

**ADAPTIVE EXPERTISE AND CONTEXTUALIZED ACTIVITIES IN  
COMPUTER AIDED DESIGN**

A Dissertation

By

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## **ABSTRACT**

In today's highly competitive market with economic, environmental, and social challenges, it is imperative that engineers are educated to adapt to the new challenges. Engineering education could play a critical role to improve engineering students' self-regulated and adaptive skills that are important for their future engineering productivity and innovation. To survive and thrive in the fast-changing workplace, today's students will need to become adaptive experts. However, current engineering education practices tend to focus too much on the low-level skills required to do specific and routine tasks rather than fostering self-regulated and adaptive skills required for innovation.

Experts are defined in two distinctive characteristics: adaptive experts versus routine experts. Adaptive experts acquire the content knowledge parallel to routine experts in the field; in addition, they have the ability to effectively and innovatively utilize and extend that knowledge. In this dissertation, to determine the "baseline" adaptive expertise among the sample population, an adaptive expertise survey (AES) instrument is administered to both the practicing engineers and the students. The instrument contains questions defining four dimensions of adaptive expertise: multiple perspectives, metacognitive self-assessment, goals and beliefs, and epistemology. Participants' demographics and engineering experience were recorded and cross-tabulated with their adaptive expertise characteristics captured in the study. In addition this study explored engineering students' and practicing engineers' adaptive expertise (AE) characteristics as they used a CAD tool. The practicing engineers were asked to model a component in a CAD program that they were not familiar with. The students were asked to model a stylized familiar component that they brought from home.

In both cases, pre and post interviews were conducted to explore how the participants approached their tasks and overcame any challenges. Effects of the contextualized activity on students' AE characteristics were investigated. In general, results indicated that as students gain more experience through years their overall AE characteristics were developed. In addition, the studies signified that multiple perspectives, goals and beliefs, and metacognitive skills are good indicators of developing AE and educators should consider promoting those skills in engineering education.

## **NOMENCLATURE**

AE	Adaptive Expertise
AES	Adaptive Expertise Survey
FA	Factor Analysis
PBL	Problem Based Learning

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# **CHAPTER I**

## **INTRODUCTION**

### **I.1 Overview**

Today in the face of economic, environmental, and social challenges, formal education often becomes a gatekeeper to many professions that require specific types of skill sets and expertise. In addition, pervasiveness of digital technologies has increased the pace at which individuals communicate and exchange information, requiring competence in processing multiple forms of information to accomplish tasks that are trans-disciplinary including engineering. The ABET Inc., the primary engineering accreditation institution in the United States, has determined the most important skill sets for the preparation of engineers. These are the ability to identify, formulate, and solve workplace engineering problems and to function on multidisciplinary teams. Learning to solve workplace problems is an essential learning outcome for any engineering graduate (Jonassen, 2014). Every engineer is hired, retained, and rewarded for his or her ability to solve problems. However, according to Jonassen, Strobel, and Lee (2006), engineering graduates are ill prepared to solve complex, workplace problems. By having diverse learning experiences, students can learn to apply skills and knowledge in different contexts; this process is called ‘transfer’ (Pellegrino & Hilton, 2012). It is important for schools and colleges to develop skills such as transfer of knowledge, problem solving, critical thinking, communication, collaboration, and self-management, which are referred to as “21st century skills” (Pellegrino & Hilton, 2012). Therefore, today’s higher educational settings should be updated to help students develop

these skills.

In this more swiftly developing era, educating engineers who are able to adapt quickly to the new challenges becomes imperative. One way of helping to create diverse experiences in engineering education for students is the use of computer-aided design (CAD) tools. Therefore, in this dissertation, to be able to scrutinize the AE manifestations of engineering students, CAD tools are used as an instrument.

### **I.1.1 Engineering Education and Adaptive Expertise**

CAD tools are pervasively used throughout the development process in many industries (Field, 2004), and available in multiple platforms (Johnson & Diwakaran, 2011). In addition to their primary purpose of generating detailed drawings for use in product manufacturing, these tools are now used for numerous other development process activities (e.g., packaging, fabrication, and simulations) (Field, 2004). In engineering education, CAD tools allow students to use their knowledge and skills to create models and apply their adaptability to novel problems. These tools can support students to attain a level of expertise if a deeper practical knowledge is taught. CAD tools can greatly enhance development efficiency if expert modelers use them (Adler, 1990).

The goal of CAD instruction should be providing students with the instructive resources necessary to make them expert CAD users. However, the current state of CAD education is widely viewed as inadequate. Students are not learning the skills they need to efficiently and effectively use the modern CAD tools in which their prospective employers have invested significantly. Unfortunately, in contrast with the procedural knowledge associated with CAD expertise (Lang, et al., 1991), current CAD instruction is focused on teaching step by step declarative knowledge that is specific to performing certain tasks in

specific software platforms (Hamade, Artail, & Jaber, 2007; Ye, Peng, Chen, & Cai, 2004). Feltovich, Prietula, and Ericsson (2006) defined CAD related expertise “amassing considerable skills, knowledge, and mechanisms that monitor and control cognitive processes to perform a delimited set of tasks efficiently and effectively.” Thus, the skills developed may not easily transfer to other tasks or contexts and the skills could easily become outdated or not useful if tasks and contexts change.

One way to increase the likelihood of transferring skills to diverse tasks and contexts is to integrate adaptive expertise (AE) skills into engineering curriculum. Understanding the factors contributing AE skills and how to teach or improve AE skills is important to effectively design engineering instruction. It is also important to scrutinize the role of contextual exercises in developing AE characteristics and factors that have an effect on AE characteristics of students.

AE could be defined as capabilities of both being innovative and adaptive to new challenges while also having content knowledge associated with expertise (McKenna, 2007). Key to expertise is the mastery of concepts that allow for deep understanding of that information, transforming it from a set of facts into usable knowledge. Expertise is the ability to process information quickly and recognize related solutions to problems in a particular skill and/or domain knowledge. Expertise is the accumulation of experience and expert people come to solve more complex problems in the field, utilizing relevant prior knowledge which is in turn gradually enriched and integrated (Hatano & Inagaki, 1986). Hatano and Inagaki (1986) defined two types of expertise to make the distinction clearer: “routine expertise” and “adaptive expertise.” Adaptive experts are those who perform procedural skills efficiently and understand the meaning of the skills and nature of their

object. Routine experts simply learn to perform a skill faster and more accurately, without constructing conceptual knowledge, and can even perform a task through automation of the procedure. The fluency of finding related solutions to problems only makes students “routine” experts for specific problems. However, routine expertise does not mean students have flexible knowledge that may be needed to invent ways to solve familiar problems and innovative skills to identify new problems (Brophy, Hodge, & Bransford, 2004). AE is the term that defines capabilities of both being innovative and adaptive to new challenges while also having content knowledge associated with expertise (McKenna, 2007).

## **I.2 Purpose of the Research**

The main purpose of this dissertation is to explore the differences between novices versus expert modeling procedures within the contextual CAD exercises and to evaluate ways to promote adaptive expert characteristics in undergraduate engineering education. A learning environment informed by the How People Learn framework (Bransford, et al., 2000) with a particular emphasis on learner- centeredness and contextualized student activities is also presented.

### **I.2.1 Research Questions**

To be able to make inferences on integrating AE into engineering education, and make students enhance their AE skills, it is important to explore the factors that contribute to the development of AE skills. To address these issues, in this dissertation, three related chapters are presented to answer the three main questions:

1. Which factors can contribute to the development of AE?
2. What are the relations between the engineering students’ demographics and

their AE characteristics?

3. How do contextualized activities in CAD modeling affect students' AE characteristics and their modeling attributes?

First, the literature review section presents the factors contributing to the development of AE. The literature review aims to highlight the key characteristics of AE, and to discuss how AE can be taught or developed in engineering education. The main questions for this part are:

- Which factors can contribute to the development of AE in higher education?
- How can higher education be enhanced so that students' can develop AE characteristics?

The third chapter of the dissertation presents the study describing the implementation of an instrument used to measure adaptive expertise at two universities and practicing engineers. In one university setting, freshmen and sophomore engineering students were surveyed with the instrument; in the other, junior and senior level engineering students were surveyed. In addition to the student participants, practicing engineers from the industry were surveyed using the instrument. In this study, to measure the respondents' AE characteristics, an AE survey developed by Fisher and Peterson (2001) is used. The AE was designed to measure the adaptive expertise characteristics of the students in biomedical engineering. The instrument contains questions defining four dimensions: multiple perspectives, meta-cognitive self-assessment, goals and beliefs, and epistemology. Through the correlation analyses, the relationships among expertise related responses and demographic variables were examined.

This dissertation also includes a qualitative study that scrutinizes the pre and post

interviews conducted through a contextualized CAD modeling activity. In this study, 302 students from two different universities undertook the CAD modeling activity. A control group modeled regular textbook objects, while a contextual group used objects they were familiar with. In addition, practicing engineers used an unfamiliar CAD platform to completed the CAD activity. Effects of the contextualized activity on participants' AE characteristics are investigated.

## **CHAPTER II**

### **FACTORS CONTRIBUTING TO THE DEVELOPMENT OF ADAPTIVE EXPERTISE IN ENGINEERING EDUCATION: A REVIEW OF LITERATURE**

#### **II. 1 Overview**

Engineering education research has become a recognized field within the last decade. Inquiry into the history of engineering education shows that substantive changes have occurred and will continue to occur (Froyd & Lohmann, 2014).

Today, educating engineers to be able to invent and solve novel problems is more important than before. Engineers need to adapt to the new challenges of current era where science and technology are developing swiftly. In addition, people have been increasingly reliant or dependent on technologically mediated systems to perform a wide array of tasks and there have been increasing demands for the specialization of individual skills and expertise (Kozlowski, 1998). Therefore, it is important to understand how to improve students' adaptive expertise (AE) skills so that engineering education can be enhanced in a way to train more adaptive engineers who are also experts on their field. This chapter aims to highlight the key characteristics of AE, and to discuss how AE can be taught or developed in higher education and engineering education. Thus, the main questions guiding this literature review are:

- Which factors can contribute to the development of AE in higher education?
- How can higher education be enhanced so that students' can develop AE characteristics?

## **II. 2 The Review of Literature**

### **II.2.1 Expertise**

When people develop expertise in a particular domain, they are more capable of thinking critically and effectively about the problems in those areas when compared to their novice counterparts. Experts know when to apply a procedure or rule; they predict the correctness or outcomes of an action and this capability for self-regulation (including self-monitoring and self-evaluation) enables them to profit a great deal from learning and practice (Hatano & Inagaki, 1986). Chi, Glaser, and Farr (1988) summarized some key characteristics of experts: (1) Experts are mainly competent in their own domains. (2) Experts are faster than novices at performing the skills on particular domain and they can quickly solve problems with little errors. (3) Experts have superior short-term and long-term memory. (4) Experts see and represent a problem in particular domain at a deeper level than novices. (5) While experts try to understand a problem deeply and take their time, novices immediately attempt to solve for an unknown. (6) Experts are capable of self-monitoring their own understandings (pp. 17-20). Expertise is not simply performing general abilities like memory and intelligence, in a specific domain. On the other hand, expertise is the ability to acquire extensive knowledge, which affects what experts notice and how they organize, signify, and interpret information, which in turn, affects their abilities to remember, reason, and solve problems (Hatano & Inagaki, 1986). In addition, experts have a great capability for anticipation, they are able to approach systems as more global and functional representations, and experts have better abstraction abilities (Guerin, Hoc, & Mebarki, 2012). Popovic (2004) claims that the level of expertise in product design plays an



important role in problem representation. In his study, using a knowledge connection model, Popovic suggests that experts and novices differ in how they organize knowledge, the amount of information they use, how they access domain-specific knowledge, how they apply domain-specific goal strategies.

### **II.2.2 Routine vs Adaptive Expertise**

In early representations of expertise, it was assumed that training for problem solving would enhance efficiency of decision-making skills (Newell & Simon, 1972). However, research soon indicated that effective decision-making skills were restricted by problem content and with general skills supporting little transfer across domains (Anderson, 1993; Gagne, 1977; Hatano & Inagaki, 1986). It was recognized that experts acquire extensive and well-organized domain knowledge, and compile procedural rules for addressing restricted problems (Anderson, 1993).

Adaptive expertise was first formally termed and conceptualized by Hatano and Inagaki (1986) who distinguished adaptive expertise from routine expertise. Automaticity characteristics appear with a well-practiced performance that is predicted on extensive practice and experience, which is defined as routine expertise (Hatano & Inagaki, 1986). Routine experts can solve large number of problems, they can simply learn to perform a skill faster and more accurately, without constructing/enriching their conceptual knowledge (Holyoak, 1991). They can solve problems fast, accurate, and fluent of performance, but they lack flexibility and adaptability to new problems. Experts who can apply the skills that they can also predict the outcomes of those skills and who can solve the problems for the novel situations using their knowledge and experiences can be defined as “adaptive experts” (Hatano & Inagaki, 1986). Routine experts are very fluent and efficient in applying their

skills to the situations where they are proficient and they get used to do but some experts may not be able to be as fluent and effective as they are when they face with a novel situation. Experts can quickly and effectively adapt to new challenges. Experts with conceptual understanding who are able to conceive new procedures when the old ones failed are adaptive experts. Lately, et al. (2012) define AE as “higher order problem-solving involving knowledge transfer across the disciplines” (p. 217). When novices become adaptive experts, they do not only implement practical skills efficiently but also understand the implications of the skills (Brophy et al., 2004). For example, a practicing engineer who is expert on modeling an object for years in a platform can be very fluent and effective on what he has been doing for years. However, if the platform is changed, the work responsibility is changed, or novel workplace problems appear and engineer is working under stress, she may not be adapt to new situations under new circumstances if she is a routine expert rather than an adaptive expert.

Engineers are hired, retained, and rewarded for their abilities to solve workplace problems. Engineers are important for a nation because to maintain economic success and sustain developments in technology, engineering technologies are significant. Therefore, the engineers of tomorrow must be prepared for future technological and social changes and for being able to attain new knowledge swiftly and apply it to evolving problems (Jonassen, Strobel, & Lee, 2006). Like routine experts, adaptive experts are lifetime learners, but unlike routine experts, adaptive experts are never fulfilled with their existing levels of understanding and attempt not only to work more efficiently but also to work more innovatively (Crawford, 2007; Donovan, Bransford, & Pellegrino, 1999).

To be able to understand adaptive expertise deeper, it is important to understand

the key aspects of developing expertise and developing adaptiveness, which are presented next.

### **II.2.3 Factors That Contribute to Developing Expertise**

Hatano and Oura (2003) summarized expert characteristics and how expertise can be developed; (1) Experts acquire rich and well-structured domain knowledge consist of segments ready to use, (2) gaining expertise requires experience in solving problems in the domain, with deliberate practice often requiring effortful persistence and delay of gratification, (3) knowledge and skills attainment is complemented by person's interest, values, and identity, (4) gaining expertise is assisted by other people and artifacts (unlike in social learning novices are not expected to solve problems all by themselves, (5) expertise occurs in the process of generating the goal outcomes of the activity, (6) expertise in each domain takes time because there are a large number of domains in which people can gain expertise.

In addition, there are some other key aspects that support developing expertise. Motivation, self-regulation, using relevant knowledge, and transfer of that knowledge are key aspects to develop expertise (Fazey, Fazey, & Fazey, 2005; Hatano & Inagaki, 1986; Newton, 1993; Zimmerman, 1989).

**Motivation.** Learning can be defined as the acquisition of information that causes a change in behavior that result from experience (Donovan et al., 1999). Because learning requires conscious and thoughtful effort, motivation is significant for learning (Newton, 1993) and it is one of the factors that foster learning because individuals pursue goals to increase their competence with motivation. These learning goals differ across individuals based on their self-concepts (Dweck & Leggett, 1988) as well as extrinsic and intrinsic

motivation. Extrinsic motivation refers to doing something for external rewards while intrinsic motivation refers to doing something for its inherent interest or pleasure (Bohlin, Durwin, & Reese-Weber, 2009). According to the cognitive theories of motivation; changing an individual's cognition is also changing the motivation and so the learning. Those cognitions can be listed as expectations for success, valuing of learning tasks, goals, beliefs about the ability, and expectations of successes and also failures (Bohlin et al., 2009). Learning complex tasks requires focused attention and cognitive effort. In addition, metacognitive and self-regulatory skills entail the capability to manage motivation (Kanfer & Ackerman, 1989).

People have different expectations of success so that the motivation for learning is also different. Those expectations depends on many different factors like past experiences, values, beliefs, and developmental and cultural differences. Learner's goals and beliefs are the views that they have concerning their learning goals (Fisher & Peterson, 2001). Goals set up individuals' display of responding, motivation, and learning. These goals are nurtured by individuals' self-conceptions that identify individual differences in beliefs and values that appear to generate individual differences in behavior like learning (Dweck & Leggett, 1988). Elliot (2005) reviews the history of achievement goal that focuses on achievement and motivation. According to the review, achievement goal construct was established in 1970s and since then researches and developments on motivation and achievement has been a hot topic and continuous to create significant research across disciplines. Achievement goal construct proposed that achievement situations are constructed and engaged through motivation, which is characterized as beliefs on success, effort, and ability (Elliot, 2005).

Effective management of the learning process enhances self-efficacy allowing the

individual to tackle difficult tasks and to continue when facing the novel challenges as well as to maintain motivation under challenging performance conditions (Bandura, 1991; Gist & Mitchell, 1992; Newton, 1993).

**Self-regulated learning strategies.** Zimmerman (1989) defines self-regulated learners as “metacognitively, motivationally, and behaviorally active participants in their own learning process and direct their own efforts to acquire knowledge and skill rather than relying on teachers, parents, or other agents of instruction” (p. 329). Encouragement of active learning strategies is a key factor for the development of adaptive expertise (Smith, Ford, & Kozlowski, 1997). Adaptive experts have metacognitive and self-regulatory skills (Kozlowski, 1998). According to Zimmerman (1989), to describe a person as a self-regulated learner, learning must involve the use of specified strategies to achieve academic goals. Self-regulated learners set their learning goals, attempt to benefit from their educational experiences, monitor their progress, make regulations in their efforts, and establish new, more challenging goals as they accomplish earlier ones (Miller & Brickman, 2004). Practicing what is learned contributes to retention of learning and facilitates future learning opportunities Fazey et al. (2005) emphasized that individuals can learn more efficiently when they use their prior knowledge and experiences through self-regulated learning strategies such as planning, monitoring, and reviewing.

New developments in the science of learning highlight the significance for people to be able to take control of their own learning (i.e., self-regulated learning). People can recognize when they understand or when they need more information so that they can learn more effectively (Bransford et al., 2000; Zimmerman, 1989). Metacognition is another important aspect of effective learning. Flavell (1979) defines metacognition as executive-

level processes requiring knowledge, awareness, and control of cognitive activity involved in goal attainment. Metacognition refers to people's abilities to predict their performances, and self-monitor, self-evaluate, and self-regulate their own understandings on various tasks (Brerardi-Coletta, et al., 1995). In their conference paper, Fisher and Peterson (2001) stated that "Individuals with high levels of metacognition frequently question their own understanding of a situation, and are able to recognize areas where their knowledge may be incomplete or insufficient" (p. 4). Experts have strong metacognitive skills that they can monitor their problem solving, question limitations in their knowledge, and elude simple interpretations of a problem. Pellegrino and Hilton (2012) define metacognition as the ability to reflect on one's own learning and make adjustments accordingly that also enhances deeper learning.

**Relevant knowledge.** The ability to learn how to recognize meaningful segments of information with learning experiences enhances expertise. For an expert, knowing more means having more conceptual segments of information among a lot of information and expert knows the efficient method to retrieve related part of the information –relevant knowledge- to apply those to solve problems (Chi, 2006; Pellegrino & Hilton, 2012).

What makes experts different from novices is their ability to perceive patterns in their knowledge that they can easily organize and integrate structures of knowledge (Glaser, 1992). Among a vast variety of knowledge relevant to a particular area, experts know to find what is relevant and they organize around big ideas rather than memorizing, recalling, and manipulating equations to solve a problem (Bransford et al., 2000). Therefore, to be an expert in an area, it is important to be able to organize the knowledge available and before finding a solution quickly without comprehending, it is important to understand and

interpret it deeply on which variety of prior knowledge, skills, beliefs, and concepts play important role. Although experts' fluent and useful retrieval of knowledge seems like faster than novices' retrieval of knowledge, the effortful attempt of experts to understand problems rather than to jump immediately to solution strategies may take more time than novices (Bransford et al., 2000; Guerin et al., 2012). Hence, being fast in solving problems does not directly mean being an expert unless the solution is relevant, efficient, and have little errors.

**Deeper learning and transfer of knowledge.** Developing expertise in an area of knowledge requires time and practice. In addition, learners need feedback to guide and optimize practice activities so that with strong interpersonal skills they can understand and apply such feedback (Pellegrino & Hilton, 2012). This can also be called deeper learning that should be the primary goal for teaching in every level of education, where students can succeed in solving new problems and adapting to new situations.

Recently, educators promote “deep learning” that is defined as the process through which an individual becomes capable of taking what was learned in one situation and applying it to new situations (i.e., transfer). Transfer of learning is a critical element of adaptive expertise (Kalyuga, 2009). Without the ability to correctly apply knowledge within situations, there is little development of expertise, especially, no adaptive expertise (Paletz et al., 2013). Deeper learning is the process of developing expertise, which acquires stable, transferable knowledge that can be applied to new situations. Through deeper learning, the individual develops expertise in a particular domain of knowledge and/or performance. Pellegrino and Hilton (2012) define deeper learning also as innovation, creativity, and creative problem solving that help students develop transferable knowledge. This

transferable knowledge can be applied to solve new problems or respond effectively to new situations.

#### **II.2.4 Factors That Contribute to Development of Adaptiveness**

Adaptiveness can be developed in students leading to positive outcomes in learning and achievement. More adaptive students will become more successful practicing engineers (Fisher & Peterson, 2001). The key aspects for developing expertise mentioned above - motivation, self-regulation, using relevant knowledge, and transfer of that knowledge- are the key aspects of developing adaptiveness as well. Therefore, to develop AE characteristics, all of those attributes are important. Nevertheless, there are some more specific characteristics that differentiate “adaptive expertise” from “expertise.” These characteristics are discussed in the following part.

**Innovation.** Adaptiveness allows students to identify and solve novel problems. It eventually leads to students’ depth of knowledge and habits of mind providing them success in their career and enable them to be innovators in their field (Brophy et al., 2004).

McKenna (2007) defines innovation as a process of generating new knowledge and ideas that are useful for achieving a novel and appropriate goal where new knowledge can improve previous ideas or find new directions for approaching one’s goal. Innovation also relates to inquiry and self-regulating skills that is necessary to identify and grasp a problem, to identify what further knowledge is necessary, and to create ideas and control existing knowledge to acquire relevant knowledge (McKenna, 2007).

According to Schwartz, Bransford, and Sears (2005), adaptive expertise emerges from a balance between efficient use of knowledge and the innovation skills associated with accessing prior knowledge, and generating new ideas and new knowledge. The dimension of



innovation includes many attributes connected with design and complex problem solving activities that an innovative attitude requires a level of determination and motivation to go beyond the routine (McKenna et al., 2006). In engineering education, designing and modeling courses can be thought as a natural setting for applying innovative activities where students design, model, create, and present their products. Innovation is the aspect that differentiates adaptive experts from the routine experts.

**Efficiency.** While routine experts are efficient only, adaptive experts have both efficiency and innovative characteristics (Brophy et al., 2004). McKenna (2007) defines efficiency as one's ability to fluently apply knowledge and skills. To be an adaptive expert, the ability to innovate and being efficient should be developed together (Schwartz et al., 2005).

Schwartz et al. (2005) presented a two by two efficiency and innovation matrix (Figure 1) to characterize adaptive expertise.

		Innovation	
Efficiency		<b><i>ROUTINE EXPERT</i></b> (High Efficiency, Low Innovation)	<b><i>ADAPTIVE EXPERT</i></b> (High Efficiency, High Innovation)
		NOVICE (Low Efficiency, Low Innovation)	<b><i>RUDDERLESS &amp; OVERWHELMED</i></b> (Low Efficiency, High Innovation)

Figure 1  
Four-quadrant model to characterize adaptive expertise (Schwartz et al., 2005)

To explain the efficiency scale, Schwartz et al. (2005) provide examples: If a doctor is a routine expert who frequently performs a particular type of surgery, she can diagnose and treat a new patient quickly and effectively. To solve a problem, those who are high in efficiency can rapidly retrieve appropriate knowledge and effectively apply that knowledge and skills. The other scale in the matrix is innovation, which signifies taking risks and preferring challenges rather than being efficient and safe. Innovative person thinks deeply and creatively to solve a problem. For example, skilled musicians avoid well-learned routines so that he could move to a new level of playing ability.

McKenna et al. (2006) reevaluated the efficiency and innovation matrix (Figure 1) to examine an “optimal adaptability corridor” (OAC), the function of which is to confirm that innovation and efficiency develop together. Figure 2 represents the balance between efficiency and innovation.

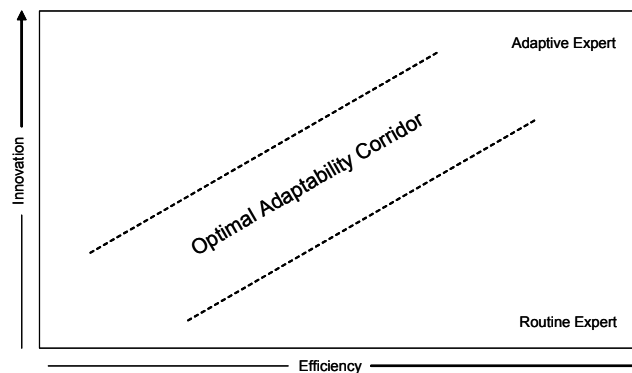


Figure 2  
Adaptive expertise as a balance between two dimensions for learning and assessment:  
efficiency and innovation (McKenna et al., 2006)

The balance between two characteristics of AE is significant to develop instruction cause AE provides a useful way of framing the target for engineering education, in

particular design education that focused almost exclusively on the efficiency scale (McKenna et al., 2006). Although that there are possibly many different trajectories one of which might take to navigate to the goal of reaching adaptive expertise, McKenna et al. (2006) acknowledged the importance of the OAC reminding educators of the prominence of efficiency and innovation and as a framework for assessing the instructional experiences.

Paletz et al. (2013) stated that innovation without efficiency runs the risk of being out-of-touch, unaccepted, or too slow to be of use; efficiency without innovation can be acceptable but may not evolve the domain as needed. Therefore, students should be encouraged to grow and develop these two dimensions simultaneously. According to McKenna et al. (2006), traditional engineering education has focused almost exclusively on the efficiency scale. Attaining innovation requires not only a combination of social, motivational, and environmental conditions but also learning how to transfer the right knowledge in the right way at the right time (Paletz et al., 2013).

**Experiences.** Students' experiences play an important role in their capabilities for effective learning, on building knowledge and skills for adaptiveness, and on being more innovative (Martin et al., 2006). According to Fazey et al. (2005), to develop adaptive expertise; individuals need to have diverse experiences and be able to reflect on their experiences, and they need to seek out opportunities to look situations from different perspectives. Therefore, students should be encouraged to be vulnerable to the possibility of changing their current way of thinking. These opportunities can be offered students in different ways. Because Computer Aided Design (CAD) tools are one of the most pervasive tools used in engineering education and in the field, these tools can support students to develop AE throughout their education. Kalyuga (2009) stated that students with sufficient

levels of experience in a domain are able to adapt the learning environment themselves by selecting their own learning tasks or methods, making those students motivated and gaining self-regulated skills.

### **II.2.5 AE in the Context of Higher Education**

Adaptive expertise has relevance across a variety of disciplines, including medicine, engineering, business, and education (Bell et al., 2012). Therefore, it can be beneficial to scrutinize and understand how AE can be developed through higher education in general to be able to make inferences for developing AE in engineering education.

First of all, Hatano and Inagaki (1986) projected three learning environment factors that contribute to the development of adaptive expertise. First, learners must encounter variability such that they should apply a procedure with variations. This way, students can learn how to meet changing demands by applying their knowledge flexible in different contexts (Hatano & Inagaki, 1986; Hatano & Oura, 2003). Second, students should be able to use risky adaptive strategies rather than using safe usual ones. In addition, according to Hatano and Inagaki (1986), active participation in learning process and working collaboratively can be effective on developing adaptive expertise.

Developing adaptive expertise is not a quick process. Bransford (2007) suggested it might be more difficult to teach how to be adaptive to a routine expert who is set in his ways. However, it is likely possible for individuals to exhibit both routine and adaptive expertise simultaneously. Therefore, it is important to help learners understand themselves as thinkers, problem solvers, and lifelong learners. Understanding how to foster development of adaptive expertise is an essential implementation for promoting progression in learners. Although most researchers consider adaptive expertise as a step after mastery of

content knowledge (Kalyuga, 2009; Martin et al., 2006; McKenna, 2007; Walker et al., 2006) associated with routine expertise, some researchers in the field think adaptive expertise can and should develop alongside routine expertise (Brophy et al., 2004; Crawford, 2007). Therefore, while learners master in content knowledge, they can possibly develop the cognitive and metacognitive skills that complement adaptive expertise (De Arment, Reed, & Wetzel, 2013).

Jonassen et al. (2006) discussed some implications for engineering education to increase students' ability of being more adaptive. These implications are briefly explained here: (1) Students should be prepared for future learning situations, in school or out, which comprises the ability to solve problems and to learn independently and collaboratively because in engineering contexts, the need for continuous, lifelong learning has been always becoming greater. (2) For preparing engineering students to become better problem solvers, integrating problem-based learning to courses is also important that it will replace traditional courses with integrated, interdisciplinary sets of complex problems, where learning is self-monitored and self-directed; students must decide what knowledge they need to construct in order to solve the problems. (3) To make students more capable to understand nature of workplace problems in their learning experiences, complex and ill-structured problems should be integrated. (4) In addition, engaging students in solving as many different kinds of problems as possible also make them be able to find an optimal solution within determined constraints. (5) As it is important for engineers to be able to function on multi-disciplinary teams and teamwork, collaborative learning should be an important part of engineering classrooms.

According to Kozlowski (1998), to be able to encourage students to develop

adaptiveness, critical learning outcomes (i.e., learning strategies, metacognitive and self-regulatory skills, knowledge structure, efficacy, and motivational skills) are required. Because experts' knowledge is organized around important ideas or concepts and experts acquire the necessary segment of knowledge, higher education curricula should also be organized in ways that lead to conceptual understanding. It is important to cover the facts and big ideas before moving to the next topic rather than giving a little time to develop important, organizing ideas (Bransford et al., 2000). Before that, the learning goals and a model of how learning is expected should be determined clearly even before higher education as early as for elementary education. Therefore, students can be prepared to think critically and how to attain necessary knowledge through years by gaining experience before coming to university. According to Bransford et al. (2000), one way to develop expertise in students is to assign them real-world problems relating the concepts and formulas with real life use and if the instruction is well designed on this students can learn when, where, and why to use the knowledge they are learning.

On one hand developing declarative domain knowledge and enhancing practice on solving domain related problems are mainly the results of training routine experts. On the other hand, for enhancing more complex problem solving abilities, realistic problems may be given to students so that transfer is conceptualized as the reproduction of skills across environments, from training to the performance context (Kozlowski, 1998). For the development of metacognitive and self-regulation skills, increased levels of learner control over sequencing of learning task and selecting an appropriate level of objective specificity are essential conditions (Kalyuga, 2009). Moreover, connecting topics with students' personal lives and interests, and engaging students in collaborative problem solving, and

emphasizing the importance of developed knowledge and skills students motivate children for deeper learning (Pellegrino & Hilton, 2012). In their book, Pellegrino and Hilton (2012) list recommendations for promoting deeper learning and expertise some of which are summarized as follows:

- Curriculum and instructional programs should be designed to include research based teaching methods; for example, elaboration, questioning, and explanation should be integrated, learners should be engaged in challenging tasks with the guidance and feedback, and students should be supported to learn with examples like step by step modeling procedures that they can carry out a procedure to solve a problem.
- Modeling and feedback techniques that highlight the processes of thinking rather than focusing exclusively on the products of thinking should be integrated into education.
- Problem-solving and metacognitive skills should be taught within a specific subject area rather than as a stand-alone course.
- Proficiency cannot be gained without time, effort, motivation, and illuminating feedback. Hence, sustained instruction and effort are essential to develop expertise in problem solving and metacognition.

While all these suggestions are to develop students' expertise, they do not clearly delineate or target routine expertise and adaptive expertise. The distinction between these types of expertise has implications for defining learning outcomes and designing instruction therefore, instructional goals need to be clear about which type of expertise is the final

outcome (Brophy et al., 2004).

According to Kalyuga (2009), training for adaptive and flexible expertise necessitates developing advanced forms of generalized knowledge and skills that are applicable to a greater variety of situations. Learning environments that provide more freedom for structuring students' learning tasks support students with advanced metacognitive and self-regulation skills. In this way, learner-controlled settings could be effective both in developing domain knowledge and skills, and in improving learner's metacognitive and self-regulation skills as indispensable attributes of adaptive expertise (Kalyuga, 2009).

To explore how problem-based learning may offer a time-efficient approach to developing adaptive expertise in engineering education, Froyd (2011) presented a conference paper that compared two by two process-content matrix adapted from Coppola and Daniels (1996) and two-by-two, innovation-efficiency matrix used to characterize adaptive expertise adapted from Schwartz et al. (2005). Coppola and Daniels (1996) worked about goals for learning chemistry and they proposed that in order to devote precious class time to issues of process, students would end up not knowing as much. They meant that you couldn't just teach "thinking" without also having something to think about. Therefore, process is contextualized by the content. They suggested that content and process were two different dimensions for characterizing learning outcomes assuming that learning along each dimension can be characterized as either high or low, a two-by-two matrix can be constructed (Figure 3).



Process	
Content	(High Content, Low Process)
	<b>UNENGAGED</b> (Low Content, Low Process)
	<b>EXPERT</b> (High Content, High Process)
	(Low Content, High Process)

Figure 3  
Expert and unengaged quadrants (Coppola & Daniels, 1996)

Froyd (2011) presented a conference paper that reviewed and showed how Coppola and Daniels’ two-by-two matrix is very similar to the two-by-two matrix that Schwartz et al. (2005) use to characterize adaptive expertise (Figure 1). Both matrixes presents two dimensions: efficiency -related to content- and innovation -related to process- and it can be seen that two sets of researchers, with different backgrounds and starting at different points in posing questions about student learning, have constructed very similar characterizations of student learning goals. Figure 4 presents both to make visualize them easier.

Process	
Content	(High Content, Low Process)
	<b>UNENGAGED</b> (Low Content, Low Process)
	<b>EXPERT</b> (High Content, High Process)
	(Low Content, High Process)

Innovation	
Efficiency	<b>ROUTINE EXPERT</b> (High Efficiency, Low Innovation)
	<b>ADAPTIVE EXPERT</b> (High Efficiency, High Innovation)
	NOVICE (Low Efficiency, Low Innovation)
	<b>RUDDERLESS &amp; OVERWHELMED</b> (Low Efficiency, High Innovation)

Figure 4  
Process-content matrix (Coppola & Daniels, 1996) and innovation-efficiency matrix (Schwartz et al., 2005)

The main questions that Froyd (2011) asked were: If the desired end point of student development in engineering curricula is the adaptive expert quadrant (expert quadrant in the Coppola and Daniels' framework), what trajectories of student development would be superior to others? And what characterizes more efficient -in terms of time- trajectories to reach adaptive expertise? To address these questions in his study, instead of indicating only high and low values, Froyd (2011) used two continuous paths assuming that both the content/efficiency and process/innovation dimensions have real numbers in the two-dimensional space, in which one end point is where a student begins an undergraduate engineering curriculum and the other end point where she ends (Figure 5).

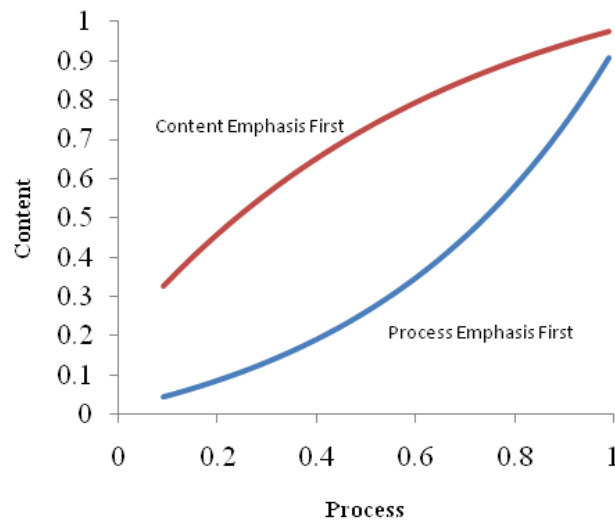


Figure 5  
Student development via two different paths: content emphasis first and process emphasis first (Froyd, 2011)

The first kind of path is the content emphasis first where students develop mastery with respect to the content/efficiency dimension first. Then, after their content/efficiency

expertise has reached a high level, they invest time and resources in developing process/innovation expertise. The second path is the process emphasis first path. They first develop mastery with respect to the process/innovation dimension first. Then, after their process/innovation expertise has reached a high level, they invest time and resources in developing content/efficiency expertise. According to Froyd (2011), traditional design of engineering curricula and engineering courses tend to emphasize trajectories of student development that resemble the content emphasis first path. Second path that emphasizes innovation more should be taken into consideration to implement into engineering education. However, pure implementation of the second path is unreasonable because as Coppola and Daniels (1996) claimed “Process is contextualized by the content—you cannot just teach “thinking” without also having something to think about.” Therefore, learning regarding the content/efficiency dimension cannot be at a very low level while process/innovation development is being emphasized (Froyd, 2011).

### **II.2.6 Problem-Based Learning in Engineering Education**

In most undergraduate classes, students learn to solve textbook problems that are constrained and well structured, with known solution paths and convergent answers.

Outside of classrooms, Jonassen et al. (2006) claim that workplace problems are more likely to be ill structured and unpredictable because they possess conflicting goals, multiple solution methods, unanticipated problems, and distributed knowledge. Cross (2004) identifies specific behaviors that distinguish the nature of expert performance in design. He synthesized that expert designers appear to spend substantial time and attention on defining the problem. Cross (2004) also explains that expert designers are solution focused and take effort to structure the problem appropriately. Therefore, learning to solve

classroom problems does not effectively prepare engineering graduates to solve workplace problems, which is an important part of being an adaptive expert. According to Jonassen (2014), engineering educators must adopt new pedagogies to encourage their graduates become effective engineers. Because engineering students learn to solve problems that are unlikely to transfer to workplace problem solving and to achieve this goal, problem based learning (PBL) can be a preferable method of teaching in engineering classroom.

PBL instruction is a part of constructivism as a cognitivist approach (Prince & Felder, 2006). All versions of cognitive theory including constructivism state that “knowing” consists of having mental models that have been created and stored in the learner's long-term memory as a function of interacting with the environment (Bartlett, 1932). These models were deemed essential to reasoning and problem solving in any expert practice. Constructivism adheres to the mechanisms of creating and storing mental models, but with the learner in control (Bartlett, 1932; Dewey, 1916; Glasersfeld, 1989; Piaget, 1973). Unlike novices, experts deploy these models to analyze, design, interpret, diagnose, and predict (Kolmos & Graaff, 2014). PBL in approach concerns the learning process of working with problems, which involves identification, analysis, and solution and it can be real-life/authentic, and practical problems (Kolmos & Graaff, 2014) that will support engineering students’ to be better prepared for the field.

As stated, PBL is a part of cognitivist approach that learners explore their own understanding and they explore during the learning process (Prince & Felder, 2006). Newstetter and Svinicki (2014) presented design principles for cognitivist instruction which are also significant aspects of developing AE:

- A focus on making connections with the learner's prior knowledge.

- Taking advantage of prior knowledge and experience of the learner.
- Aiming for deep processing of information (learning with understanding) rather than passive dependence on surface features.
- Involving the learner actively.
- Developing metacognitive knowledge that allows students to control their own learning.

## II. 3 Conclusion

Adaptive skills are fully developed and refined in the performance environment that is a learner-centered environment, and curriculum and instruction must reflect such approaches if students are to develop adaptive skills. Learner centered instruction is self-reflective, where learners monitor their understanding and learn to adjust strategies for learning (Hung, Jonassen, & Liu, 2008). Therefore, it may be beneficial to shift more training to the performance context and students centered approaches such as PBL that aims to enhance learning by requiring learners to solve problems. Unfortunately, a few engineering programs have implemented PBL throughout their curriculum (Jonassen, 2014). Engineers are hired, retained, and rewarded for solving problems, problems that are unlike the well-structured problems that they learn to solve in most engineering education programs but workplace problems are ill structured. Engineers regularly solve combinations of decision-making problems, troubleshooting problems, and most commonly design problems. To help engineering students learn to solve workplace problems in order to become more effective and innovative engineers, some form of PBL may be implemented

to curriculum.

For the development of AE, encouraging students' involvement is required so that their motivation and self-regulation skills are enhanced. Alternative techniques can be based on the learner-controlled actions that give the students control over the tasks they want to study or practice that is essential characteristic for the development of learner metacognitive and self-regulation skills (Kalyuga, 2009). However, because it is difficult to eliminate the system control, it can be a good choice to create a combination of system and learner control or vary the level of learner control as expertise and self-regulation skills develop for creating the ideal learning environment to develop AE. This kind of learning environment would be more flexible as well. According to Bransford (2007), knowledge and its organization is important for flexibility and self-exploring how to organize knowledge can help people use their knowledge in ways that support flexibility.

It can also be interfered from the literature that learners should experience courses of inquiry and innovation that include challenges and struggles. This can help learners make their experiences explicit and help them improve their innovations by connecting them to expert knowledge (Schwartz et al., 2005). Innovation might also be achieved through dynamic transfer whereby a number of interactions with the problem-solving environment may lead one to transfer prior knowledge to the new condition. Through these interactions with and influences of the environment, a coordination of previously learned concepts is eventually constructed that deliver one to an innovation (McKenna, 2014).

### **II.3.1 Limitations and Future Directions**

After reviewing the literature, open questions still remain about how to balance the dimensions contributing development of AE when providing instruction to engineering

students. And what kind of activities can be provided to advance students' AE characteristics? However, through the literature, it is understood that promoting learning in ways that better prepare students for future learning with problem based learning and related approaches may be a good way to develop AE characteristics.

In the literature, applying the adaptive expertise framework for instructional or research purposes is the lack of specificity for what might characterize “efficiency” and “innovation” that are the key elements of AE. According to (McKenna, 2014), the lack of specificity raises challenges with regard to developing metrics such that one might measure AE, or even be able to recognize it when it occurs. It is difficult to develop instruments to detect the phenomena or to know how to structure experiences in order to develop AE. Hence, more studies are required to clarify how engineering education should be shaped to enhance students' AE characteristics.

In addition, for future studies it can be recommended that the engineering faculty should also be directed in a way to develop AE for both themselves and their students. Engineering educators should also evaluate their current classroom activities in terms of learning theories and have the tools to develop new designs for developing AE in their students. Moreover, because classroom instruction most often derives from one's conception of how students learn, the goal for future research may be to work on how engineering faculty can be assisted to be more reflective about their own theory of learning. A more ambitious suggestion can be to provide engineering faculty and researchers with tools for thinking about, identifying, and designing educational research studies on development of classroom activities for enhancing AE.

# **CHAPTER III**

## **THE RELATIONSHIPS BETWEEN ADAPTIVE EXPERTISE DIMENSIONS AND STUDENTS' DEMOGRAPHIC CHARACTERISTICS**

### **III.1 Introduction**

To be an adaptive expert, learning experiences should promote being innovative and efficient to grow and develop simultaneously (Schwartz et al., 2005). Adaptive experts tend to be more open to investigate, to use their metacognitive and self-regulation skills, and to hold more advanced personal epistemologies. These characteristics make the adaptive experts flexible, innovative, and creative especially in novel situations (Hatano & Oura, 2003). Engineering is a field that is continually changing, so, it is important to train adaptive expert engineers to prepare them for this swiftly developing industry. Therefore, identifying the AE characteristics of engineering students will help to make suggestions to enhance the quality of Computer Aided Design (CAD) education.

This work describes the implementation of an instrument used to measure adaptive expertise characteristics of the students in two courses at two universities and practicing engineers. The instrument contains questions defining four dimensions: “multiple perspectives, meta-cognitive self-assessment, goals and beliefs, and epistemology.” In one university setting, freshmen and sophomore engineering students were surveyed with the instrument; in the other, junior and senior level engineering students are surveyed. In addition to the student participants, practicing engineers from industry are surveyed. Participants’ demographic characteristics data were collected. These data are used to



examine the relationships among participants' expertise related responses and demographic variables. The observed differences between students' and engineers' responses to the survey items are reported. In general, results indicated that practicing engineers revealed more adaptive expertise characteristics than students. In addition, senior students revealed more adaptive expertise characteristics than their freshmen counterparts.

In their conference paper, Fisher and Peterson (2001) identified four main concepts -multiple perspectives, metacognition, goals and beliefs, and epistemology- that form the basis of adaptive expertise. They developed a survey to measure these qualities of adaptiveness in targeted engineering students. This study aims to use this adaptive expertise survey (AES) developed by Fisher and Peterson (2001) to interpret the students' AE characteristics. In addition, the purpose of the work is to explore the relations between students' demographics and AE characteristics.

### **III.1.1 Four Dimensions of Adaptive Expertise**

**Personal epistemology.** Adaptive experts frequently hold more sophisticated personal epistemology (Fisher & Peterson, 2001). Personal epistemology research explains it as the beliefs and theories that individuals hold about knowledge and knowing (Hofer, 2004). In other words, epistemology is a metacognitive process. It is one's beliefs on knowledge and attitudes towards the nature of the knowledge in the field and its generation. Adaptive experts believe that the knowledge in their field is dynamic in nature and it is subject to change as needed. They view the domain knowledge as not static or fixed, but dynamic and subject to change (Hatano & Inagaki, 1986). These characteristics of adaptive experts allow individuals to be more flexible to adapt the novel situations and to inquire or generate new knowledge instantaneously. Flexibility is an important aspect of being an

adaptive expert (Brophy et al., 2004). However, it is not an easy characteristic that experts can have with practice only. In a study (Mercier & Higgins, 2013) to examine whether collaborative a multi- touch classroom supported the development of mathematical adaptive expertise, and specifically aspects of fluency and flexibility, when compared to a similar, individual task. In this study, a task for a multi- touch classroom that aimed to support both fluency and flexibility was developed. According to the results, all students increased in fluency after completing these activities, while students who used collaborative class also increased in flexibility. Mercier and Higgins (2013) concluded that while fluency could be developed with practice, designing activities that support the development of flexibility was more difficult.

**Metacognition.** Metacognition is an important factor of adaptive expertise (Hatano & Inagaki, 1986). The learner engages in self-monitoring and organization through “metacognition” that should be thought of as self-regulatory executive functioning that keeps the learning process flowing smoothly (Atkinson & Briggs, 1983). Students with metacognitive skills can successfully monitor their own understandings and they can recognize that their knowledge may be incomplete in some situations (Donovan, Bransford, & Pellegrino, 1999; Fisher & Peterson, 2001). In addition, being able to identify when additional information is required for understanding, whether new information was consistent with what students already knew, and what correlations could be drawn that would improve their understanding are all metacognitive characteristics (Hatano & Inagaki, 1986). Metacognition plays a role in adaptive experts’ ability to self-assess and judge when their current levels of understanding are not sufficient (Bransford et al., 2000). Metacognitive self-assessment is the ability to know when to select an efficient or an

innovative procedure (Crawford, 2007). Metacognitive practice allows for learning to occur during the course of problem solving as well while as learners actively engage with and assess their own thinking and understanding.

It is also important for a student to be confident on what she is doing. Confidence is one of the important characteristics of adaptive expertise that confidence supports creating novel but safe and attractive products (Walker et al., 2006).

**Goals and beliefs.** The students having concerns for their learning have some goals and beliefs for their learning and development. Therefore, they view challenges as learning opportunities and they seek out for those opportunities (Fisher & Peterson, 2001). Those students also have some self-regulation strategies that are also characteristics of adaptive expertise. Self-regulation strategies help identifying goals to generate ideas or improve an existing idea (McKenna, 2007). Adaptive experts also display the ability to transfer their knowledge, skills, beliefs, and attitudes to new situations. Pandey, Petrosino, Austin, and Barr (2004) define three important aspects of adaptive expertise as; (1) factual knowledge, which is a student's ability to retain key facts and principles, (2) conceptual knowledge, which is a student's ability to comprehend the underlying principles of the material taught as well as his or her quantitative skills, and (3) transfer, which is a student's ability to extend his or her knowledge to novel and unfamiliar situations.

**Multiple perspectives.** For being an adaptive expert, it is also important for students to have multiple perspectives that they should be able to look from different perspectives and should be able to use more than one way to analyze or solve problems (Fisher & Peterson, 2001). In addition, with a fluent and flexible use of knowledge a student will be able to identify and expand on creative ideas that are important part of adaptive

expertise (Brophy et al., 2004). Martin et al. (2006) suggest that if people experience substantial opportunities to engage in activities that promote the development of both knowledge and innovation, they can progress along a path to develop adaptive expertise. Innovation is the ability to consider a problem from multiple perspectives and ability to escape from routine approaches (Walker et al., 2006). Hatano and Inagaki (1986) thought that certain individual characteristics, like curiosity, may also influence the development of adaptive expertise. Confirming this, Bell et al. (2012) claim that students who are to become adaptive experts must retain motivation to solve problems through innovative ways. Innovation is one aspect of adaptive expertise, and it regulates skills necessary to identify what prior knowledge is needed to generate new ideas (McKenna, 2007). In an engineering education context, innovation is the ability to stop and consider a problem from multiple perspectives rather than barring on a more immediate and smaller set of possibilities (Walker et al., 2006). To be an adaptive expert, efficiency should accompany to innovation. Efficiency is a combination of consistency and accuracy, which is one other dimensions of adaptive expertise (Brophy et al., 2004; Walker et al., 2006). McKenna (2007) defines efficiency as one's ability to fluently apply knowledge and skills. To meet novel challenges or problems of practice, adaptive experts respond flexibly to variable contexts, know how to constructively consider and account for multiple perspectives and potential solutions. Furthermore, they can modify their existing procedural skills or create new procedures (Hatano & Oura, 2003).

## III.2 Methods

### III.2.1 Participants and Data Collection

The data has been collected through a National Science Foundation Project for three years from two campuses. The AES has been applied to 479 students at Two Southern US Campuses. In addition, 23 practicing engineers completed the survey. AES included demographic questions and a 42 items, 6-point AE Likert-scale (Fisher & Peterson, 2001). A sample student form including demographic questions and the AE survey items is in the Appendix-A. The number of participants who completed the surveys and their demographic information are summarized in Table 1.

Table 1  
Number of participants and their demographics

	Sex			Age			Major		Work exp.		Research exp.		First generat.		Rank			
	N	M	F	18-22	23-30	30 +	Mech. Eng.	Other	Yes	No	Yes	No	Yes	No	Fr.	So.	Jn.	Sn.
CampusI	259	235	24	120	30	7	259	0	109	150	136	123	NA	NA	0	0	63	195
CampusII	220	183	37	67	35	3	215	3	46	174	57	163	74	146	118	40	22	40
							Highest degree		Years in service									
							BS	Other	<5	>5, <10	= >10							
Engineers	23	23	0	0	1	22	23	0	1	4	18							
Total	502	441	61	187	66	32								Total	118	40	85	235

## III.3 Analyses and Results

### III.3.1 Reliability of the Scale

The reliability of the scale was computed with Cronbach's alphas. The Cronbach's alpha of the survey was computed 0.83 (N=419), which indicates that the survey was a

reliable instrument. “Metacognitive self-assessment” dimension had the highest reliability coefficient ( $\alpha=0.75$ ) while “Goals and beliefs” dimension had the lowest reliability coefficient ( $\alpha=0.56$ ). “Multiple perspectives” ( $\alpha=0.69$ ) and “Epistemology” ( $\alpha=0.61$ ) sub-dimensions were acceptably reliable as well.

### III.3.2 ANOVA

**Relations between Survey Dimensions and Participants’ Characteristics.** To examine the relationships between the sub-dimensions of the scale and participants’ characteristics (e.g., school, rank, years of experience, employment experience, etc.), F-tests (ANOVA) were run. Here the statistically significant results were reported only.

*Differences with respect to experiences.* When we compare students who have employment experience and who have not, it was observed that students who had any technical employment and research experience related to engineering (e.g., machines shops, labs, project tasks, etc.) ( $N=193$ ,  $M=4.48$ ,  $SD=.59$ ) had more “metacognitive self assessment” sub-dimension score in AES than students who didn’t ( $N=286$ ,  $M=4.30$ ,  $SD=.61$ ,  $F(1, 477)=9.955$ ,  $p=.002$ ). Experienced students ( $N=193$ ,  $M=16.74$ ,  $SD=1.52$ ) had more overall sub-dimensions score than inexperienced ones as well ( $N=286$ ,  $M=16.34$ ,  $SD=1.62$ ,  $F(1, 477)=7.390$ ,  $p=.007$ ). For the professional work experience, students who had a professional work experience related to engineering (e.g., internship, co-op, etc.) ( $N=155$ ,  $M=4.45$ ,  $SD=.57$ ) had more “metacognitive self assessment” sub-dimension score in AES than students who didn’t ( $N=324$ ,  $M=4.33$ ,  $SD=.63$ ,  $F(1, 477)=4.223$ ,  $p=.04$ ). Experienced students’ ( $N=155$ ,  $M=4.04$ ,  $SD=.56$ ) “multiple perspectives” sub-dimension score was also higher than inexperienced ones ( $N=324$ ,  $M=3.91$ ,  $SD=.57$ ,  $F(1, 477)=5.302$ ,  $p=.022$ ) and experienced students ( $N=155$ ,  $M=4.38$ ,  $SD=.61$ ) had more “epistemology” sub-dimension

score in AES than students who didn't have that experience as well ( $N=324$ ,  $M=4.26$ ,  $SD=.53$ ,  $F(1, 477)=4.843$ ,  $p=.028$ ). Overall, students who had work experience ( $N=155$ ,  $M=16.74$ ,  $SD=1.66$ ) had higher total dimensions score in AES than inexperienced students ( $N=324$ ,  $M=16.39$ ,  $SD=1.55$ ,  $F(1, 477)=5.022$ ,  $p=.025$ ).

*Differences with respect to rank.* When the relationship between students rank and their AES scores was scrutinized, it was observed that seniors ( $N=235$ ,  $M=4.05$ ,  $SD=.56$ ) had more “multiple perspectives” sub-dimension score in AES than freshmen ( $N=118$ ,  $M=3.80$ ,  $SD=.51$ ,  $F(3, 474)=5.763$ ,  $p=.001$ ). Senior students ( $N=235$ ,  $M=4.40$ ,  $SD=.54$ ) had more “epistemology” sub-dimension score in AES than freshmen ( $N=118$ ,  $M=4.15$ ,  $SD=.56$ ,  $F(3, 474)=6.497$ ,  $p=.002$ ). Similarly, seniors ( $N=235$ ,  $M=16.78$ ,  $SD=1.58$ ) had more overall sub-dimension scores in AES than freshmen ( $N=118$ ,  $M=16.10$ ,  $SD=1.47$ ,  $F(3, 474)=5.416$ ,  $p=.002$ ).

*Differences with respect to school.* When two campuses and practicing engineers were compared, analyses indicate that engineers ( $N=23$ ,  $M=4.28$ ,  $SD=.46$ ) had more “multiple perspectives” sub-dimension scores than Campus II students who are mostly freshmen ( $N=220$ ,  $M=3.88$ ,  $SD=.58$ ,  $F(2, 499)=6.869$ ,  $p=.006$ ). Campus I students who are mostly seniors ( $N=259$ ,  $M=4.01$ ,  $SD=.56$ ) had more “multiple perspectives” sub-dimension scores than Campus II students who are mostly freshmen ( $N=220$ ,  $M=3.88$ ,  $SD=.58$ ,  $F(2, 499)=6.869$ ,  $p=.047$ ) as well. In addition, Campus I students ( $N=259$ ,  $M=4.44$ ,  $SD=.51$ ) had more “epistemology” sub-dimension score than Campus II students ( $N=220$ ,  $M=4.13$ ,  $SD=.57$ ,  $F(2, 499)=20.123$ ,  $p=.000$ ) and practicing engineers ( $N=23$ ,  $M=4.43$ ,  $SD=.49$ ) also had more “epistemology” sub-dimension score than Campus II students ( $N=220$ ,  $M=4.13$ ,  $SD=.57$ ,  $F(2, 499)=20.123$ ,  $p=.038$ ). Similar pattern was observed for the overall sub-

dimension score in AES. Campus I students ( $N=259$ ,  $M=16.68$ ,  $SD=1.54$ ) had more overall sub-dimension score in AES than Campus II students ( $N=220$ ,  $M=16.30$ ,  $SD=1.63$ ,  $F(2, 499)=6.606$ ,  $p=.031$ ). Engineers who work for the industry ( $N=23$ ,  $M=17.34$ ,  $SD=1.22$ ) had more overall score than Campus II students ( $N=220$ ,  $M=16.30$ ,  $SD=1.63$ ,  $F(2, 499)=6.606$ ,  $p=.011$ ) as well.

### **III.4 Discussion and Conclusion**

According to the results of statistical analyses, students who have technical employment and research experience related to engineering have more metacognitive self-assessment and overall dimensions score than inexperienced students. In addition, students who have a professional work experience like internships have more metacognitive self-assessment, multiple perspectives, epistemology, and overall sub-dimensions scores than students who don't have professional experience. It is observed that for the goals and beliefs dimensions having any research or professional experience did not show any statistically significant difference. This result can be explained through the definition of goals and beliefs manifestation of AE. As Fisher and Peterson (2001) explained in their conference paper, through their learning development the students can have some concerns on their learning and they have lots of goals and beliefs. In addition, they see all the challenges as a new learning opportunity. If the result of this work can be an evidence of that, we can claim that with the increasing work and research experience, students' goals and beliefs characteristics might not be affected because they are less likely to have more concerns about their learning goals when they gain more experience.

When we analyze the data to see if students' AES scores are different with respect



to their ranks, as expected, when the students were more experienced through years their AE characteristics were enhanced. These results indicate that senior students only have higher “multiple perspectives,” “epistemology,” and overall dimension scores than freshmen.

A similar conclusion is also evident when the two campuses are compared. In Campus I, most students were seniors, while in Campus II the students were mostly freshmen and sophomores. For all the observed statistically significant differences, Campus I students and practicing engineers have higher “multiple perspectives,” “epistemology,” and overall sub-dimensions scores than Campus II students. These results indicate that over time through their engineering education, students gain more AE characteristics in general. In their study on the development of AE, Paletz et al. (2013) also claimed that AE characteristics are significantly increased over time. Martin, Petrosino, Rivale, and Diller (2006), examined development of adaptive expertise in the context of a bio-transport course in biomedical engineering. They scrutinized change in pre or post data on an adaptive beliefs survey regarding performance on adaptive expertise exams outcomes. Those exams had three types of problems: knowledge, innovation, and adaptive expertise where adaptive expertise items required students to transfer existing knowledge to a novel problem that was not directly taught in the course. They used the adaptive expertise survey including items concerning four constructs of adaptive expertise (i.e., multiple perspectives, metacognition, goals and beliefs, and epistemology) derived from Fisher and Peterson (2001). Students completed the survey during the first and last weeks of class and improvement over time was examined. According to the results of their study, Martin et al. (2006) observed that knowledge, innovation, and adaptive expertise improved from Exam 1 to Exam 3. Adaptive

expertise survey scores remained stable across the course, but students who had higher scores on exam 1 had higher scores on the ore-survey as well. Students who had lower scores on pre-survey revealed the greatest improvement on the adaptive expertise items from Exam 1 to Exam 3 emphasizing the potential for development of adaptiveness. In addition, Walker et al. (2006) investigated the concept of AE in the context of an introductory engineering science course and a senior design course in biomedical engineering. They used a design scenario approach (McMartin, McKenna, & Youseffi, 2000) to evaluate students' responses to an open-ended problem. Based on students' responses they evaluated the quality of strategies, the quality of students' questions, and confidence. Moreover, they categorized the quality of strategies as the efficiency dimension of AE and the quality of students' questions as the innovation dimension. Their findings suggest that fourth-year students devised more efficient and innovative solutions than first-year students and over time all students became more confident in their approach.

#### **II.4.1 Limitations and Future Directions**

Although these results revealed as significant, the number of participated engineers ( $N = 23$ ) are relatively low. Therefore, to be able to make a more precise conclusion to compare students and engineers, future work is required with a higher number of engineer participants that may allow for matching of sample characteristics between students and engineers and for more representative samples. These results can shed light on to research conducted to enhance CAD curriculum to develop AE in engineering education. These findings show that metacognitive self-assessment and epistemology skills are good indicators of developing adaptive expertise and the educators should consider promoting these skills in CAD education.

Here in this study, significant results are presented, though development of AE in engineering education is a relatively new research topic. Therefore, more work including longitudinal studies is required to be able to make claims about development (i.e., growth or change) of AE. Future research can unpack what other characteristics contribute developing AE and what kind of exercises and practices will enhance students' AE characteristics.

# **CHAPTER IV**

## **ADAPTIVE EXPERTISE DEVELOPMENT IN ENGINEERING EDUCATION THROUGH CONTEXTUAL MODELING ACTIVITIES IN COMPUTER AIDED DESIGN TOOLS**

### **IV.1 Introduction**

Educating engineers to attain self-regulation and mindfulness skills (including metacognitive self-assessment and epistemology skills) has become a necessity if we want our engineers to practice their profession with adaptive expertise. To achieve this goal, engineering education must integrate practice and mastery of self-regulation and mindfulness skills (including metacognitive self-assessment and epistemology skills) in engineering curriculum and instruction. In a study to examine engineering design learning (Atman, Kilgore, & McKenna, 2008), it was claimed that students did not always put their design knowledge into practice. In other words, there was a lack of transfer of knowledge or application of skills. Phase (2005) suggests a better alignment of engineering curricula and the nature of academic experiences with the challenges and opportunities graduates will face in the workplace. Jonassen (2014) suggest that a student-centered approach where students are prepared for real-life engineering problems should be integrated into the engineering curriculum.

With advancements in educational and learning sciences research, today's higher educational settings could be informed by such research to help students develop transferable knowledge and skills (Salomon & Perkins, 1998). Building on 30 years of

learning sciences research, the How People Learn (HPL) framework presents the foundation for effective teaching, with relevant applications to higher education (Bransford et al., 2000). Key components of the framework focus on the characteristics of learners, the acquisition and transfer of knowledge, and the critical role of environments. Brophy et al. (2004) defines the interaction of efficient and innovative uses of knowledge as Adaptive Expertise (AE). Hence, it is important to understand what contributes to AE skills and what kind of activities can be integrated properly to improve AE skills so that students can transfer their knowledge to novel situations in a creative, innovative, and efficient way. Consequently, more adaptive and effective engineers can be prepared for industry. To promote the development of AE within higher education, it is necessary to consider what is known about learning and teaching. The key thing is to understand the malleable and less malleable factors contributing to AE skills and how to teach or improve AE skills. In addition, scrutinizing potential factors that have an effect on AE characteristics of students, such as rank differences, gender differences, and differences in experience on the field is needed. Moreover, different exercises in the classroom may have some effect on students' AE manifestation. This study tries to understand if those factors make any differences on AE behaviors of students.

#### **IV.1.2 Purpose of the Study**

This study attempts to understand students' AE characteristics while using a Computer Aided Design (CAD) tool through examining a contextualized activity. CAD tools are used in this work as a tool because effective use of CAD software creating diverse experiences in engineering education is required. CAD tools are pervasively used throughout the development process in many industries (Field, 2004). Consequently, today's

engineering students will go into such a professional field where CAD tools are ubiquitous and available in multiple platforms (Johnson & Diwakaran, 2011). CAD tools are the tools where students use their knowledge and skills to create models and apply their adaptability to novel problems. In addition, educators often claim that design is at the core of engineering (Dym et al., 2005). Therefore, these tools can support students to attain a level of expertise if a deeper practical knowledge is taught.

This study scrutinizes which AE characteristics are revealed during the pre and post exercise interviews; these results are compared to with a survey that tabulates students' AES scores. In addition, the effect of differences in AE manifestation between students completed different CAD activities is assessed. In addition the developmental or academic-year status of student (e.g., freshman versus upperclassmen) is assessed. A comparison between practicing engineers and students is also presented.

Understanding how engineering students approach design problems in both stylized exercises and contextual exercises will help researchers and educators develop CAD education in particular and engineering education in general. This work will also provide insight for educators to understand what kind of exercise aspects affect the manifestation of AE characteristics in students.

## **IV.2 Literature Review**

### **IV.2.1 Contextual Learner-Centered Exercises**

Computers and related technologies improved our ability to communicate and accomplish complicated tasks. This doesn't mean that students will develop advanced cognitive skills and desired attitudes by simply using the technology as the way experts use

them. With the support of educational learning theories, computer technologies can improve students' ability to learn more efficiently. Therefore it is important to consider learning theories while designing engineering curriculum. Newstetter and Svinicki (2014) state that designing learning environments without a learning theory is similar to designing a bridge without mechanical laws and principles. In both cases, the goal is unlikely to be accomplished; the learner fails to change in desired ways and the bridge collapses.

Students learn more effectively when the discourse of the activity they engage in has a personal meaning to them (Bransford, et. al., 2000). In this section of this dissertation, it is referred to the kinds of learning activities that include a learner perspective as contextualized learning activities. The CAD exercise presented here is designed through considering these principles. In a CAD instructional context, a contextualized activity can include designing a product that has direct connections to the students' daily life activities or with their personal interest.

Learning science research has documented the positive impact of learner-centered instructional strategies and contextual exercises on students' cognitive and affective domains (Bransford, Brown, & Cocking, 2000). Bransford, Brown, and Cocking (2000) claimed that an ideal learning environment includes characteristics of knowledge, learner, assessment, and community centeredness (also known as How People Learn framework). Learner-centered characteristic highlights discovering students' prior knowledge and interest and constructing the learning activity that properly addresses students' content understanding trajectory and personal interest. In current higher education settings engaging students in real life challenges is not a pervasively used method. Curriculum and instruction designed to nurture adaptive expertise characteristics by engaging students in real-life

problem can provide an important model of successful learning (Bransford et al., 2000).

Hatano and Oura (2003) noted “while basic schools cannot make students real experts, they can place students on a trajectory towards expertise or prepare them for future learning” (p. 28). Harris and Cullen also noted the need to integrate more self-learning into the engineering curriculum (Harris & Cullen, 2009).

#### **IV.2.2 Adaptive Expertise**

Adaptive Expertise is the term that defines capabilities of both being innovative and adaptive to new challenges while also having content knowledge associated with expertise (McKenna, 2007). Key to expertise is the mastery of concepts that allow for deep understanding of that information, transforming it from a set of facts into usable knowledge. The ability to process information quickly and recognize related solutions to problems in a particular area and/or domain of knowledge is known as expertise. Expert people come to solve more and more complex problems in the field, utilizing relevant prior knowledge which is in turn gradually enriched and integrated (Hatano & Inagaki, 1986). Hatano and Inagaki (1986) defined two types of expertise to make the distinction clearer: “routine expertise” and “adaptive expertise.” Adaptive experts are those who perform procedural skills efficiently and understand the meaning of the skills and nature of their object. Routine experts simply learn to perform a skill faster and more accurately, without constructing conceptual knowledge, and can even perform a task through automation of the procedure. The fluency of finding related solutions to problems only makes students “routine” experts for specific problems. However, routine expertise does not mean students have flexible knowledge that may be needed to invent ways to solve familiar problems and innovative skills to identify new problems (Brophy et al., 2004). While the development of



routine expertise is valuable for usual settings, novel problem solving based on innovative aspects of the learning context and learners' characteristics is necessary for efficient instruction. AE is the term that defines capabilities of both being innovative and adaptive to new challenges while also having content knowledge associated with expertise (McKenna, 2007).

#### **IV.2.3 Aspects of Adaptive Expertise**

There is some evidence that the CAD tools that engineers use influence their ability to solve engineering problems creatively; this is important to engineers (Robertson & Rachliffe, 2009; Robertson, Walther, & Rachliffe, 2007). Creativity is one of the important aspects of adaptive expertise (Fisher & Peterson, 2001). Through an extensive literature review, Fisher and Peterson (2001), have identified four primary aspects of adaptive expertise: (a) multiple perspectives which is ability to recognize situations where creativity is possible, (b) metacognitive self-assessment referring to the learners' use of diverse techniques to self-assess and monitor his/her own understanding and performance, (c) goals and beliefs defining the views that students have concerning their learning goals and the nature of expertise, and (d) epistemology referring to how individuals perceive the nature of knowledge.

*"Multiple perspectives"* signifies the willingness of students to use a variety of representations and approaches when working on a problem (Hatano & Inagaki, 1986). This means students who have multiple perspective characteristics know that there may be more than one way to analyze, approach, and solve problems. In addition, they are open the new information and apply this information to the situations where creativity is possible (Fisher & Peterson, 2001). These students can act flexibly to novel situations. Flexible use

of knowledge and efficiency are also a part of adaptive expertise (Brophy et al., 2004).

Efficiency is one's ability to fluently apply knowledge and skills (McKenna, 2007).

Consistency and accuracy are components of the efficiency that is defined as ability to devise appropriate strategies for addressing a problem (Walker et al., 2006). Innovation can also be defined as a part of multiple perspectives. That is to say, innovation is the ability to consider a problem from multiple perspectives and the ability to escape from routine approaches (Walker et al., 2006). Innovation is one aspect of AE and regulates the skills necessary to identify what prior knowledge is needed to generate new ideas (McKenna, 2007).

*“Metacognitive self-assessment”* is one of the important characteristics of being an expert that experts can monitor their problem solving, question limitations in their knowledge, and avoid simple interpretations of a problem (Pellegrino & Hilton, 2012). People who have metacognitive self-assessment ability can use various techniques to self-asses and monitor personal understanding and performance. They can use different representations and methods to solve a problem and can question their own understanding. In addition, they can recognize areas where their knowledge is incomplete (Fisher & Peterson, 2001). Besides being aware of what they know and what they do not, people who have the metacognitive self-assessment characteristics have confidence in solving challenging problems. The level of confidence is one of the dimensions of adaptive problem solving which supports creating novel but safe and attractive products (Walker et al., 2006). Donovan et al. (1999) interpreted that a “metacognitive” approach to teaching can help students learn to take charge of their own learning by defining learning goals and monitoring their progress in achieving them.

*“Goals and Beliefs”* defines the views that students have concerning their learning goals. Self-regulation strategies as a part of AE, helps identify goals to generate ideas or improve an existing idea (McKenna, 2007). Pellegrino and Hilton (2012) argued that beliefs about learning are an essential component of transferable knowledge and beliefs and motivation support deeper learning. In addition, students who have goals and beliefs for their learning view challenges as an opportunity for growth and are able to proceed in the face of uncertainty (Fisher & Peterson, 2001). In addition, student beliefs about learning, motivation, and metacognition are all dimensions of the self-regulated learning focusing on setting goals and working to achieve them (Pellegrino & Hilton, 2012). According to Kalyuga (2009), increased levels of learner control over learning tasks and selecting their learning goals are considered as an important condition for the development of metacognitive and self-regulation skills.

*“Epistemology”* is a metacognitive process; it is one’s beliefs on knowledge, and attitudes towards the nature of the knowledge in the field, and its generation (Hofer, 2004). Students who demonstrate the epistemology attribute, perceive knowledge as an evolving entity rather than static; they realize the need to continually practice knowledge (Fisher & Peterson, 2001). Fisher and Peterson (2001) also state that these students appreciate that others with different backgrounds can provide useful insights and contributions to their work.

These aspects of AE are also included in the description of 21<sup>th</sup> century skills that includes critical thinking, problem solving, communication, collaboration, creativity and innovation. Pellegrino and Hilton (2012) define 21<sup>th</sup> century skills as knowledge that can be transferred or applied in new situations and 21<sup>th</sup> century competencies as knowing how,

why, and when to apply those skills and knowledge to solve challenging problems. In order for students to develop these skills, it is important to create learning environments that support the development of cognitive, intrapersonal, and interpersonal competencies as a part of adaptive expertise.

In addition, the four aspects - multiple perspectives, metacognitive self assessment, goals and beliefs, and epistemology - highlighted by Fisher and Peterson (2001) are important pieces for deeper learning, helping students develop transferable knowledge that can be applied to solve new problems or respond effectively to new situations. Deeper learning occurs when the learner is able to transfer what was learned to new situations (Pellegrino & Hilton, 2012). The How People Learn Framework (Donovan et al., 1999) emphasizes the importance of knowledge transfer, in that it allows the student to apply what was learned in new situations and to learn related information more quickly.

According to Rogoff and Gardner (1984), scaffolding within a contextual learning activity was affective in guiding the transfer of knowledge and skills from more familiar contexts, so assisting the learner to make connections within the context of the activity. Contextual Learning is based on a constructivist theory of teaching and learning that argues that humans generate knowledge and meaning from an interaction between their experiences and their ideas (Piaget, 1970). According to contextual learning theory, learning occurs only when students process new information or knowledge in such a way that it makes sense to them in their own frames of reference (their own inner worlds of memory and experiences) (Schung, 2012). Contextualized or stimulated learning could be used to encourage learners to adapt different levels of uncertainty, and to make decisions about adaptive plans and responses through the use of diverse reasonable scenarios (Bell et al., 2012). McLellan

(1996) defines contextual activity by using the term situated activity where situated learning is promoting the ability to look for, recognize, evaluate, and use information resources productively.

Therefore, CAD activities introducing students to new challenges with contextual exercises rather than stylistic textbook exercises can be used to test if a student can effectively transfer what was learned to the new situation. Moreover, introducing students to new challenges in CAD modeling can help scrutinize CAD tools in terms of their capability of enhancing students' adaptive expertise characteristics.

### **IV.3 Methods**

#### **IV.3.1 Participants and Data Collection**

Data were collected over three years from different groups of students each semester. 395 students who enrolled in the CAD courses in the two campuses in Southern US completed an adaptive expertise survey (AES). The survey comprised demographic questions and a 42 items, 6-point Likert- scale (Fisher & Peterson, 2001). 302 of these students also participated in the CAD modeling activities in which students were divided into two groups. An experimental group completed the contextualized activity and the control group completed a traditional stylized CAD activity. For the contextualized activity, the goal was to give students a novel activity that they have never done before. An attempt was made to create a new challenge for students where they could apply their existing knowledge. Students were asked to bring a familiar object, that they used daily to the CAD lab and to model that object in the CAD software. Figure 6 is an apple cutter that student use it daily. Therefore s/he selected this object and modeled for the contextual exercise.



Figure 6  
An object selected for contextualized CAD exercise

In the control group, students were asked to model a stylized textbook object like a machine part that was available in their textbooks. The control group was also divided into two groups. The first group of students was given 2D drawings while the other group was asked to use 3D models of stylized object to model in CAD. Figure 7 indicates the 2D drawing, 3D print and drawing the object in CAD for control exercise; this object was based on an example found in Toogood and Zecher (2011).

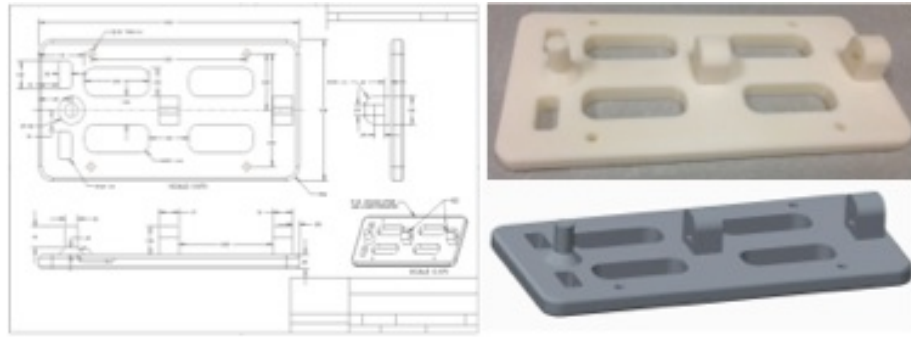


Figure 7  
Object for the textbook CAD exercise

Students were given an hour to model the objects in the CAD software. In addition to those students, 21 engineers who had been working in industry and had done CAD modeling as a significant part of their professional responsibilities at the time the data collected also completed the AES. And as a challenge and novel problem, 15 of those engineers were also asked to model an object in a CAD platform on which they had little or no familiarity. The screen capture software Camtasia was used to record the screens as the students and engineers modeled. Each participant was interviewed before and after their modeling activities. Interview questions are presented in Appendix B. Each interview lasted around 8-12 minutes (total pre and post). In Table 2, the number of participants and the activities they completed are summarized. All participants completed the AES.

Table 2

Number of participants and the activities they completed

	# of students in Campus I (Fall 11- Spring 14)	# of students in Campus II (Fall 11- Spring 14)	# of engineers	Total
AES	214	181	21	416
Contextualized CAD modeling	67	77	15	159
Traditional CAD modeling	108	50		158

Pre and post interviews were analyzed to identify student attributes and manifestations of adaptive expertise in the contextualized and stylized CAD modeling activities. The interviews was designed considering the four AE dimensions –multiple perspectives, metacognitive self-assessment, goals and beliefs, and epistemology- summarized by Fisher and Peterson (2001). Questions in the interview protocols aimed to capture students’ AE characteristics. During both pre and post interviews, participants were asked questions to understand if they knew what they were actually doing and if they were aware of their own knowledge necessary for the activity they were conducting. This is a part of metacognitive self-assessment aspect of AE. In addition students self-confidence levels are assessed in both pre-post interviews. Walker et al. (2006) claimed that self-confidence an important aspect of AE. In addition, other questions are asked to understand if participant are open to novel innovative problem solving strategies, and other open-ended questions to acquire AE manifestations from their responses.



By using both AES data and interview data, the correlations between students' AES scores and AE manifestations during their pre and post interviews were assessed. Students' AES scores were compared with their pre and post interview responses. This study allows for the summary of some particular aspects that may contribute to developing AE in engineering students.

#### **IV.4 Analyses and Results**

The recorded interviews were transcribed verbatim. The transcriptions were read several times. According to the literature and the four dimensions (Fisher & Peterson, 2001) defined, students' responses were categorized. For the analysis of interviews constant comparative approach (Glaser & Strauss, 1967)) was used. In this approach, the responses are categorized and sub categories are created from those categories. The process in general, reduces the data into small set of themes that characterizes the process being studied. After the categories were determined with the selective coding method (Creswell, 2007), the transcriptions were coded and the number of selected responses was compared with the students' AES scores to see if there was a correlation and if there was some group differences in manifestation of AE in pre and post interviews.

##### **IV.4.1 Relationship Between Students' AES Scores and Manifestation of AE Behavior in Interviews**

Here only statistically significant and meaningful results are reported. The variables for the analyses are, pre interview data, post interview data, and four sub-dimensions of the AES: multiple perspectives, metacognitive self-assessment, goals and beliefs, and epistemology (Fisher & Peterson, 2001).

To determine the significant correlations between AES survey results and AE manifestations during pre/post interview of CAD modeling activities, two sample t-tests analyses were conducted using IBM SPSS Statistics 22. For the AES and pre/post interviews of the CAD modeling exercises, students' ( $N=233$ ) "goals and beliefs" sub-dimension of AES scores and "goals and beliefs" manifestation in pre-interview were significantly correlated ( $r(231)=.146, p<.05$ ). During the pre-interview, students' ( $N=233$ ) overall sub-dimension of AES scores and overall manifestation of AE behavior were significantly correlated as well ( $r(231)=.132, p<.05$ ). When post interviews were scrutinized, it was observed that students' ( $N=233$ ) "multiple perspectives" sub-dimension of AES scores and "multiple perspectives" manifestation were significantly correlated ( $r(231)=.186, p<.05$ ).

The students' ( $N=233$ ) overall sub-dimension of AES scores and overall manifestation of AE behavior in post-interview were significantly correlated as well ( $r(231)=.165, p<.05$ ). When overall pre and post interviews total responses were compared with the AES scores, results indicate that students' ( $N=233$ ) total "multiple perspectives" manifestation during interviews were significantly correlated with total "multiple perspectives" sub-dimension score of AES ( $r(231)=.110, p<.05$ ). In addition, overall manifestation of adaptive expertise is significantly correlated with overall total AES scores ( $r(231)=.156, p<.05$ ).

**Group differences.** To determine if there were significant differences between groups, one-way ANOVA was conducted using IBM SPSS Statistics 22. For the CAD modeling pre and post interview analyses, the effect of the CAD exercise (contextualized and control CAD modeling activities) was tested, Gender effects, grade-level effects

(sophomore, junior, and senior level), campus, and experience (e.g., student vs. engineer status) effects on AE manifestations were also assessed.

*Contextualized and control CAD differences:* One-way ANOVA test results show that students who used a 2D textbook drawing to create a model in CAD platform ( $N=92$ ,  $M=1.28$ ,  $SD=1.19$ ) had more “metacognitive self assessment” manifestation than students who created a model of a 3D familiar object in CAD platform ( $N=110$ ,  $M=.86$ ,  $SD=.80$ ,  $F(2, 228)=4.758$ ,  $p=.009$ ) through the pre-interview. For the post interview; the group who used 3D textbook object ( $N=29$ ,  $M=1.00$ ,  $SD=1.04$ ) had more “multiple perspectives” manifestation than the group of students who used a 2D drawing ( $N=92$ ,  $M=.57$ ,  $SD=.76$ ,  $F(2, 228)=3.679$ ,  $p=.029$

When assessing the total AE manifestations for both pre and post interviews, ANOVA tests indicated that the students who created a model of 3D textbook object in the CAD platform ( $N=29$ ,  $M=8.52$ ,  $SD=4.26$ ) had more overall manifestation of AE behavior than the students who used a 3D familiar object to model in CAD ( $N=110$ ,  $M=5.81$ ,  $SD=2.93$ ,  $F(2, 228)= 6.193$ ,  $p=.002$ ) and the students who used a 2D drawing ( $N=92$ ,  $M=6.24$ ,  $SD=4.29$ ,  $F(2, 228)=6.193$ ,  $p=.016$ ). The students who used the 3D textbook object ( $N=29$ ,  $M=2.38$ ,  $SD=1.70$ ) also had more “multiple perspectives” than the students who used a 3D familiar object to model in CAD ( $N=110$ ,  $M=1.57$ ,  $SD=1.31$ ,  $F(2, 228)= 3.468$ ,  $p=.043$ ). In addition, the students who created a model of 3D textbook object in CAD ( $N=29$ ,  $M=3.69$ ,  $SD=1.83$ ) had more “goals and beliefs” manifestation than the students who modeled a 3D object familiar to them ( $N=110$ ,  $M=1.89$ ,  $SD=1.84$ ,  $F(2, 228)= 10.153$ ,  $p=.000$ ) and the students who used a 2D drawing ( $N=92$ ,  $M=2.05$ ,  $SD=2.09$ ,  $F(2, 228)= 10.153$ ,  $p=.001$ ).

*Grade-level differences:* ANOVAs were conducted to examine whether there were grade-level (e.g., sophomore, junior, and senior levels) differences in AE manifestations for both pre and post interviews. Results indicated that senior students ( $N=103$ ,  $M=2.62$ ,  $SD=2.11$ ) had more “goals and beliefs” manifestation of adaptive expertise behavior than first-year students or freshmen ( $N=56$ ,  $M=1.21$ ,  $SD=1.69$ ,  $F(3, 227)=8.405$ ,  $p=.000$ ). Furthermore, senior students ( $N=103$ ,  $M=7.15$ ,  $SD=4.13$ ) had more overall manifestation of adaptive expertise behavior than first-year students or freshmen ( $N=56$ ,  $M=4.70$ ,  $SD=2.77$ ,  $F(3, 227)=7.956$ ,  $p=.001$ ) and sophomores ( $N=21$ ,  $M=4.62$ ,  $SD=2.31$ ,  $F(3, 227)=7.956$ ,  $p=.039$ ). Additionally, juniors ( $N=51$ ,  $M=7.14$ ,  $SD=3.75$ ) had more overall manifestation of adaptive expertise behavior than freshmen ( $N=56$ ,  $M=4.70$ ,  $SD=2.77$ ,  $F(3, 227)=7.956$ ,  $p=.008$ ). Juniors ( $N=51$ ,  $M=2.65$ ,  $SD=1.87$ ) had more “goals and beliefs” manifestation of adaptive expertise behavior than freshmen ( $N=56$ ,  $M=1.21$ ,  $SD=1.69$ ,  $F(3, 227)=8.405$ ,  $p=.003$ ) as well.

*Campus and experiential differences:* The two university campuses and student vs. engineer status on AE manifestations during pre and post interviews of CAD modeling activities were also compared. Results from one-way ANOVAs show that, during the pre-interview, the engineers who have greater professional experience and work in industry ( $N=14$ ,  $M=1.79$ ,  $SD=1.42$ ) had more “metacognitive self assessment” manifestations of adaptive expertise behavior than Campus II students who are mostly freshmen ( $N=92$ ,  $M=.92$ ,  $SD=.92$ ,  $F(2, 242)=4.594$ ,  $p=.014$ ). Engineers ( $N=14$ ,  $M=1.43$ ,  $SD=1.16$ ) had more “multiple perspectives” manifestation than Campus II students ( $N=92$ ,  $M=.54$ ,  $SD=.69$ ,  $F(2, 242)=7.729$ ,  $p=.001$ ) and Campus I students ( $N=139$ ,  $M=.72$ ,  $SD=.82$ ,  $F(2, 242)=7.729$ ,  $p=.007$ ) during the post-interview as well. Furthermore, engineers ( $N=14$ ,

$M=3.21$ ,  $SD=1.97$ ) had more overall manifestation of adaptive expertise than Campus II students ( $N=92$ ,  $M=1.67$ ,  $SD=1.35$ ,  $F(2, 242)= 10.165$ ,  $p=.006$ ).

Total AE manifestations in both pre and post interviews are also compared. Results indicated that in general, Campus I students (who are mostly seniors) and engineers had more AE manifestation than Campus II students who are mostly freshmen. In fact, Campus I students ( $N=139$ ,  $M=7.23$ ,  $SD=4.05$ ) had more overall manifestation of adaptive expertise behavior than Campus II students ( $N=92$ ,  $M=4.95$ ,  $SD=2.84$ ,  $F(2, 242)=11.468$ ,  $p=.000$ ). Campus I students ( $N=139$ ,  $M=1.89$ ,  $SD=1.67$ ) also had more “multiple perspectives” manifestation of adaptive expertise behavior than Campus II students ( $N=92$ ,  $M=1.36$ ,  $SD=1.29$ ,  $F(2, 242)=3.492$ ,  $p=.033$ ). In addition, Campus I students ( $N=139$ ,  $M=2.71$ ,  $SD=2.03$ ) had more “goals and beliefs” manifestation than Campus II students ( $N=92$ ,  $M=1.38$ ,  $SD=1.73$ ,  $F(2, 242)=16.255$ ,  $p=.000$ ). Engineers also ( $N=14$ ,  $M=2.79$ ,  $SD=1.81$ ) had more “multiple perspectives” manifestation than Campus II students ( $N=92$ ,  $M=1.49$ ,  $SD=1.21$ ,  $F(2, 242)=6.370$ ,  $p=.006$ ).

#### **IV.5 Discussion and Conclusion**

It was expected that participants’ AES scores would match with their reported AE characteristics in the interviews. Between the four sub-dimensions of AES, during pre-interview, students’ “goals and beliefs” sub-dimension and “goals and beliefs” manifestation as well as overall sub-dimensions scores in AES and in interviews are significantly correlated. For the post interview, students’ “multiple perspective” sub-dimension and “multiple perspectives” manifestation were significantly correlated. The overall scores in AES and interviews are also significantly correlated. When overall pre and post interviews

total responses are compared with the AES scores, results indicate that students' total "multiple perspectives" manifestation during interviews are significantly correlated with total "multiple perspectives" sub-dimension score of AES. In addition, overall manifestation of adaptive expertise is significantly correlated with overall total AES scores.

The multiple perspectives characteristic is defined as openness to new information and novel ways to solve problems by recognizing opportunities for creativity (Fisher & Peterson, 2001). More importantly, the students' overall sub-dimension of AES scores and overall manifestation of AE behavior in interviews are significantly correlated as was expected expecting. It can be concluded that, participants AES responses were consistent with their interview responses.

One-way ANOVA was used to see if the groups were different from each other in terms of the AE manifestation during the interviews.

For the differences between students who used different objects to model (3D textbook object, 2D textbook drawing, and 3D familiar object), it was expected that when students were given a novel challenge that they had not completed previously, they would respond to interview questions differently by means of the AE manifestation. Results indicated that in general, the students who used a 3D printed textbook object to create a model in CAD had more AE manifestations than other groups.

Indeed, through the pre interview, exceptionally, students with 2D textbook drawing had more "metacognitive self assessment" manifestation than students with a familiar 3D object. Here, it can be inferred that 3D objects were more challenging for students because they regularly worked with 2D drawings in the class. Although effortful problem solving in unfamiliar new situations requires metacognitive skills (Kalyuga, 2009),

in this study it was observed that students who used 2D drawings expressed more of their metacognitive self-assessment skills comfortably before they start drawing. For the post interview; 3D textbook object students had more “multiple perspectives,” “goals and beliefs,” and more overall manifestation of AE behavior than students with 2D drawing. For the post interview, students were interviewed after their exercise and it can be interpreted that because 3D drawings were more challenging for students, they might comment more on their performance and might expressed more AE manifestations. In general and unexpectedly, for both pre and post interviews, results indicated that students with 3D textbook object had more overall manifestation of AE behavior than students with a 3D familiar object to model in CAD.

For the students, using a familiar object was a novel, more challenging situation. It was proposed that a novel problem would make students express more AE manifestation during the interviews, however it did not. The reason why students worked with familiar objects revealed less AE manifestation may be the students underestimated the complexity of modeling a familiar object and they might believe that this process would be easier than they expected. They might realize that their modeling plans did not work out like they assumed. Thus, during the interviews they did express less AE manifestation.

In addition, an assessment of any differences between students of different rank was undertaken. For both pre and post interviews, seniors have more “goals and beliefs” and more overall manifestation of adaptive expertise than freshmen. The two campuses and the engineers were also compared by means of their AE manifestations during pre and post interviews of CAD modeling activities. Engineers have more multiple perspectives and overall manifestations of adaptive expertise than Campus II and Campus I students. Here, it

can be concluded that when the two campuses are compared, in campus I, most students were seniors while in campus II, the students were mostly freshmen and sophomores; for all the observed statistically significant differences, students in campus I reported higher AE scores than the students in campus II. As expected, students were more experienced with the modeling practice and their AE characteristics were enhanced. The same conclusion is also evident when the two campuses and engineers are compared. Engineers conveyed more multiple perspectives AE characteristics in interviews than students in both campuses. This was also an expected result. In 2001 Fisher and Peterson, also found a similar patterns in their study. According to their findings, levels of adaptive expertise from freshmen to seniors to faculty increased monotonically. In addition, the average adaptive expertise score of the engineering faculty was higher than that of the engineering freshmen. In another related work that used a design scenario to assess how undergraduates approach novel design challenges, Walker et al. (2006) concluded that fourth-year students created more efficient and innovative solutions than did first-year students. Fourth-year students were also more confident in their problem-solving abilities. Over time all students became more innovative and more confident as was observed in this study as well. As expected, much of the increase in innovation for beginning students emerged related to their experience and greater understanding of context.

In this study, only the multiple perspectives characteristic of AE was significantly higher in engineers, here it can be concluded that with experience their multiple perspective characteristic was enhanced. For the engineers' part, there was a limitation that although these results were significant, the number of engineers (N= 14) was relatively low. Future work with an increased number of engineers should generate more precise and clear results.



These results provide insights to research conducted to enhance CAD instruction. These findings show that multiple perspectives, goals and beliefs, and metacognitive skills are good indicators of developing adaptive expertise and that educator should consider promoting those skills in CAD education.

These findings confirm the importance of practice for developing AE through engineering education by enhancing regular CAD exercises in the classroom. According to Kalyuga (2009) instructing for adaptive and flexible expertise requires developing advanced forms skills that are applicable to a greater variety of situations. Integrating novel and challenging problems to classroom exercises will encourage students be more flexible, and adaptive. In a study on assessing AE, Pandey et al. (2004) find that challenge-based instruction can accelerate the trajectory of novice to expert development. With non-routine and creative exercises in classroom, essential attributes of adaptive expertise can be developed (Kalyuga, 2009). New challenges provide learners with additional contexts and develop their innovation skills which are necessary to manage the novel problems they will face after graduation, and potentially identify opportunities for new discoveries (Brophy et al., 2004). In another study on the development of AE, Martin et al. (2006) claim that educators can and do help students develop adaptive expertise, even when students do not necessarily show such qualities initially. This can be achieved by using well-informed teaching methods that require students to engage in complex problem solving. Learning experiences that reflect both knowledge and novelty can increase the chances that people will develop adaptive expertise in their fields of interest (Martin et al., 2006)

This study contributes to the literature as follows: (1) the results point to the importance of exploring the role of contextualized exercise on students' expressions of AE

manifestations; (2) it was observed that substituting a routine exercise with a challenging one made a difference in students' AE behaviors; (3) the results provide evidence that AE is developed through the years and increases with experience.

#### **IV.5.1 Limitations and Future Directions**

The findings presented here are initial steps in understanding AE in context of CAD design activities. More study is required to entirely understand what kind of activities will better increase students' adaptive expertise characteristics through their education. Future work should include equal numbers of male and female students as well as equal numbers of students and engineers to better understand these differences.

## **CHAPTER V**

### **SUMMARY AND CONCLUSION**

#### **V.1 Summary**

This dissertation aims to investigate the CAD expertise through ‘routine’ versus ‘adaptive’ expert features, and to evaluate ways to encourage adaptive expert characteristics in undergraduate engineering education. To address those issues three main questions are answered in four main chapters first of which was the introduction chapter.

The second chapter was a literature review aiming to present, “Which factors can contribute to the development of AE?” This chapter presented the factors contributing to the development of AE. Key characteristics of AE were highlighted. According to the related literature, four main factors -motivation, self-regulation strategies, relevant knowledge, and deeper learning and transfer of knowledge- contribute to develop expertise. Furthermore, to be able to develop adaptiveness besides expertise, innovation, efficiency and experiences are the key characteristics. To develop those skills through higher education, environments where students are engaged in the activities that they solve real life problems, and they face with novel challenges should be provided so that they can be motivated and develop self-regulation strategies. In addition, a problem-based instruction may be supportive on developing AE characteristics of engineering students.

Chapter III investigated if engineering students’ demographic characteristics are related to their observable AE characteristics. The implementation of an instrument used to measure AE was presented. The AE survey was developed by Fisher and Peterson (2001)

for measuring the adaptive expertise in biomedical engineering students. The instrument contains questions defining four dimensions: multiple perspectives, meta-cognitive self-assessment, goals and beliefs, and epistemology. According to the results of statistical analyses, students who have technical employment and research experience related to engineering (e.g., machines shops, labs, project tasks, etc.) more metacognitive self-assessment and overall dimensions score than inexperienced students. In addition, students who have a professional work experience related to engineering (e.g., internship, co-op, etc.) have more metacognitive self-assessment, multiple perspectives, epistemology, and overall sub-dimensions scores than students who don't have professional experience. It is observed that for the goals and beliefs dimensions having any research or professional experience did not show any statistically significant difference. In addition, when students' rank was compared it was observed that that senior students have higher "multiple perspectives," "epistemology" and overall dimension scores than freshmen. A similar conclusion was also evident when the two campuses are compared. In Campus I, most students were seniors, while in Campus II the students were mostly freshmen and sophomores. For all the observed statistically significant differences, Campus I students and practicing engineers have higher multiple perspectives, epistemology, and overall sub-dimensions scores than Campus II students.

In Chapter IV, results of contextualized CAD activities were presented. Pre and post interviews conducted through the modeling activities were scrutinized. According to the results of that study, students' "goals and beliefs" sub-dimension and "goals and beliefs" manifestation as well as overall sub-dimensions scores in AES and in interviews are significantly correlated. For the post interview, students' "multiple perspective" sub-

dimension and “multiple perspectives” manifestation were significantly correlated. The overall scores in AES and interviews are also significantly correlated. When overall pre and post interviews total responses are compared with the AES scores, results indicate that students’ total “multiple perspectives” manifestation during interviews are significantly correlated with total “multiple perspectives” sub-dimension score of AES. Most importantly, as expected, overall manifestation of adaptive expertise is significantly correlated with overall total AES scores. Moreover, in general, students who used a 3D printed textbook object to create a model in CAD had more AE manifestations than other groups who modeled 2D drawings or 3D familiar daily used objects. In addition, for both pre and post interviews, seniors have more “goals and beliefs” and more overall manifestation of AE than freshmen. The two campuses and the engineers were also compared by means of their AE manifestations during pre and post interviews of CAD modeling activities. Engineers have more multiple perspectives and overall manifestations of adaptive expertise than students.

## **V.2 Conclusion**

In conclusion of these studies, it was observed that as students gain more experience through years their overall AE characteristics were developed as well. It was also evident when practicing engineers and students were compared that overtime individuals gain more AE characteristics in general. As expected, much of the increase in innovation and efficiency of approaching the novel problems is related to their experience and greater understanding of context. These outcomes confirm the importance of practice to improve AE through engineering education by enriching regular CAD exercises in the classroom.

Kalyuga (2009) emphasized the significance of integrating advanced skills that are applicable for various situations into the engineering curriculum to develop AE skills. Integrating novel, challenging and contextual problems to classroom exercises will encourage students be more flexible, and adaptive. Pandey et al. (2004) assessed AE in their study and found that challenge-based instruction can accelerate the trajectory of novice to expert development. With non-routine and creative exercises in classroom, essential attributes of AE can be developed (Kalyuga, 2009). New challenges provide learners with additional contexts and develop their innovation skills which are necessary to manage the novel problems they will face after graduation, and potentially identify opportunities for new discoveries (Brophy et al., 2004). Learning experiences that reflect both knowledge and novelty can increase the chances that people will develop AE in their fields of interest (Martin et al., 2006). In addition, through the light of literature, it can be suggested that engineering training should promote learning with a problem based or related approaches that emphasizes students' efforts to solve complex problems. In this approach, the problem should be authentic which means that it should reflect a real life problem that an expert on the field can handle (Koschmann et al., 1996). In problem based learning, the instruction begins with the presentation of problem and then students realize that they lack information and skills that they need to find a solution. In this way, students are motivated and engage in self-regulation strategies to meet their needs so that the activity turns out to be under students' control which makes learning meaningful (Donovan et al., 1999).

### **V.2.1 Limitations and Future Directions**

With the review of literature and the conducted studies, there are still questions that might not be answered precisely because development of AE in engineering education is a

relatively new topic in the literature. Therefore, more work is required to be able to make definite claims about development of AE. Future research can unpack what other characteristics contribute to developing AE and what kind of exercises and practices will enhance students' AE characteristics. Open questions still remain about how to balance the dimensions contributing development of AE when providing instruction to engineering students.

In brief, this study can provide insights to research conducted to enhance engineering education that can support development of AE. These findings in the dissertation show that multiple perspectives, goals and beliefs, and metacognitive skills are good indicators of developing AE and educators should consider promoting those skills in engineering education. Wineburg (1998) defines adaptive expertise as: “the ability to apply, adapt, and otherwise stretch knowledge so that it addresses new situations - often situations in which key knowledge is lacking.” Preferably, the expertise characteristics that students improve through their undergraduate education should be adaptive in nature and be extendable to engineering practices in general.

While AE related research studies in engineering education and this dissertation have presented findings with respect to developing aspects of AE within engineering, there should be more in-depth future studies specifying the nature of efficiency and innovation. In addition, some researchers (Ericsson et al., 2006; Ericsson & Lehmann, 1996) have suggested that on average it takes approximately ten years of deliberate practice, along with the accumulation of experience to develop recognized levels of expertise. If this time frame is taken into consideration in the development of AE, this dissertation and most studies in the literature focus mostly on relatively brief snap shots in time to observe development of

AE. Therefore, in the future, the literature would benefit from studies that examine AE from a more longitudinal perspective. Examining adaptive expertise over a more extended period of time could yield useful insights. Moreover, the important aspects of development of AE that are presented (such as innovation, efficiency, experiences, multiple perspectives, metacognitive self-assessment, goals and beliefs, and epistemology) has been studied less in the literature. Therefore, several new research directions could be conducted that examine the role of these personal characteristics of AE. It is also important to note that engineering design activity almost always involves working in teams. Therefore, the collaborative nature of engineering practices should be taken into consideration while scrutinizing how AE can be developed, in contrast to just focusing on an individual's path to AE. McKenna (2014) suggests that future area of research could involve investigating how the adaptive expertise framework might be applied to groups, organizations, or collections of individuals such that the unit of analysis is the group, not the individual.

### **V.2.2 Significance of the Research**

To sum up, this study contributes to the literature as follows: (1) the results point to the importance of exploring the role of contextualized exercise on students' expressions of AE manifestations; (2) it was observed that substituting a routine exercise with a challenging one made a difference in students' AE behaviors; (3) the results provide evidence that AE is developed through the years and increases with experience; (4) currently the literature is lack of such a comprehensive empirical based CAD modeling study to identify expert modeling procedures across CAD platforms; (5) this work can make a significant contribution to engineering instruction by emphasizing that learner centered problem based contextualized



exercises are significant to develop students' AE characteristics through their undergraduate education.

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## APPENDIX A

### Adaptive Expertise Related to Computer Aided Design (CAD) Student Survey

Thank you for participating in this study.

This survey includes two sections. Section I asks for your demographic information. Section II includes some opinion and attitude questions towards the characteristics of adaptive expertise. Section II items are to explore your personal views and experiences. Your responses to this survey will remain confidential and will not be shared with anyone other than the researchers.

#### Section I: Demographic Questionnaire

Please answer the below questions by checking the appropriate boxes or filling in the necessary field:

1	Name – Last Name (write in)		
2	Sex (check)	<input type="checkbox"/> Male	<input type="checkbox"/> Female
3	Age (write in)		
4	Rank/ level in college (check)	<input type="checkbox"/> Freshman	<input type="checkbox"/> Sophomore
		<input type="checkbox"/> Senior	<input type="checkbox"/> Junior
5	Major (write in)		
6	Have you had a professional work experience related to engineering (e.g., internship, co-op, etc.)?	<input type="checkbox"/> Yes	<input type="checkbox"/> No
7	Have you had any technical employment and research experience related to engineering (e.g., machines shops, labs, project tasks, etc.)	<input type="checkbox"/> Yes	<input type="checkbox"/> No

#### Section II: Adaptive Expertise Questionnaire

*In this section, please read each item carefully and indicate your position by circling one of the numbers in the 6 point scale as 1 (strongly disagree), 2 (disagree), 3 (slightly disagree), 4 (slightly agree),*

*5 (agree), and 6 (strongly agree). Note that number 6 on the right designates the highest agreement and number 1 on the left designates the lowest agreement with the item.*

		Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
		1	2	3	4	5	6
1.	I create several models of an engineering problem to see which one I like best.	1	2	3	4	5	6
2.	As I learn, I question my understanding of the new information.	1	2	3	4	5	6
3.	I feel uncomfortable when I cannot solve difficult problems.	1	2	3	4	5	6
4.	Knowledge that exists today may be replaced with a new understanding tomorrow	1	2	3	4	5	6
5.	Usually there is one correct method in which to represent a problem.	1	2	3	4	5	6
6.	I often try to monitor my understanding of the problem.	1	2	3	4	5	6
7.	I am afraid to try tasks that I do not think I will do well.	1	2	3	4	5	6
8.	Most knowledge that exists in the world today will not change.	1	2	3	4	5	6
9.	When I consider a problem, I like to see how many different ways I can look at it.	1	2	3	4	5	6
10.	As a student, I cannot evaluate my own understanding of new material.	1	2	3	4	5	6
11.	Although I hate to admit it, I would rather do well in a class than learn a lot.	1	2	3	4	5	6
12.	Scientists are always revising their view of the world around them.	1	2	3	4	5	6
13.	I tend to focus on a particular model in which to solve a problem.	1	2	3	4	5	6
14.	I rarely monitor my own understanding while learning something new.	1	2	3	4	5	6
15.	One can increase their level of expertise in any area if they are willing to try.	1	2	3	4	5	6
16.	Facts that are taught to me in class must be true.	1	2	3	4	5	6
17.	I am open to changing my mind when confronted with an alternative viewpoint.	1	2	3	4	5	6
18.	When I know the material, I can recognize areas where my understanding is incomplete	1	2	3	4	5	6
19.	Expertise can be developed through hard work.	1	2	3	4	5	6
20.	Existing knowledge in the world seldom changes.	1	2	3	4	5	6
21.	I rarely consider other ideas after I have found the best answer.	1	2	3	4	5	6
22.	I have difficulty in determining how well I understand a topic.	1	2	3	4	5	6
23.	To become an expert in engineering, you must have an innate talent for engineering.	1	2	3	4	5	6
24.	Challenge stimulates me.	1	2	3	4	5	6
25.	I find additional ideas burdensome after I have found a way to solve the problem.	1	2	3	4	5	6

26.	I monitor my performance on a task.	1	2	3	4	5	6
27.	Experts in engineering are born with a natural talent for their field.	1	2	3	4	5	6
28.	Scientific theory slowly develops as ideas are analyzed and debated.	1	2	3	4	5	6
29.	For a new situation, I consider a variety of approaches until one emerges superior.	1	2	3	4	5	6
30.	As I work, I ask myself how I am doing and seek out appropriate feedback.	1	2	3	4	5	6
31.	Experts are born, not made.	1	2	3	4	5	6
32.	Even if frustrated when working on a difficult problem, I can push on.	1	2	3	4	5	6
33.	Scientific knowledge is developed by a community of researchers.	1	2	3	4	5	6
34.	I solve all related problems in the same manner.	1	2	3	4	5	6
35.	Poorly completing a project is not a sign of a lack of intelligence.	1	2	3	4	5	6
36.	When I solve a new problem, I always try to use the same approach.	1	2	3	4	5	6
37.	Scientific knowledge is discovered by individuals.	1	2	3	4	5	6
38.	When I struggle, I wonder if I have the intelligence to succeed in engineering.	1	2	3	4	5	6
39.	There is one best way to approach a problem.	1	2	3	4	5	6
40.	I seldom evaluate my performance on a task.	1	2	3	4	5	6
41.	I feel uncomfortable when unsure if I am doing a problem the right way.	1	2	3	4	5	6
42.	Progress in science is due mainly to the work of sole individuals.	1	2	3	4	5	6

*Thank you for your time ☺*

*Please return the forms to the researchers.*

## APPENDIX B

Interview Questions for the Adaptive Expertise/

Contextualized Exercises in CAD

### Pre-interview Questions

1. What are the things you consider first when you are asked to model an object?
  - a. Why?
2. What challenges have you previously encountered in the modeling process?
  - a. If you run into that challenge today, how do you plan on overcoming it?
3. Do you have any strategies for modeling the object today?
  - a. If so, which strategies do you anticipate using?
4. Are you familiar with the object you are going to model today?
5. If you are familiar with the object you are modeling or if you use it often in your daily life, would it be easier for you to model it?
  - a. Why, why not?
6. How important is it to know about the object you are going to model?
7. How confident are you in this modeling process?

(1: not confident 6:very very confident)

1      2      3      4      5      6

### Post-interview Questions

1. Were things you considered before you began modeling the object, helpful to you in the process?
    - a. How and why?
  2. What challenges did you encounter during the modeling process?
  3. How did you overcome these challenges?
  4. Was your knowledge of the object or being familiar with it, helpful to you in your modeling process?
    - a. How and why?
  5. How confident are you in your model?
  6. (1: not confident 6:very very confident)
- 1      2      3      4      5      6



## APPENDIX C

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**TEXAS A&M UNIVERSITY**  
**DIVISION OF RESEARCH - OFFICE OF RESEARCH COMPLIANCE AND BIOSAFETY**

1186 TAMU, General Services Complex College Station, TX 77843-1186 750 Agronomy Road, #3501	979.458.1467 FAX 979.862.3176 <a href="http://researchcompliance.tamu.edu">http://researchcompliance.tamu.edu</a>
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Human Subjects Protection Program

Institutional Review Board

**APPROVAL DATE:** 11-Jun-2012

**MEMORANDUM**

**TO:** JOHNSON, MICHAEL D  
77843-3367

**FROM:** Office of Research Compliance  
Institutional Review Board

**SUBJECT:** Amendment

**Protocol Number:** 2011-0556

**Title:** Assessing the Effect of Contextual Exercises on Student Adoption of Expert CAD Modeling Techniques

**Review Category:** Expedited

**Approval Period:** 11-Jun-2012 To 13-Jul-2012

**Approval determination was based on the following Code of Federal Regulations:**

Modification Eligible for Expedite Review (45 CFR 46.110): The modification(s) do not affect the design of the research AND the modification(s) add no more than minimal risk to subjects.

**Provisions:**

**Comments:** Clarified consent form with regard to optional use of audio recordings

This research project has been approved. As principal investigator, you assume the following responsibilities

1. **Continuing Review:** The protocol must be renewed each year in order to continue with the research project. A Continuing Review along with required documents must be submitted 45 days before the end of the approval period. Failure to do so may result in processing delays and/or non-renewal.
2. **Completion Report:** Upon completion of the research project (including data analysis and final written papers), a Completion Report must be submitted to the IRB Office.
3. **Adverse Events:** Adverse events must be reported to the IRB Office immediately.
4. **Amendments:** Changes to the protocol must be requested by submitting an Amendment to