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Measuring adaptiveness among college students and working professionals

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The concept of adaptive expertise (AE) describes individuals with both deep content knowledge and the ability to apply this knowledge more broadly in practice. Four characteristics of adaptive expertise have been identified in the learning sciences literature, specifically: 1) multiple perspectives, 2) metacognition, 3) goals and beliefs, and 4) epistemology.

Within the realm of education, engineering programs are increasingly being asked to prepare students to enter an interdisciplinary workplace as "T-shaped" professionals with deep understanding and the ability to apply this understanding across a range of problems. As such, the traits of adaptive expertise are characteristics that engineering educators are being required to instill in their students. However, empirical literature examining adaptive expertise measurements among students and working professionals is scarce. More data is required to assess the levels of adaptiveness displayed by both students and working professionals and to examine points in both an individual's education and professional career in which adaptiveness is developed.

In this study we use an existing, validated adaptive expertise survey instrument to:

1. Generate baseline data concerning levels of AE displayed by various student populations at a large, public university.
2. Compare the levels of AE displayed by students and working professionals.

The longer term goal of this project is to provide baseline data against which student gains in adaptiveness can then be measured and that will allow activities designed to improve levels of Adaptive Expertise to be developed and assessed.

Introduction

Given the increasing degree to which engineering is becoming an interdisciplinary profession, the National Academy of Engineering (NAE), the American Society for Engineering Education (ASEE), and various other organizations have discussed the need for engineering graduates of the future to be adaptable, "T-shaped" professionals who are able to apply their knowledge across a broad range of subjects [1-5]. This "T-shape" refers to a deep content knowledge or expertise (the vertical of the "T") and the ability to apply this theory across a broad range of contexts (the horizontal of the "T").

Within the learning science literature, the concept of Adaptive Expertise (AE) has been defined as "the ability to apply, adapt, and otherwise stretch knowledge" such that an individual can effectively apply their expertise in new contexts [6]. Adaptive Expertise differs from routine expertise, which defines someone who is able to operate productively within a given field [7], in that AE reflects the ability to apply one's expertise more broadly across a range of problems and fields. Clearly, there are parallels between the concept of AE and that of the "T-shaped" professionals desired as the outcome of efforts in undergraduate STEM education.

Given the importance of AE to the engineering profession, and the desire to develop adaptiveness in individuals, various efforts have been made to operationalize the concept of AE such that it can be measured. For example, numerous studies in the biomedical engineering field have linked adaptiveness to innovation and efficiency in solving "novel problems" [8-12]. An adaptive expert is then someone who is both efficient and innovative in the manner in which they can apply their prior knowledge. Such a definition of AE leaves out other possible dimensions of adaptiveness besides these more creative elements however.

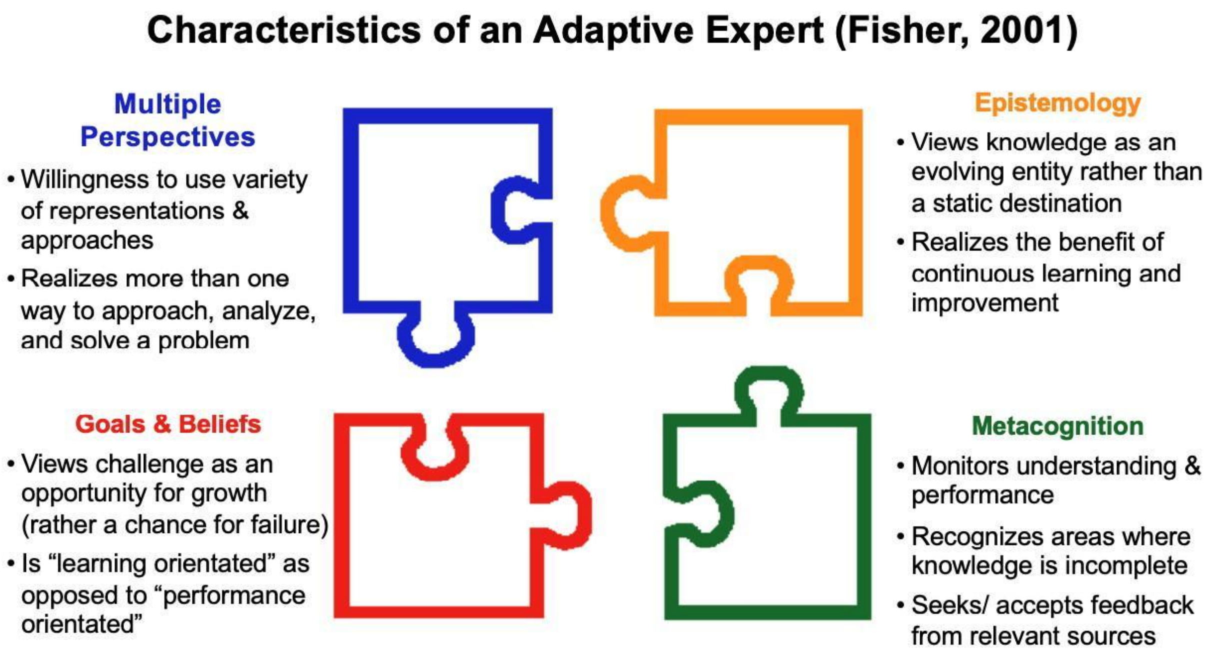

Figure 1. Four constructs describing the characteristics of adaptive expertise (adapted from [13]).

Based on a review of contemporary literature and their understanding of AE as being composed of multiple constructs that enhance one's ability to effectively use and apply knowledge, Fisher and Peterson operationalized a framework of adaptive expertise consisting of four measurable dimensions as detailed in Figure 1 [13]; (1) multiple perspectives; (2) metacognition; (3) goals and beliefs; and (4) epistemology. In this definition, creativity and innovation are not elements of AE, but someone who is more adaptive based on this framework is more likely to recognize situations that require creative solutions and be better prepared to apply their knowledge in new ways. Based on this definition and these four constructs, Fisher and Peterson also developed a survey measure of AE which consists of 42 questions scored on a 6-point Likert scale (see Appendix A). At the same time as they developed this definition of AE and their survey, Fisher and Peterson also collected data concerning the levels of AE displayed by various populations in an engineering department and demonstrated that growth in these constructs over the course of an undergraduate program was possible. The authors also compared the AE levels of students and faculty, with faculty in general displaying higher levels of AE than students [13].

Johnson et al. [14] confirmed the reliability of the survey tool developed by Fisher and Peterson in a 2012 study, although low participation rates of various sub-populations reduces the ability to make comparisons. Pierrakos et al. [15] also performed a study examining the reliability of the survey tool and again, found it to be a reliable instrument, in addition to showing differences in AE levels displayed by senior students in two design programs, one of which was designed to teach adaptive expertise and included mastery-based learning as well as "Explicit Values of the Course being grit, metacognition, innovation, collaboration, and quality". More recently, Fisher (co-author of the AE survey) and colleagues have been reporting data concerning AE levels displayed by undergraduate STEM students at a private university [16], and have detailed growth in AE levels among low-income students in particular as they progress through their course of study [17]. Only one study (to our knowledge) has compared the levels of AE displayed by students with working professionals [18]. In this work, the survey of Fisher and Peterson was used to examine AE levels displayed by students in a CAD course and CAD practitioners. The main conclusion in this regard was that CAD practitioners displayed higher levels in the AE dimension of multiple perspectives than students. Further analysis was however limited by the small sample sizes examined in this study.

Further work is, therefore, required to better understand the levels of AE displayed by various student populations as well as those of working professionals and other groups of interest in order to establish AE baseline data. Only once this baseline data is available, can gaps in levels of AE (between students and professionals for example) be determined and activities and interventions designed to promote growth in AE be developed. If these interventions can then be promoted and put into practice, engineering graduates will be better equipped to enter the workforce.

As such, the specific goals of this (work in progress) study are to:

1. Generate more data concerning levels of AE displayed by various student populations at a large, public university.
2. Compare the levels of AE displayed by students and working professionals.

Methodology

A previously validated adaptive expertise survey [13] was used to collect AE data concerning students and working professionals in STEM fields.

In early 2023, the Adaptive Expertise (AE) survey of Fisher and Peterson [13] was deployed online to both students in the Mechanical Engineering Department at The University of Delaware, as well as alumni of the program and their contacts. Respondents also provided various demographic information as well as other details of interest to the research team e.g. level of education, field of professional work, etc. Participants were recruited via an email campaign targeting both current undergraduate students in the program and alumni. Participation was incentivized with a gift card raffle. The AE survey, questions detailed in Appendix A, was coded into Qualtrics for distribution.

One hundred and fifty seven (157) students responded to the survey (42 1st year, 29 2nd year, 47 3rd year, 22 4th year & three 5th year students. Of these student respondents, 97 identified as men and 44 as women, while 17 students indicated they were from a group that is traditionally underrepresented in STEM, with 14 students identifying as Spanish, Hispanic or Latino. Only four students of the 157 responses were from departments other than Mechanical Engineering.

A total of 97 working professionals in STEM fields also responded to the survey. Of these respondents, 71 identified as men and 23 as women, while seven identified as coming from populations traditionally underrepresented in STEM. All of these participants were reached via networks held by the Mechanical Engineering Department at University of Delaware, and as such almost all professionals held positions, or had retired from positions, in closely related occupations that would be considered typical of mechanical engineering graduates (a bias inherent in this data set). The total number of participants in this study (n=254) is a particular strength of this work as almost all prior studies quoted in the literature had significantly smaller samples.

In terms of data analysis, scores in the various AE subscales were calculated based on the mean of the Likert scale responses to the AE survey. Overall AE scores were then determined as the mean of these subscale scores. Various statistical analyses (t-test, one-way ANOVA) were performed on the resulting data in order to evaluate the results and reveal any potential differences in AE displayed by various populations.

Results

Adaptive Expertise (AE) survey results are broken down by survey subpopulation and discussed here. For brevity, the AE dimensions (subscales) are indicated as follows; MP - Multiple Perspectives; META - Metacognition; GB - Goals & Beliefs; EPIST - Epistemology.

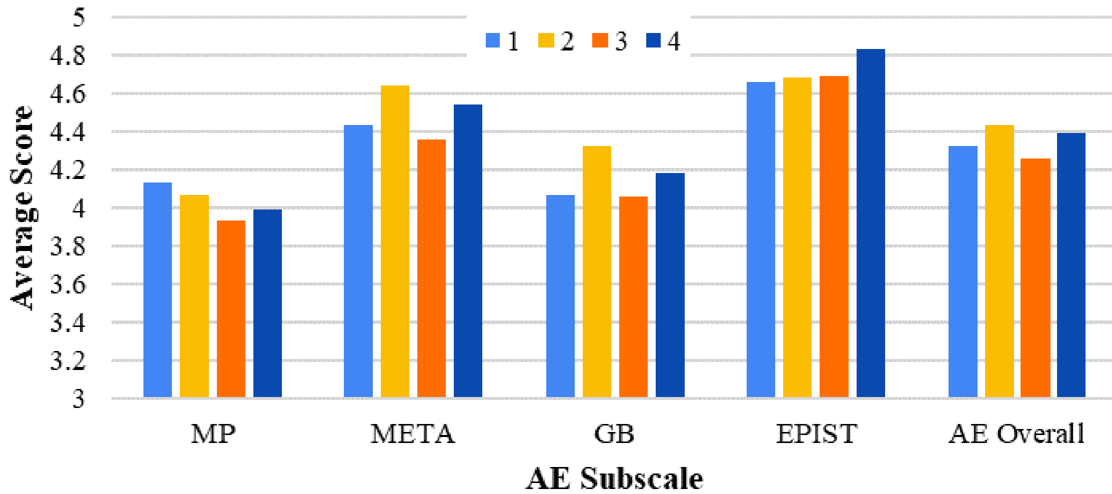

Figure 2: AE scores of undergraduate students broken down by year of study (1st- 4th year)

Initially, the levels of Adaptive Expertise (AE) displayed by students was broken down by year of study and compared. This breakdown is detailed in Fig.2. It is important to note that these are different students in each year as this is not a longitudinal study. In contrast to other studies [16-17] no statistically significant differences in the overall AE levels or individual AE dimensions were found between students of different years of study in any of the various analyses performed (comparing distinct years of study, and comparing first- and second-year students combined to juniors and seniors combined).

It is possible that this lack of difference is actually indicative of the population or that it is the result of a bias in the survey population examined here. In terms of this potential selection bias, the population of students who responded to the AE survey had an average GPA of 3.445 ($SD = 0.452$) which is higher than the departmental average GPA ($M = 3.232, SD = 0.584$) by 0.213 points and indicates that the survey was completed by a certain group of students rather than being representative of the entire population. Having said this, however, both this study and prior work by other researchers [17] found no correlation between GPA and the level of Adaptive Expertise displayed by undergraduate students (Pearson Correlation for all AE subscales correlated with GPA had $p >> .01$). Questions remain however as to whether the student sample in this study is reflective of the wider student population given the higher than average GPA of the participants in this study.

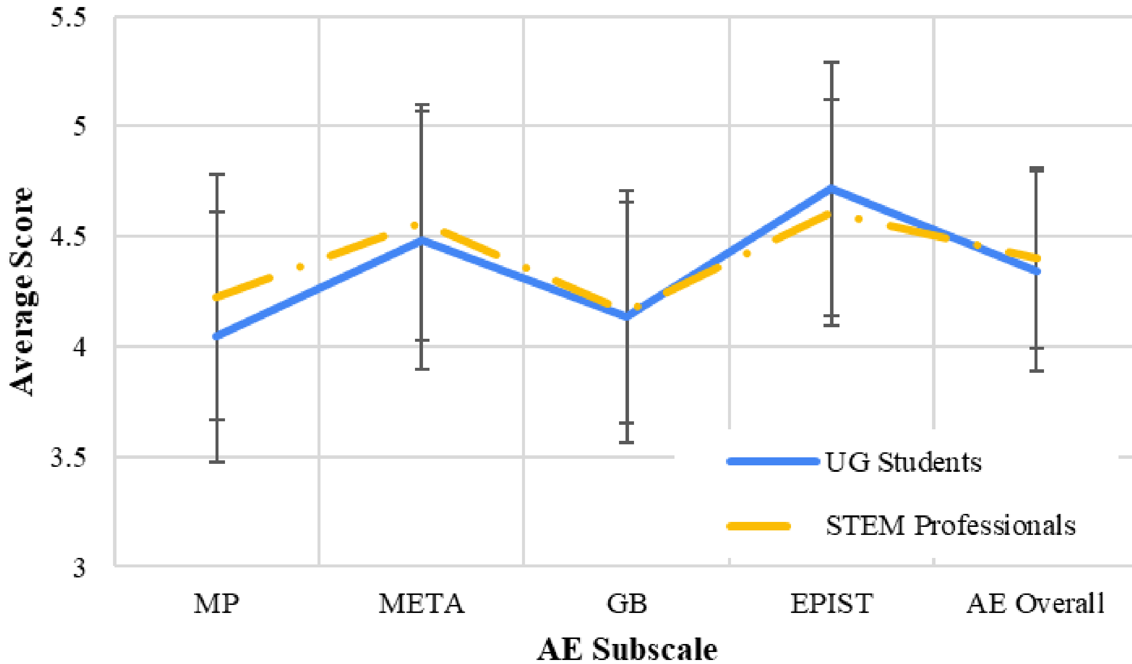

Figure 3: Comparison of AE levels displayed by undergraduate students and STEM professionals

Figure 3 details the differences between the AE scores of working professionals and undergraduate students (the undergraduate students were examined here as a single group given the lack of significant differences in AE scores by year of study). A statistically significant difference was found between students and professionals only in the AE dimension of Multiple Perspectives (MP $t(252) = -2.470, p = .014$) where professionals outscored students by an average of 0.18 points. In all other subscales, there was no significant difference in AE scores. This result is in line with that reported by prior researchers [18] where CAD practitioners (n=14) were compared to students in a CAD course (n=92) and also displayed statistically significant differences only in the category of multiple perspectives where practitioners again outscored the undergraduate students. While more data is required to further validate these findings, the correlation between the results found here and in prior work do identify a potential gap in the category of MP between students and working professionals. This result makes some logical sense as practical work would be expected to open one's eyes to new ways of doing things and thinking when one is exposed to a diverse workplace with engineers from different schools and fields. Future work at the undergraduate level could then focus on how this gap can be reduced in order to better prepare students for their careers.

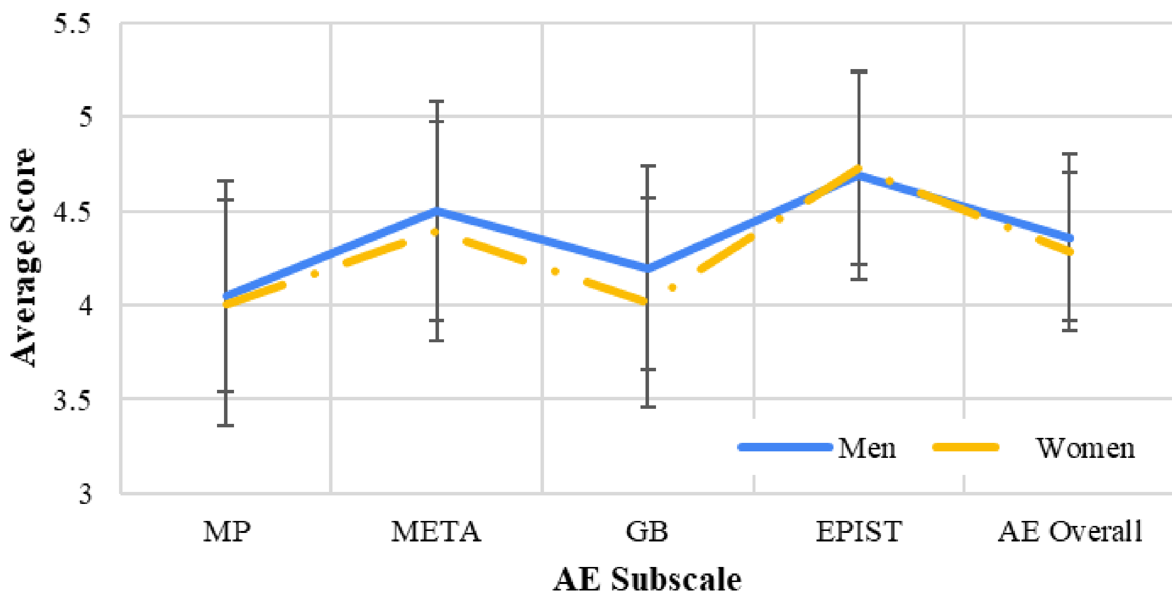

Figure 4: Comparison of undergraduate student AE scores by gender

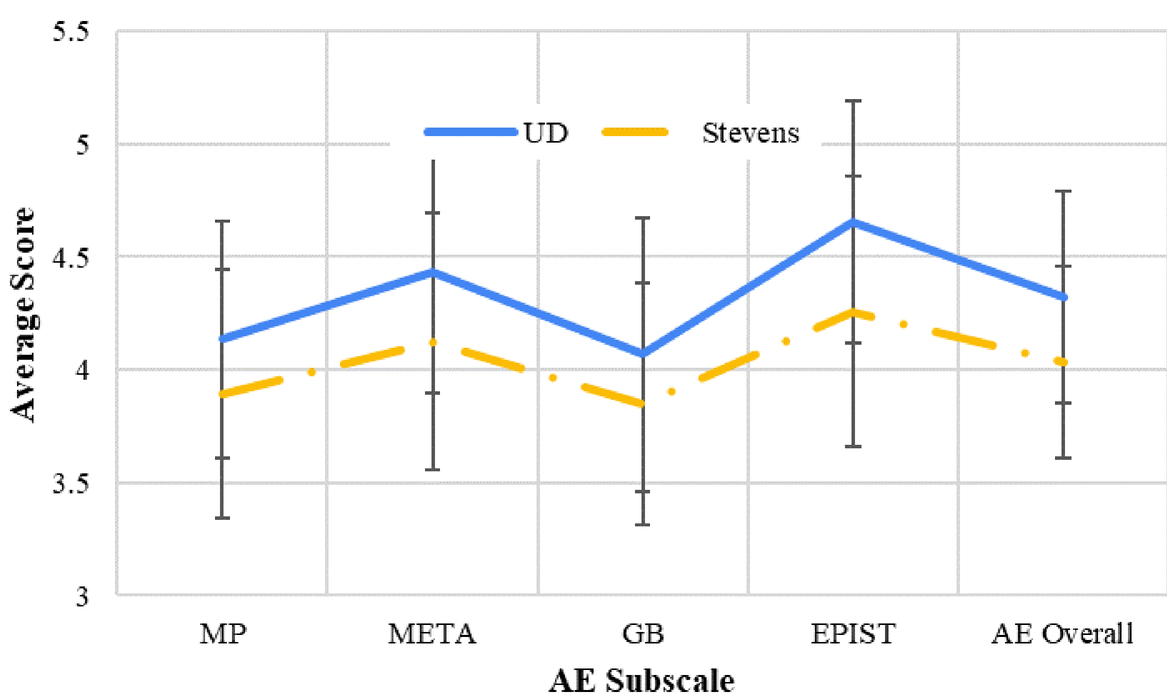

Figure 5: Comparison of AE scores between first-year Mechanical Engineering students at University of Delaware and Stevens Institute of Technology [16]

A breakdown of the AE subscale scores displayed by both male and female students is shown in Figure 4. No statistically significant differences were observed in any of the AE subscales, or AE overall, when results were broken down by gender. While this result is positive in terms of the parity it represents, the work of other authors [16] has shown differences in adaptiveness when genders are compared. Future work will seek to explore any potential gender differences in AE in more detail by enlarging the survey population.

Finally, a comparison between the first year mechanical engineering students surveyed in this work (University of Delaware, a large, public university) and those surveyed by Fisher and colleagues [16] (Stevens Institute of Technology, a small, private university) was performed. Results are shown graphically in Figure 5. There is a clear, statistically significant difference between the AE levels displayed by students at University of Delaware and Stevens Institute of Technology [16]. With first-year students at the University of Delaware reporting higher levels of AE in all four dimensions as well as overall when compared to Stevens students ; MP $t(108) = 2.273, p = .025$; META $t(108) = 2.811, p = .006$; GB $t(108) = 1.986, p = .05$; EPIST $t(108) = 3.513, p < .001$; and overall AE $t(108) = 3.356, p = .001$. It should be noted that while a statistically significant difference in AE scores was observed here, it is not clear how large of a gap this represents as baseline data for AE levels displayed by students is so sparse in the literature. Future work will seek to add to this data and determine whether differences in institution type or culture affect the levels of AE displayed by students. For example, in Mechanical Engineering at the University of Delaware there is a major focus on the "growth mindset" (i.e. malleability of skills, we can all learn with practice and effort, etc.) from day one of the program. As this growth mindset is linked to the defining characteristics of AE, it is unclear if this focus leads to differences in student adaptiveness between different populations i.e. compared to students at schools with a different focus.

This result was unexpected and it is hard to envision what differences there are in the first-year student populations at each school that would lead to the significantly higher levels of AE displayed by University of Delaware students. It is possible, however, that a selection bias, as possibly discussed in terms of GPA, or some other unknown dimension is at play. Further work will seek to add to the data collected here in an attempt to eliminate any potential biases in the survey population.

Summary & Future Work

A previously validated survey instrument designed to measure Adaptive Expertise (AE) was delivered to undergraduate students in a Mechanical Engineering Department as well as to practicing STEM professionals. The goal of this work was to develop data concerning the levels of AE displayed by both students and working professionals as relatively little data exists in the literature in this regard.

Students across all four years of study (n=157) responded to the survey and showed similarities in the levels of adaptiveness they displayed. No significant differences by year were found in the dataset collected here. There were however differences noted in the levels of adaptiveness displayed by students when compared to working professionals (n=97). Working professionals scored significantly higher in the AE subscale of multiple perspectives (MP), indicating a willingness to use varied approaches to problem solving, but not in any other AE subscales or in overall levels of AE. No statistically significant differences were found when data was broken down by gender but, in a surprising result, first-year students in this survey population were found to show statistically higher levels of AE than students measured in prior work at another institution.

Future work will seek to broaden the survey population such that a more representative sample of both students and STEM professionals can be examined. Work will also be performed to examine whether factors other than selection bias are playing a role in the observed results. For example, whether institutional culture is a factor that can account for differences between student populations. Longer term goals of this project will involve examining the development of AE longitudinally (i.e. surveying the same students over a period of time), the determination of gaps in AE levels between various populations, and the design and development of interventions to promote growth in AE.

Acknowledgements
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Appendix A: Adaptive Expertise (AE) Survey of Fisher & Peterson [13]

Survey administered using a six-point Likert scale with the order of items scrambled. Note that items marked (*) and in italics denote "negative" items where "strongly disagree" would correspond to the characteristics of an adaptive learner.

Table A1. Fisher-Peterson Adaptive Expertise (AE) Survey items grouped by construct.

Item	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 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 & 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.*