I have found the best answer.
7 (*)	I find additional ideas burdensome after I have found a way to solve the problem.
8	For a new situation, I consider a variety of approaches until one emerges superior.
9 (*)	I solve all related problems in the same manner.
10 (*)	When I solve a new problem, I always try to use the same approach.
11 (*)	There is one best way to approach a problem.
	Metacognitive Self-Assessment
12	As I learn, I question my understanding of the new information.
13	I often try to monitor my understanding of the problem.
14 (*)	As a student, I cannot evaluate my own understanding of new material.
15 (*)	I rarely monitor my own understanding while learning something new.
16	When I know the material, I can recognize areas where my understanding is incomplete.
17 (*)	I have difficulty in determining how well I understand a topic.
18	I monitor my performance on a task.
19	As I work, I ask myself how I am doing and seek out appropriate feedback.
20 (*)	I seldom evaluate my performance on a task.
	Goals and Beliefs
21	Challenge stimulates me.
22 (*)	I feel uncomfortable when I cannot solve difficult problems.
23 (*)	I am afraid to try tasks that I do not think I will do well.
24 (*)	Although I hate to admit it, I would rather do well in a class than learn a lot.
25	One can increase their level of expertise in any area if they are willing to try.
26	Expertise can be developed through hard work.
27 (*)	To become an expert in engineering, you must have an innate talent for engineering.
28 (*)	Experts in engineering are born with a natural talent for their field.
29 (*)	Experts are born, not made.
30	Even if frustrated when working on a difficult problem, I can push on.
31 (*)	I feel uncomfortable when unsure if I am doing a problem the right way.
32	Poorly completing a project is not a sign of a lack of intelligence.
33 (*)	When I struggle, I wonder if I have the intelligence to succeed in engineering.
	Epistemology
34	Knowledge that exists today may be replaced with a new understanding tomorrow.
35	Scientists are always revising their view of the world around them.
36 (*)	Most knowledge that exists in the world today will not change.
37 (*)	Facts that are taught to me in class must be true.
38 (*)	Existing knowledge in the world seldom changes.
39	Scientific theory slowly develops as ideas are analyzed and debated.
40	Scientific knowledge is developed by a community of researchers.
41 (*)	Scientific knowledge is discovered by individuals.
42 (*)	Progress in science is due mainly to the work of sole individuals.

Table 1. Final items for the adaptive expertise survey. Items marked (*) denotes “negative” items; see text for more details. (The order of items was scrambled on the actual survey.)

Results and Discussion

Table 2 presents the means and standard deviations of scores for each of the adaptive expertise constructs for each subject group. It also shows values of Cronbach's alpha, which provide a measure of internal consistency for each construct. Because of the relatively small sample sizes in this preliminary study, we have relatively weak power to detect significant differences between the different groups. However, Table 2 does seem to suggest some trends in the data. With this caveat in mind, we discuss these preliminary results.

		Cronbach s α	Average	Std Dev
All Engineering Freshmen N = 209	Multiple Perspectives	0.80	3.72	0.65
	Metacognition	0.78	4.25	0.65
	Goals and Beliefs	0.66	3.94	0.54
	Epistemology	0.72	4.59	0.58
	AE TOTAL	**0.85**	**16.49**	**1.69**
BME Freshmen N = 37	Multiple Perspectives	NA	3.70	0.61
	Metacognition	NA	4.34	0.67
	Goals and Beliefs	NA	3.97	0.54
	Epistemology	NA	4.85	0.50
	AE TOTAL	**NA**	**16.86**	**1.64**
BME Seniors N = 44	Multiple Perspectives	0.77	4.06	0.55
	Metacognition	0.79	4.36	0.60
	Goals and Beliefs	0.78	4.23	0.60
	Epistemology	0.72	4.76	0.53
	AE TOTAL	**0.87**	**17.40**	**1.60**
Engineering Faculty N = 17	Multiple Perspectives	0.80	4.41	0.74
	Metacognition	0.78	4.76	0.66
	Goals and Beliefs	0.77	4.43	0.51
	Epistemology	0.71	4.98	0.58
	AE TOTAL	**0.89**	**18.58**	**1.90**

Table 2. Adaptive expertise data collected during Spring 2000.

One of the difficulties associated with this analysis was deciding on the appropriate criteria with which to define the subject populations. This was particularly troublesome for the freshmen participants, as a number of students were either undecided about their major or had switched majors (either within or out of the engineering school) shortly after the completion of the survey. Thus it was necessary for us to make decisions regarding which data to include in our analysis. Students were included in the BME freshmen data set if they listed their major as BME at the time of the survey. Also included were students who completed the survey and were subsequently found registered within the BME department at the end of their first quarter of their sophomore year. Thirty two students listed BME as their major on the freshmen survey; of that number five students were not listed as being registered with the department at the end of their sophomore year and are believed to have left (or had not officially entered) the BME program. Five students did not describe themselves as BME at the time of the survey, but were included in the BME freshmen data because they subsequently registered with the department. We chose to group the BME freshmen as such because of our desire to collect data on a typical population of freshmen BME students, a group that would undoubtedly include such students.

The average scores in Table 2 show increasing levels of adaptive expertise across the groups, from freshmen to seniors to faculty. The average total adaptive expertise scores for seniors was more than half a standard deviation higher than the average adaptive expertise score of freshmen. The average adaptive expertise score of engineering faculty was a whole standard higher than that of the engineering freshmen. The senior data comes from biomedical engineering students at Northwestern University. Due to various circumstances (internships, co-ops, transfers), not all of these students started their studies at Northwestern at the same time. Unfortunately, this work marks the first time that such data has been collected with this group of students. Thus, it is impossible to determine whether the higher adaptive expertise scores of seniors, in comparison with the freshmen, is a true indication of student growth. This result might be caused by some extraneous effect, such as students with lower adaptive expertise scores leaving the program prior to their senior year, which would artificially boost the group average.

The engineering faculty represent a variety of engineering disciplines, although a majority of the respondents are BME faculty at either Northwestern or Vanderbilt Universities who are associated with a National Science Foundation Engineering Research Center in the area of bioengineering education. At this stage of our work, there is no reason to believe that there would be a significant difference in adaptive expertise among engineering faculty from different fields, or that the scores of the faculty who participated in the study where significantly different than perhaps more typical engineering faculty.

The average scores for the freshmen in each of the four adaptive expertise constructs seems to indicate that the BME freshmen are a representative subset of the larger group of engineering freshmen, with the exception of the epistemology category. Such a difference (which remains to be verified with additional data) may suggest that a BME freshmen population does indeed view the world from an epistemological standpoint different from other types of freshmen engineering students. Even if such a claim were to substantiated at some point, the question would still remain as to whether students with this type of disposition are drawn to BME, or whether freshmen BME students begin to quickly develop this type of epistemology at the start of their freshmen year. If the latter scenario is found to be true, it is still an open question as to whether this sort of development can be purposefully facilitated within the curriculum.

Comparison of the BME freshmen and senior survey data shows an increase in the scores for the constructs of multiple perspectives and goals and beliefs. The data for these cases are not statistically significant for our limited sample sizes, but will be examined after more data has been collected. Under the same constraints, it is interesting that the scores for metacognition appear to be stable between the two populations. As our data collection efforts continue, we will track the adaptive expertise scores of the BME freshmen as they progress throughout the curriculum at Northwestern.

Figure 1 plots adaptive expertise scores for BME seniors as a function of overall grade point average. The correlation of adaptive expertise with grade point is low (less than 0.30), making it difficult to make any definitive remarks concerning the data at this time. However, it is interesting that a majority of the BME seniors with a GPA greater than 3.40 had AE scores somewhat greater than the class average (see the box in Figure 1). Such a result, if found to be valid for a much larger number of students, could suggest any number of interesting possibilities. Perhaps students who have higher GPAs (and presumably have a greater content understanding then their colleagues) innately develop an appreciation for the utility of adaptiveness in their classwork. Another possibility is that students who start with (or later develop) higher levels of adaptive expertise are more successful in their classwork because of their adaptiveness. However, even if one of these two hypotheses were found to be true, it would still be necessary to show that adaptiveness can be deliberately and effectively nurtured in students. Even if this were to be the case, it is still unclear exactly how such adaptiveness could be fostered in the curriculum.

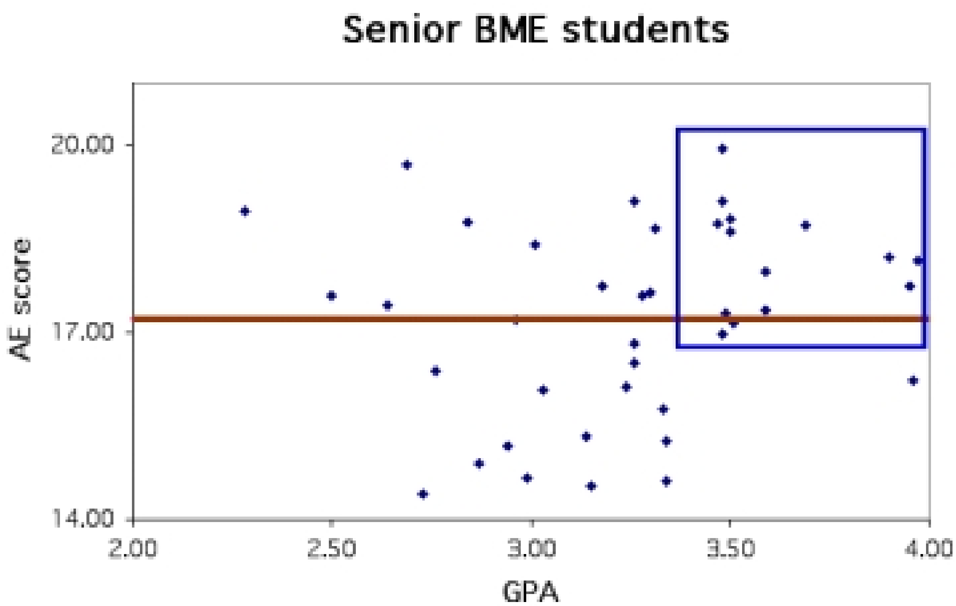

Figure 1. Comparison of adaptive expertise scores and overall GPA for senior biomedical engineering students. (The line represents the average score of the BME seniors.)

Interestingly, the seniors with the four lowest grade point averages of participating BME seniors reported above-average levels of adaptive expertise. While we have yet to investigate this result in detail, we offer several conjectures. First, high levels of adaptiveness might not necessarily prove that students have greater ability to master the content knowledge covered in their classes, or that adaptive students put forth the time and effort necessary to excel in their classes. Another possibility is that students with both lower GPAs and lower AE scores would be inclined to transfer out of BME because the low GPAs violated their more goal-orientated learning goals. In this scenario, students with low GPAs but high levels of adaptiveness are less frustrated with their apparent lack of “success” and are more willing to remain in the program.

Based on the discussion in previous sections, assessing adaptive expertise may offer a more useful reflection of student development than more traditional “content only” evaluations. Such a scheme would acknowledge the importance of other types of growth (rather than the simple acquisition of content knowledge) as necessary for preparing graduates for careers in engineering. For instance, Perry's Model of Development[25] has been used quite extensively to study the cognitive development of undergraduate students in a variety of fields. Work using this model has lead one group of engineering educators to suggest that[6]:

> "Most students, regardless of field of study, enter college at Perry's position 2 or 3 and graduate at position 3 or 4. This low level of intellectual development suggests that most college programs, while successfully teaching facts and procedures, do little to promote growth toward intellectual maturity… (those students at the lowest stages of Perry's model) are capable of a high level of performance on problems that require only highly structured analytical techniques. It is thus possible for a student to earn good grades in engineering science courses that emphasize analysis while doing poorly in those requiring synthesis and evaluation. This may be one reason why industry contends that new engineering graduates are poorly prepared to 'do engineering.'"

Obviously continued work needs to be done in this area. In particular, we are interested in studying adaptive expertise in the context of design work. One possibility for future work is to develop "mini-design" projects, structured such that students are provided the opportunity to demonstrate adaptiveness (or lack thereof) within the context of a realistic engineering activity. We feel that once a better understanding of adaptive expertise has been developed, it may be possible to purposefully develop (or modify) learning opportunities to facilitate this type of student development. Thus we feel that in the future it will be possible to enhance adaptive expertise within undergraduate students without distracting from the content material that is currently covered within the curriculum.

Student Interviews

In order to cross-validate our survey findings on adaptive expertise, we conducted a limited number of student interviews with selected freshmen (four) and senior (eight) BME students from extreme ends of the adaptive expertise scale. We designed an interview protocol with the goal of soliciting from the students concrete instances in their undergraduate experience where they were presented with opportunities to demonstrate the attributes of an adaptive expert. Topics that were discussed during the interview included: expectations that the students had concerning their engineering education, their experiences in both classroom settings and design projects, and their future plans upon graduation. The interviews were approximately one hour in length, and were recorded for subsequent transcription and analysis. The interviewer was unaware of the student's adaptive expertise score at the time of the interview.

Table 3 shows selected quotes from the student interviews. In most instances, interview data validated the measurements obtained; students with higher scores on the adaptive expertise survey seemed to indicate higher levels of adaptiveness in the interviews. Occasionally a particular student response may not support the score obtained from the survey, but taken as a whole there seemed to be a relationship (albeit qualitative) between the student's survey score and his/her responses during the interview. For purposes of this paper, we will present only a brief sampling of the senior interview data that we collected, focusing on those instances where we feel that the quotations indicate either a strongly adaptive, or non-adaptive, response (see Table 3). A more thorough discussion of the interviews will be presented elsewhere[26].

Student Quote	Comment
(JM, senior, describing his favorite classes): "Another (favorite) class… not that it was tremendously interesting all of the time, but it was a new approach and a new way of thinking about things that I hadn't seen before."	Adaptive response (MP)
(DH, senior, describing her experience in engineering): "Something that I learned in engineering was, at least for most problem-solving, if there is… something that you can't find, you go to the engineering library and look in other sources."	Adaptive response (MP)
(LG, senior, describing her initial reaction to college classes): "… I just remember in chemistry my freshmen year, like you think that you know something, and then you find out on the test that you really don't…"	Non-adaptive response (MC)
(SH, senior, describing reading that she did prior to a summer internship): "You kind of sit there and try to memorize it, and think 'OK, I know anatomy', but then you get into a clinical setting… and I couldn't locate (an anatomical feature)."	Non-adaptive response (MC)
(CB, senior, describing her transition from freshman to senior): "I had drive when I was a freshmen, but when I saw that everyone else was working hard to get the same grades that I was getting without working very hard… I decided, hey, this is working so I'm not going to stress over (school)."	Non-adaptive response (MC, GB)
(LG, senior, in response to feeling confused during her senior design project): "(I felt) like I was going to fail… I was thinking 'This is all wrong and I'm going to fail this and I'm going to fail that.'"	Non-adaptive response (GB)
(PM, senior, in response to her senior design project): "I felt that the design project going in was going to be some kind of test of my abilities, and it wasn't because I did extremely well in the design project… our design (was) successful, but I'm not a great engineer…"	Non-adaptive response (GB, EP)
(ST, senior, describing specific skills that he will use in his career): "I don't feel that I will… use too many of the very specific skills that I've learned super-directly in any job I get. I think that the most powerful thing that you learn… is how to learn, and drawing parallels between the things that you've already learned before… and being able to fill in the details later."	Adaptive response (EP)
(ST, senior, describing when he first felt like an engineer): "The two courses were the (BME senior) design and the (BME) lab course… They were teaching you a lot of different things… and a lot of different ideas, all at the same time. Very realistic in many aspects, I guess."	Adaptive response (EP, MP)
(LG, senior, describing what she learned in a senior lab class): "… sometimes things that were supposed to work didn't, and he (the professor) would be as perplexed as (us)… He'd try to fix them along with us, and eventually got them to work by trying different things… just seeing the imperfections, and processes that are really supposed to work in the real world… and everything doesn't work as perfectly as you would think."	Student developing a more adaptive perspective (EP, MP)

Table 3. Selected quotations from the student interviews demonstrating a range of adaptiveness responses. The adaptive expertise scores of these individuals were: JM = 18.83, DH = 18.75, LG = 14.89, SH = 15.78, CB = 17.44, PM = 14.41, and ST = 18.62. The average score for BME seniors was 17.40. (MP = multiple perspectives, MC = metacognition, GB = goals and beliefs, EP = epistemology)

Nearly all of the students interviewed seemed to be able to recall specific instances or aspects of their design work that we would describe as facilitating growth in adaptiveness. Experiences such as design projects, co-op opportunities, and internships are often recognized by students and educators alike as being extremely useful learning opportunities, although the explicit benefit of such opportunities typically go unassessed. Based on the small number of interviews conducted, we would suggest the possibility that these opportunities to practice "real-world engineering" lead to positive student growth exactly because they lead students to develop, to varying degrees, higher levels of adaptiveness. In these situations students often encounter ill-defined problems for which there does not exist an obvious solution, and they need to develop the capacity to look at multiple perspectives in order to address the various requirements to solve the problem. Because of the length and complexity of the solution, they realize the importance of, and have the chance to develop, metacognitive techniques to track their understanding and task performance. They realize that dealing with ambiguity is commonplace in engineering, and become more comfortable in these situations. Finally, in these situations they develop an appreciation of the nature of knowledge and its application in individuals, within groups, and in society.

We found that the interview data provided a much richer description of how adaptive expertise is manifest, and can change, over time. Although it is obviously much more difficult to quantify the adaptiveness of the students based solely on their interviews, we certainly feel that through the interviews it was possible to compare, at least at a broad scale, the level of adaptiveness of different students. Recently, schools have tried to implement various programs that introduce to engineering students at the very beginning of their studies these types of realistic engineering experiences[3-6]. These programs have generally been regarded as largely successful, although we are unaware of studies that have conclusively identified the exact manner in which students benefit from these experiences. We conjecture that students benefit from these experiences because it leads to opportunities for the development of adaptiveness within the engineering domain. One interesting possibility for future work is to follow students through a quarter-long design project in order to document the relationship between adaptiveness and student design work.

Summary

In this paper we have attempted to rigorously define what it means to be an adaptive expert in the field of engineering. Based on a review of the cognitive science literature, we identified four constructs (multiple perspectives, metacognition, goals and beliefs, and epistemology) which together form the foundation of adaptiveness in this context. We then developed a survey to measure the adaptiveness of undergraduate engineering students and engineering faculty. Because we are in the initial stages of data collection, in many cases we are unable to provide statistically significant evidence to rigorously support many of the ideas discussed in this paper. However, we discuss some interesting trends to provide the reader with a flavor of our ongoing work, as well as to suggest how this concept of adaptive expertise may be useful as a tool for describing and measuring student development. Specifically, one set of results suggests that adaptiveness increases as individuals progress from initial student to graduating senior to engineering faculty. Interview data collected from several students who completed the survey are consistent with our preliminary analysis, and provide concrete examples of how different levels of adaptiveness may be expressed within undergraduate students. In the future, we plan to investigate the possibility that changes in curriculum might be implemented to facilitate the development of adaptive expertise in engineering undergraduates.

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