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A review of Adaptive Expertise and its integration within undergraduate engineering curricula

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Abstract

While engineering programs must continue to cover as much content knowledge as possible, they 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 towards professional practice. As such, it is clearly necessary for schools to foster additional skills and attitudes that will better prepare students for careers as practicing engineers. Additionally, a change in focus from course-centric to student-centric learning affords the opportunity to critically address the question of the types of student growth that engineering programs should strive to develop. In this context, the concept of “adaptive expertise” has been previously developed within the field of undergraduate engineering education. An adaptive expert refers to 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 their content knowledge in practice. Here we examine the different operational constructs for adaptive expertise that have been presented in the literature, discuss the application of measurement tools that have been proposed to characterize student growth in adaptive expertise, and present examples of curricular changes that have been proposed in the literature as a means to facilitate the growth of adaptive expertise in students. We then draw conclusions about how this survey of adaptive expertise may inform engineering educators who wish to adapt the explicit integration of adaptive expertise within the undergraduate engineering curriculum. This review suggests that adaptiveness is something that can be developed in students, that this adaptiveness leads to positive outcomes with respect to the learning and application of content knowledge, and that students who are more adaptive will be better prepared to tackle the challenges encountered by practicing engineers in the workplace.

Introduction to Adaptive Expertise

Recent changes to the Accreditation Board for Engineering and Technology (ABET) criteria for accreditation refer to “Complex Engineering Problems” as the ability of students to successfully apply their content knowledge towards the solution of wide-ranging technical issues involving multiple disciplines and with significant consequences across a range of contexts (ABET, 2021). Organizations such as the National Academy of Engineering (NAE), the American Society for Engineering Education (ASEE), and various other stakeholders have also 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 (American Society of Engineering

Education, 2013; Bohle Carbonell, 2014; Moghaddam, 2018; National Academy of Engineering, 2004; van der Heijden, 2002). These requirements, as well as the shifting nature of the field towards interdisciplinary work, suggest that domain-based expertise is necessary but not sufficient for success in an engineering career. In addition to instilling high levels of content knowledge within their students, it is clear that engineering programs must prepare their students to effectively apply their content knowledge in a range of contexts.

Expertise refers to individuals who possess a level of content knowledge necessary to be able to operate productively within a given field (Bransford, 1999). In general, a few identifying characteristics of experts and expertise have been described: 1) their knowledge is more than a set of memorized facts or processes related to the field, 2) experts are able to notice meaningful features and patterns of information that is hidden to novices, 3) experts organize their content knowledge in a way that reflects deep understanding of the field, and 4) experts are able to easily and accurately retrieve important aspects of their knowledge with little cognitive effort (Bransford, 1999). It has long been understood, however, that experts within the same discipline may differ in the manner and effectiveness with which they are able to apply their expertise to solve a problem (Hatano, 1990; Wineburg, 1998).

Based on studies in the field of learning sciences, researchers have developed the concept of adaptive expertise (alternatively referred to as “adaptiveness”) to characterize the differences in the way that experts utilize their content domain expertise (Hatano, 1990; Wineburg, 1998). For example, one classical work in this area describes the differences in how two leading historians interpreted rare historical texts of Abraham Lincoln (Wineburg, 1998). Expert 1, whose professional focus was specialized on the Civil War era, immediately used their prior content knowledge as a foundation in their analysis. Here it was observed that their task progress and analysis were dominated by this prior knowledge, oftentimes at the expense of freshly evaluating the provided texts. Expert 2, on the other hand, whose content domain was a more general study of American history, was forced to employ quite different cognitive strategies to interpret the texts. These strategies included asking questions, proposing and examining potential hypotheses, and monitoring and filling gaps in their understanding. Wineburg described Expert 2 as demonstrating “the ability to apply, adapt, and otherwise stretch knowledge” so that they could effectively utilize their expertise in a new situation (Wineburg, 1998). Whereas routine experts are able to quickly and correctly apply content knowledge in the context of routine or familiar tasks, adaptive experts are better able to apply and expand their content knowledge in new contexts.

The concept of adaptive expertise has previously been applied as a framework to characterize the development of undergraduate engineering students (Fisher, 2001). Here four main constructs describing an adaptive expert were identified from a review of the literature: (1) multiple perspectives, (2) metacognition, (3) goals and beliefs, and (4) epistemology as summarized in Figure 1. The reader is referred to the original work for a more detailed discussion of the development of these constructs. It was hypothesized that the fostering of adaptiveness in undergraduate engineering students would complement their development of domain expertise as part of their studies and better prepare students for careers as practicing engineers.

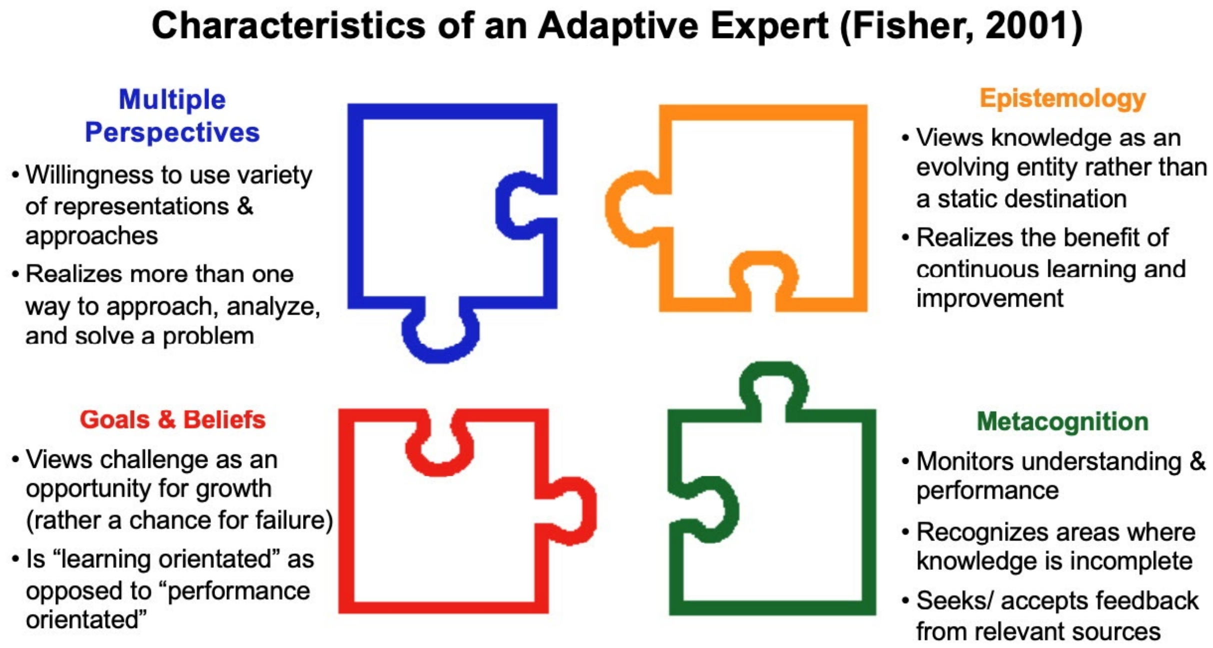

Figure 1. Four constructs describing the characteristics of an adaptive expert (adapted from Fisher, 2001).

In this definition of adaptive expertise derived for the context of engineering education, the authors were careful to differentiate adaptiveness from other terms and dispositions commonly associated with undergraduate engineering education (Fisher, 2001). For example, while creativity is not an element in this definition of adaptive expertise, adaptive experts may be better positioned to recognize areas where creativity is warranted and apply their content knowledge in creative ways. In a similar manner, while self-confidence in itself is not an element of the construct, individuals who demonstrate the epistemology and goals and beliefs of an adaptive expert will certainly feel more comfortable when presented with the challenge of learning new material. In addition, while teamwork is not an element of adaptive expertise (recall the discussion of the historians above), individuals who bring elements of adaptiveness to a team environment may enhance the performance of the team. Lastly, while terms like lifelong learning, strategic learning, and knowledge transfer are often used by engineering educators and accreditors, this concept of adaptive expertise is grounded in the learning science literature in a manner that is amenable to measurement.

An important distinction of this particular definition of adaptive expertise is 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. Based on this definition, a survey instrument consisting of 42 questions scored on a 6-point Likert scale, based on these four constructs described in Figure 1, was developed by Fisher and Peterson (2001) and is referred to as the Fisher-Peterson Adaptive Expertise (AE) Survey. The survey is provided in Appendix A. Other definitions of adaptive expertise described below, while motivated by the same goals, may be defined more broadly to include elements which are not explicitly considered in this definition.

One example of the use of the Fisher-Peterson AE Survey was by Pierrakos and co-workers (Pierrakos, 2016), who used the tool as a means to gauge the effectiveness of a senior design course designed specifically to develop adaptive expertise in students. In a comparative study of two sections of senior design (one taught in a traditional manner and one taught based on the principles of adaptive expertise), the researchers found that the Fisher-Peterson AE survey demonstrated acceptable reliability as a survey instrument, consistent with findings reported by others (Johnson, 2012). In addition, they found that there were significant differences in the average total adaptive expertise score between students in the two sections with students in the new, custom section scoring higher. They did not, however, find meaningful differences between the student populations at the construct level, and thus were unable to determine which specific dimensions of adaptive expertise differ across teaching methodologies. They attributed this to the natural limitations of self-report surveys and based on their findings recommended the development of a direct measure of the skill set of adaptive expertise. Based on their work they identified six dimensions of adaptive expertise (Pierrakos, 2016), adding the constructs of “flexible innovation” and “conceptual understanding” to the initial four constructs identified in Figure 1.

In other work, a slightly modified version of the Fisher-Peterson AE survey was edited by Ferguson and co-workers to remove perceived domain-specific terminology and then applied to study the impact of undergraduate co-operative work experiences on student growth (Ferguson, 2018). Impressively, over the course of several years, approximately 2,000 pre-test and 1,200 post-test scores on their domain-neutral version of the survey have been recorded. Based on a statistical analysis of this large data set, the authors proposed a modification of the adaptive expertise framework to include three sub-scales for capturing adaptive expertise: Domain Agility, Self-Assessed Innovative Practice, and Orientation to Innovation. Based on their three adaptive expertise constructs the researchers developed a 13 question survey instrument which has been used to characterize the impact of co-operative education placements on undergraduate student development (Ferguson, 2018).

While a number of researchers have used the definition of adaptive expertise as defined in Figure 1 or with modifications as described above, there is still considerable discussion in the literature regarding the operational definition of adaptive expertise and how to characterize its manifestation in students and practitioners (Hicks, 2014). For example, others have suggested that it may be possible to reduce the concept of adaptive expertise to the two orthogonal dimensions of innovation and efficiency as shown in Figure 2 (Bransford, 2006). In such a model "an adaptive expert is not simply the next level above a routine expert in a linear progression but instead a completely different type of expert" (Pierrakos, 2016).

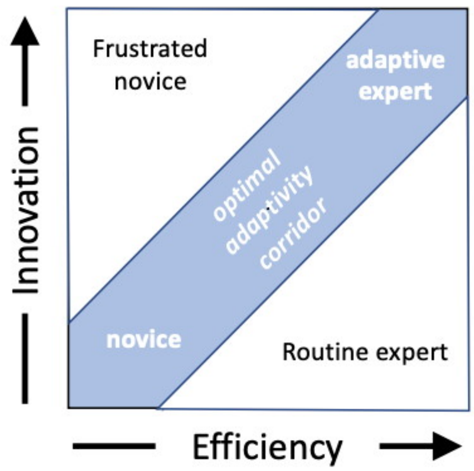

Figure 2. An alternative model of adaptive expertise represented by the two orthogonal dimensions of efficiency and innovation (adapted from Bransford, 2006).

While clearly more work must be done to develop a unified definition of adaptive expertise and related measurement tools, the purpose of this paper is to review efforts made to facilitate the development of adaptiveness (to complement content domain learning and expertise) across a number of fields, with a particular focus in engineering education. In almost all cases, it is clear that the features of adaptiveness are rarely taught explicitly in undergraduate engineering curricula and that this may impede the ability of students to effectively transfer content knowledge from one course and one context to another.

Applications of the concept of Adaptive Expertise

The general concept of adaptive expertise has been used by researchers in a number of fields as a means to characterize student growth. Although the specific definition may not be uniform across all studies, the goals of the studies are generally consistent: to use adaptive expertise as a means to characterize and describe the cognitive manner with which students are able to utilize and apply their content knowledge. In this context, adaptive expertise is often used as a means to characterize the differences in student behavior resulting from an educational intervention designed to facilitate this growth.

Recognizing that the framework underpinning adaptive expertise involves constructs typically developed via inductive teaching methods (Prince, 2006; 2007), attempts to include adaptive expertise in engineering curricula often revolve around problem- or challenge-based teaching methods (PBL and CBL). In addition, it is generally accepted that solving routine or simplified textbook-style problems, while perhaps beneficial in developing domain or content-based expertise, is not helpful in facilitating growth of adaptive expertise in students (Brophy 2004). This presents challenges as engineering theory has traditionally been taught at the undergraduate level in a rote manner focusing overwhelmingly on domain dependent, structured problem solving with an emphasis on textbook problems, significantly simplified applications, and questions with a specific solution (Bransford, 1984; Jonassen, 2000). In the sections that follow, we summarize the application of adaptive expertise in a number of different fields.

Bioengineering: A large body of research on the incorporation of adaptive expertise in undergraduate curricula stems from the field of bioengineering. Much of this work derives from researchers connected to the the VaNTH Engineering Research Center for Bioengineering Educational Technologies, funded by NSF with the aim of "developing the educational resources to prepare for the future of bioengineering" (Linsenmeier 2002). The educational strategies pursued as part of this project were based on the "How People Learn" (HPL) framework (Bransford, 2000), which suggests that learning environments be:

- *Student centered*: use students' current capabilities as a starting point for learning
- *Knowledge centered*: focus teaching on achieving mastery in the key content in the domain
- *Assessment centered*: build in opportunities for students and teachers to acquire feedback on students' progress throughout the learning process, and
- *Community centered*: are appropriate to the discipline and the community context.

One manner in which the HPL framework can guide the development of educational materials is through the use of the challenge-based STAR Legacy model shown in Figure 3 (Schwartz, 1999a; Schwartz, 1999b). This model has been used in a number of studies including those specifically targeting the development of adaptive expertise in students. In one example, Barr and co-workers presented the results of a Biomechanics course developed and taught based on the STAR Legacy model (Barr, 2005). A general affect survey developed by the same authors was used to indicate student growth in adaptive expertise during the course and demonstrated the effectiveness of this challenge-based instructional method.

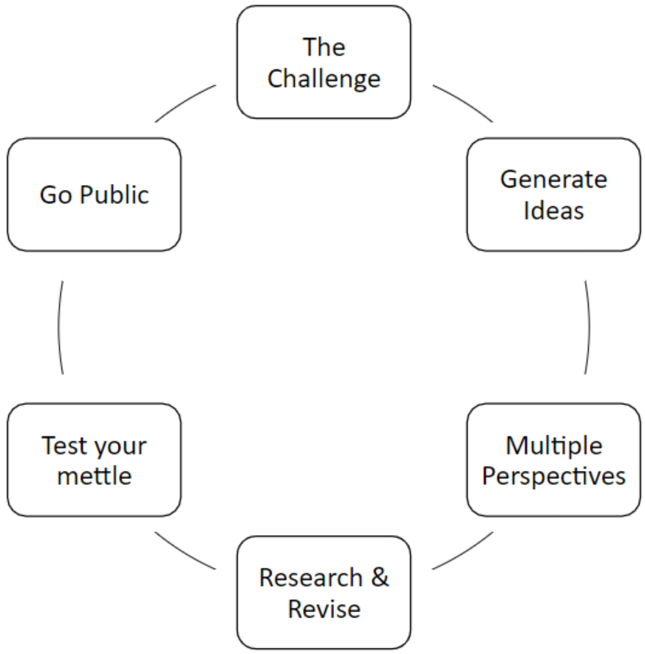

Figure 3: Legacy Cycle Framework (adapted from Schwartz, 1999a)

Several studies by Martin and colleagues have compared the adaptive expertise of students taught in “traditional” classrooms to those taught using instructional approaches based on the HPL (STAR Legacy) framework (Martin, 2005; 2007; Rayne 2006). Results from these studies showed that students engaged in both traditional and challenge-based instructional methods made similar gains in terms of content knowledge, but that students in the challenge-based courses made larger improvements in their innovative thinking capacity as assessed by the ability of those students to apply their knowledge to solve novel problems. In one study comparing the use of challenge-based teaching with students from multiple years of an undergraduate engineering program, results indicated that while younger students started with less prior content knowledge, they were more adaptive in the post-test (Rayne, 2006). It was suggested that the older students had more “preconceived notions” about the nature of the problem and struggled to think outside of the typical solution methods they had been drilled with in their college classes.

Another study in biomechanics by Pandy (2004) found similar results to those of Martin (2005; 2007) presented above. In this case adaptive expertise was assessed in terms of knowledge, conceptual understanding, and ability to transfer knowledge. Three class problems were used in a pre/post study that examined these dimensions. Students who received instruction based on the

STAR Legacy format showed improved conceptual understanding and improved ability to transfer knowledge relative to peers taught in a non-challenge-based approach.

Design Engineering: Design scenarios have been successfully used as a method to facilitate the development of adaptive expertise in engineering students (Walker, 2006). These scenarios, representing a form of problem-based instruction, are offered to students who are then left to tackle the problem without significant guidance. The development of adaptive expertise in this context was assessed by ranking the quality of student responses to specific questions such as "What do you need to do to test [the hypothesis]?" or "At this time, what other information do you need from [stakeholder]?" during think-aloud protocols as well as in-situ observations. In a study including first and fourth year college students, both sets of students were found to develop along the chosen adaptive expertise definition with dimensions of innovation, efficiency, and confidence, with the fourth year students typically scoring higher in these constructs and displaying a greater willingness to approach the problem from a broader perspective.

McKenna and co-workers have examined adaptive expertise in the context of an innovation/efficiency framework in numerous design settings (McMartin, 2000; McKenna 2006, 2007, 2008, 2015). In their words "*The adaptive expertise framework is directly applicable in the context of design and innovation given the emphasis on how one develops adaptiveness in learning, and how to apply knowledge fluidly. The process of design and innovation involves developing a solution where one does not yet exist. From this perspective, every design situation is novel, embeds ambiguity, and has no one correct answer. The very nature of design requires one to recognize how prior knowledge might apply under new circumstances"* (McKenna, 2015).

In their work these authors instituted various design activities that focused on providing learning experiences in innovation and efficiency (see Figure 2). Students were mentored in efficient approaches to design (performing research, considering alternatives, soliciting feedback at all stages, etc.) while the innovation aspects were left more open-ended. Students were encouraged to be creative and innovative as solutions of this type were needed to address the novel design challenges they faced (McKenna, 2006). The adaptivity (efficiency) of students was characterized pre-/post-test by examining student responses to a design challenge and coding the responses based on an efficiency rubric determined by the authors. Through their experience in the design course, students improved in all aspects of the efficiency dimension as characterized by the authors. Based on this work, McKenna and her colleagues propose an "invent to learn" approach based on an "inventing to prepare for future learning" (IPL) framework that they suggest may help students develop adaptive expertise during their design courses (McKenna, 2008). Schwartz and Martin (2004) examined the effectiveness of this "invent to learn" approach in the development of adaptive expertise as measured against a typical "tell-and-practice" approach amongst ninth-grade math students - the students who invented their own approaches were more successful in solving a novel problem set introduced later in the study.

In another set of work focused exclusively on computer-aided design (CAD), Ozturk and co-workers examined the validity of the Fisher-Peterson AE survey instrument based on measurements of students in CAD classes at two different schools, finding that there was significant correlation between subject scores in the “metacognition” and “epistemology” constructs, we well as between the “goals and beliefs” and “multiple perspectives” sub-dimensions (Johnson, 2012). Further, they found that the metacognitive sub-scores from the survey held the strongest correlation with the students' reported adaptive expertise characteristics elicited from structured interviews. In later work, these researchers used the 4 constructs of adaptive expertise defined in Figure 1 to gauge student levels of adaptive expertise via coding of structured pre- and post-interviews used when students were challenged to solve contextualized problems in an undergraduate CAD class (Ozturk, 2013). They concluded that metacognitive skills are a good indicator of developing adaptive expertise and that educators should consider promoting metacognitive skills in CAD education. Lastly, this same research team compared student and practicing engineer manifestations of adaptive expertise via the Fisher-Peterson AE survey instrument as well as through coded pre- and post-interview responses. Similar to the results from the initial Fisher and Peterson (2001) work, their results indicated that the practicing engineers had more “multiple perspectives” and more overall manifestations of adaptive expertise than students (Ozturk, 2015). Other researchers have also examined the applicability of using the concept of adaptive expertise to gauge student development in undergraduate CAD and design courses (Kuo, 2018; Ramos Barbero, 2018).

K-12 Teacher Training: In the context of K-12 teacher training, adaptive expertise was used by researchers examining a 6-week program to prepare veteran math/science teachers to teach high school design engineering (Martin, 2015). Their hypothesis was that these math and science teachers were traditionally trained to instruct students using the rote problem-solving techniques that are typical of a traditional curriculum. As such they would benefit from the perspective of adaptive expertise in expanding their ability to apply this knowledge in innovative ways and in addressing the more open-ended problems characteristic of engineering design. Despite the six-week intervention, using the Fisher-Peterson AE survey (see Appendix A) these researchers found that the veteran teachers scores of adaptiveness remained relatively unchanged as a result of the instruction, perhaps indicating that more explicit and formal training on adaptiveness may be necessary in this context (Martin, 2015) or that the intervention was unsuccessful in changing the veteran teachers conviction in their standard teaching practices. In the field of special educators teacher training, De Arment and co-workers have suggested the use of the HPL derived STAR Legacy Framework for promoting adaptive expertise within these pre-service educators (De Arment, 2013; Wetzel, 2015).

Medical Field: A scoping review of adaptive expertise in medical education conducted in 2020 found 48 articles: 19 examined conceptual frameworks, 24 explored interventions, and 5 sought the measurement of adaptive expertise in medical students (Kua, 2020). This review identified several principles in common with the studies of adaptive expertise found in engineering education discussed above: it is effectively taught using methods based on the HPL framework, factors influencing the development of adaptive expertise are strongly tied to the attitudes of the learner (e.g. they include motivation, beliefs and attitudes, metacognition, and desire for flexibility in learning), and a gap still exists in the development and validation of tools to measure adaptive expertise. In one study the framework of a "Master Adaptive Learner" (Cutrer, 2017) was introduced describing the attributes of an adaptive learner and combined elements of the Fisher and Peterson (2001) adaptive expertise framework as shown in Figure 1 with the HPL framework (Bransford, 1999).

Based on their review, Kua (2020) developed a conceptual framework of adaptive expertise based on terminology found in the medical literature as shown in Figure 4. The authors divided these concepts into categories based on those which "predisposed", "enabled", or "reinforced" the development of adaptive expertise. While the presentation of this framework is visually different to that used in engineering fields, in general it appears that the conceptual understanding of adaptive expertise within the engineering and medical fields does not differ substantially. In particular, the tools and techniques ("enabling factors" in Figure 4) defined as best-practices for the development of adaptive expertise (primarily challenge-based methodologies) are similar in nature in each discipline (Mylopoulos, 2018).

Conceptual Framework of Adaptive Expertise in the Medical Field		
Predisposing	**Enabling**	**Reinforcing**
Beliefs and Attitudes - positive mindset/attitude towards learning - high intrinsic motivation - humility - open to multiple perspectives - embraces complexity - excited about novelty	*Skills* - innovative - connecting and synthesizing knowledge - collaborative - clear communication - reflective	*Reminders* - constant curricular review
Knowledge - possess deeper understanding of problems - having cognitice flexibility	*Resources* - Curricular modifications i) provide variability of cases ii) allow flexibility to generate solutions iii) critical appraisal of textbooks - participation in scholarly projects	*Feedback* - mentor guided
	Social and Physical Environment - safe environment for collaborative discourse	

Figure 4. Conceptual framework of adaptive expertise developed in the medical field (adapted from Kua, 2020).

Adaptive Expertise Outside the Curriculum (internships, co-ops, etc): It has been suggested that training in contexts similar to the workplace environment might be useful to the development of adaptive expertise (Pulakos, 2000). While it seems reasonable that adaptive expertise would be developed in a less-structured learning environment such as the workplace, few studies have examined this hypothesis. It has however been found that internationally mobile interns are potentially able to demonstrate greater ethnorelative awareness, introspective reflective practice, a context-sensitive lens and more creative strategies for problem-solving (Gaisch, 2015). A variant of an adaptive expertise model, composed of domain-specific and innovative skills, was also used to characterize employee performance in the workplace (Bohle Carbonell, 2016). Here researchers found that task variety, and not work experience, was more closely related to the level of adaptiveness demonstrated by the employees. Several recent studies have aimed at examining the effect of extra-curricular activities on adaptive expertise. For example, Ferguson (2018) developed their AE survey specifically for students engaged in co-op experiences, while La Place (2020) has examined the effect of external activities, in this case student design challenges such as hackathons, on the development of student ability to apply knowledge in new situations - knowledge transfer being seen by those authors as a key component of adaptive expertise.

Integration of Adaptive Expertise within the undergraduate engineering curricula

This review has demonstrated the usefulness of challenge-based, inductive teaching methods on the development of adaptive expertise. The studies cited also give examples of how such challenge-based approaches can be integrated into curricula in various contexts and for students at different stages in their studies. In particular, the STAR Legacy model (Figure 3) indicates how a course, or modules or specific assignments within a course, can be modified and developed to better teach adaptiveness and approach instruction from an evidence-based perspective.

This wider use of challenge-based instruction was also cited by Smith (1997) who suggested best practices for “the design of a learning environment that prepares the trainee for adapting to changing task demands” as shown in Figure 5. Importantly, Smith et al. identify not only the challenge based-methods found in this review, but also focus on other characteristics of an adaptive expert such as metacognition and knowledge structures that were not explicitly measured or discussed in many of the studies reviewed here. These additional items were identified by these authors as critical to the development of adaptability and also appear in the “enabling factors” for developing adaptive expertise described by Kua (2020) in their review of adaptive expertise in the medical field (Figure 4).

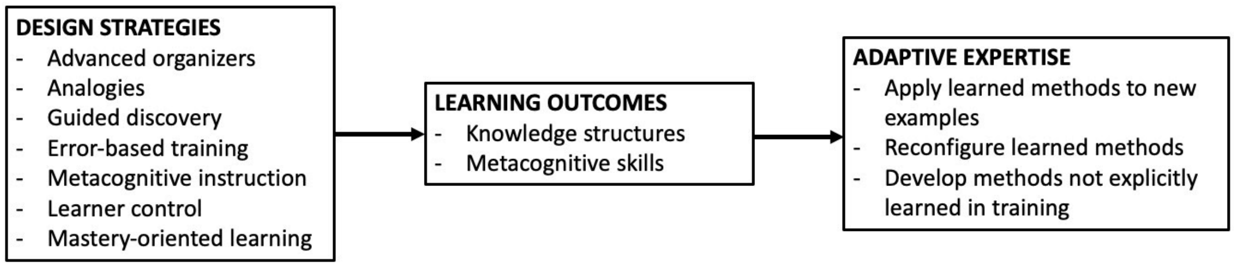

Figure 5: Design of learning environments to build adaptive expertise (adapted from Smith, 1997)

A case study of how one might adapt a Senior Design course to facilitate adaptiveness in students was given by Pierrakos and colleagues (Pierrakos, 2016). The design of their adaptive expertise-modified course was based on four principles: 1) Establishing the Class Culture via Shared and Student-Derived Values and Behaviors - where the class was envisioned as a workplace with a set of expectations; 2) Aligning Effort Contingent Learning and Rewards - supported by researchers who have suggested that focusing assessment on effort rather than ability may better support mastery learning strategies and better knowledge retention in students (Ames, 1984); 3) Empowering Students with Autonomy, Self-pacing, and Inductive Teaching Methods; and 4) Using Proactive, Team-based Motivational Strategies to Support Team Assignments and Capstone Projects. A comparison of the traditional lecture-based senior design course with the modified course developed to facilitate adaptive expertise in the students is given in Table 1 (Pierrakos, 2016).

Further, a review of the literature suggests that extra-curricular, profession-related activities may be valuable in developing adaptiveness in engineering undergraduates students. In one study an interview protocol to elicit from students examples of instances where they may have developed traits consistent with adaptiveness found extra-curricular activities such as internships, co-op experiences, and undergraduate research seemed to be impactful in the development of adaptive expertise in students (Fisher 2001). In another example, a university augmented its traditional co-op program by requiring students during their first co-op assignment to write four prompted essays reflecting on the impact of their co-op experiences with the goal of nurturing the development of adaptiveness in these students (Ferguson 2018).

Table 1. Comparison of a traditional lecture-based Senior Design course with a modified Senior Design course designed to nurture adaptive expertise in students (adapted from Pierrakos 2016).

Feature of Course	Lecture-Based Section	Adaptive-Expertise-Based Section
Content Coverage using a common book	Yes (same)	Yes (same)
Chapter Quizzes accompanying lectures	Yes	No
Midterm Exam	Yes (written)	Yes (oral)
Final Exam	Yes (written)	Yes (written)
Explicit Values of the Course being effort, metacognition, innovation, collaboration and quality	No	Yes
Optional Prep Guides accompanying each chapter and guiding students in reading coverage using questions	No	Yes
Design Challenges accompanying each chapter and the theory-based learning	No	Yes
Mastery-based learning model allowing students to resubmit work (optional) and to show stronger evidence of mastery learning and to allow for earning points back	No	Yes
Common Grading Guide for all assigned focused on effort, quality and innovation	No	Yes

Lastly, the use of simple one minute reflection papers (Butler, 2001; Stead, 2005) during and after a lecture can provide an opportunity for students to develop a metacognitive mindset. While most reflections will invariably be content knowledge-based, occasional explicit prompts can lead students towards reflections along the dimensions of the adaptive expertise constructs discussed earlier. Example prompt questions may include: “What elements presented within the lecture do you feel you need to work to further understand?”, “What are other tools or approaches one may use to solve these types of problems?”, and “How has your understanding of this topic evolved over time?”.

Conclusions

Based on the literature surveyed here there is an emerging consensus that inductive teaching methods such as challenge-based instruction are most effective at developing traits in students that are consistent with the dimensions of adaptive expertise. In particular, there is strong evidence that these instructional methodologies promote knowledge transfer and the ability of students to solve “novel problems” based around an innovation/efficiency framework of adaptive expertise. However, there are multiple operational definitions of adaptive expertise which have been developed for different contexts which complicates a direct comparison of literature results, as does an inconsistent use of validated, evidence-based measurement instruments for the assessment of adaptive expertise growth in students.

Based on this review it is clear that researchers believe that the traits of an adaptive expert will assist students in applying their developing domain knowledge, recognize new areas and manners where such content knowledge may be applied, and help students use their existing content knowledge as a foundation for acquiring new knowledge. Research work from a range of disciplines suggests that it is possible to introduce learning opportunities in unit sizes ranging from single assignments, to larger design projects, to an entire class with the goal of instilling both content knowledge and these additional attitudes and cognitive dispositions in students. These results indicate 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.

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Appendix A. Fisher-Peterson Adaptive Expertise (AE) Survey (Fisher, 2001)

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.*