



Adaptive Expertise and its Manifestation in CAD Modeling: A Comparison of Practitioners and Students

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Abstract

The state of Computer-Aided Design (CAD) education is often decried for focusing too much on the low-level skills required to do specific tasks; this often comes at the expense of promoting the strategic knowledge associated with expertise. The environment that today's students will encounter in the workplace will require them to adapt to new challenges in innovative ways. Namely, they will need to become adaptive experts. To better inform CAD education, this work examines how practicing engineers adapt to a new environment and compares this behavior to that of students.

To establish the “baseline” adaptive expertise among the sample population, an Adaptive Expertise Survey (AES) instrument was administered to both the practicing engineers and the college students. The practicing engineers in this work are asked to model a component in a CAD program that they are not familiar with. The students are asked to model either a stylized component or an artifact that they have brought from home and to which they have some attachment. In both cases, pre and post interviews inquire how the participants approach their tasks and overcome any challenges.

Recordings of the interviews are transcribed and analyzed using open and axial coding. Selective coding is used to align responses with the dimensions of adaptive expertise. This coding provides the manifestation of adaptive expertise in the exercise. Statistical analyses are used to compare participants' interview responses to their AES scores. Practitioners' and students' manifestations of adaptive expertise are compared. Manifestations of adaptive expertise are also compared to demographic data.

Introduction

CAD tools are pervasively used throughout the product development process in many industries¹. Consequently, today's engineering students will go into a professional field where they need to adapt to the new challenges of working with these tools as part of the burgeoning model based enterprise². Prospective engineers should have diverse experiences and skills to effectively use the CAD software. These experiences should also be more authentic³ and entail using CAD to meet design objectives⁴.

With CAD tools students use their knowledge and skills to create models and adapt to novel problems. These tools can support students to attain a level of expertise if a deeper practical knowledge is taught. However, most available CAD instruction is mainly dependent on step by step informative knowledge^{5,6} rather than tactical knowledge that is related with CAD expertise⁷.

Therefore, it is important to find ways to enhance engineering education with the support of effective CAD courses. In addition, understanding how engineering students approach design problems in both regular class exercises and contextual exercises will help researchers and educators develop effective CAD training in engineering education. Moreover, assessing the adaptive nature of their CAD expertise and comparing the practices of engineering students' and practicing engineers' manifestations of adaptive expertise (AE) during their CAD modeling activities may help researchers understand how AE can be developed through CAD exercises.

Adaptive vs Routine Expertise

AE is the term that defines the capability of being both innovative and adaptive to new challenges while also having content knowledge associated with expertise⁸. 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 skill and/or domain knowledge is known as expertise. This consists of solving problems in a particular domain; expertise is based upon the accumulation of experience and expert people can solve more and more complex problems in the field, utilizing relevant prior knowledge which is in turn gradually enriched and integrated⁹.

Hatano and Inagaki⁹ 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. On the other hand, 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 the flexible knowledge needed to be innovative problem solvers¹⁰.

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 an important engineering skill^{11, 12}. Through an extensive literature review, Fisher and Peterson¹³, have identified four primary aspects of adaptive expertise: [1] multiple perspectives [2] metacognition, [3] goals and beliefs, and [4] epistemology.

“Multiple perspectives” signifies the willingness to use a variety of approaches when working on a problem⁹. 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, those with multiple perspectives are open to new information and apply this information to the situations where creativity is possible¹³. These students can act flexibly to novel situations. Flexible use of knowledge and efficiency are also a part of adaptive expertise¹⁰.

“Metacognition” is how experts monitor their problem solving, question limitations in their knowledge, and avoid simple interpretations of a problem¹⁴. People who have metacognitive self-assessment ability can use various techniques to self-assess 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 incomplete¹³. Besides being aware of what they know and what they don’t, people who have the metacognitive self-assessment characteristics have confidence on solving challenging problems.

“Goals and Beliefs” defines the views that students have concerning their learning goals. Self-regulation strategies as a part of AE, helps identifying goals to generate ideas or improve an existing idea⁸. Pellegrino and Hilton¹⁴ argue 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 continue to proceed in the face of uncertainty¹³. In addition, student beliefs about learning, motivation, and metacognition are all dimensions of the self-regulated learning focusing on setting goals for purposeful and working to achieve them¹⁴.

“Epistemology” is a metacognitive process and it is one’s beliefs on knowledge and attitudes towards the nature of the knowledge in the field and its generation¹⁵. Students who demonstrate the epistemology attribute, perceive knowledge as an evolving entity rather than static so they realize the need to continually practice knowledge¹³. Fisher and Peterson¹³ also state that these students appreciate what a diverse group can contribute in the way of insights and contributions to a project.

Study Purpose

This study explored students’ and practicing engineers’ AE characteristics as they model objects using CAD tools. Student participants that modeled objects that they frequently use in their daily lives characterized their modeling activities as contextualized. The effect of the contextualized activities on participants’ AE characteristics has been investigated. Statistical analyses were used to compare practitioners’ and students’ manifestations of adaptive expertise.

Study Methods

This project has been funded by the National Science Foundation in 2011. Two engineers and two learning scientists have worked together to implement the project activities and reiterate the research design. In each semester for the last four years, data were collected from experimental and control groups at Texas A&M University, College Station (TAMU) and Prairie View A&M University (PVAMU). Engineering students who enrolled the CAD courses in the two campuses were invited to participate in the study. Each semester, the study purpose and participant rights were explained to the students. The students who volunteered participation provided their consent by the signing the Institutional Review Board approved consent forms. The majority of the students

volunteered to participate in the research activities each semester; a few students did not consent. Data from the practicing engineers have been collected in two different occasions at Applied Materials, 3M, and General Motors. In this paper, results of the interviews from the total participant group of student and engineer are discussed. In previous work¹⁶⁻²¹, other analyses of the research data that have been cumulatively collected since 2011 are reported.

Participants and data collection

Data from the students were collected over four years from different levels each semester. A total of 395 students who enrolled in the CAD courses at TAMU and PVAMU completed an Adaptive Expertise Survey (AES). The survey comprised demographic questions and a 42 items, 6-point Likert-scale¹³. The survey questions are listed in the appendix. Out of 395 students, 302 students participated in the CAD modeling activities in which students were divided into two groups as control versus experimental. Students in the experimental group completed the contextualized activity and the students in the control group completed a traditional CAD modeling activity. The traditional CAD modeling activity did not involve any contextual object modeling or personally meaningful connections. The drawing for the traditional CAD modeling activity is shown in Figure 1. Students were provided with a sketch or 3D model of an object that was not easily identifiable to them. The goal for the contextual activity was to provide the students with a novel activity that they have never tried before. An attempt was made to create a new challenge for the 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. In the control group, students were asked to model the stylized textbook²² object shown in Figure1.

Twenty-one engineers participated in this study. The engineer participants had been working in industry at the time data were collected and they typically performed CAD modeling as a significant part of their professional responsibilities. The 21 engineers completed the AES. As a challenge and novelty, 15 of the engineer participants were 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 one-on-one. Each interview lasted between 5 minutes and 15 minutes. The final version of the interview questions are presented in the Appendix. In Table 1, the number of participants and the activities they completed are summarized. All participants completed the AES.

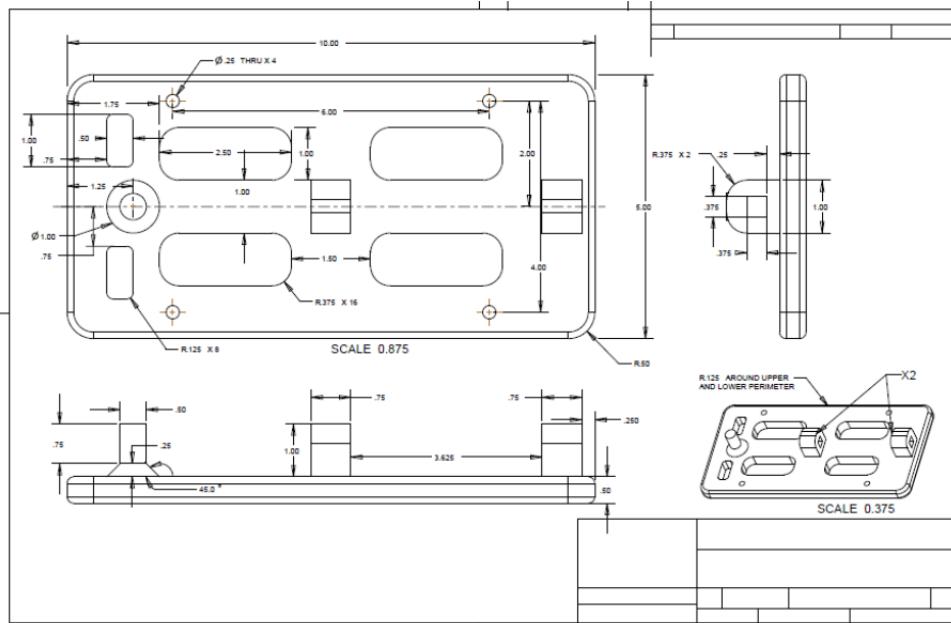
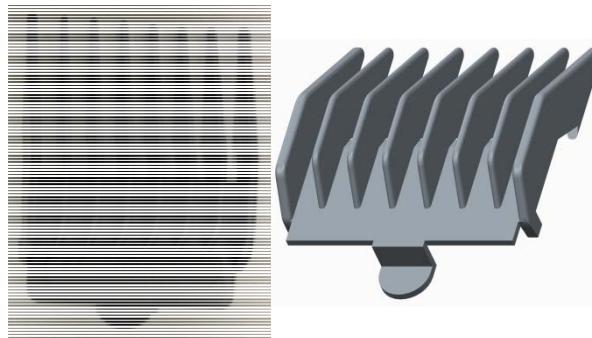


Figure 1. Drawing for Traditional CAD Modeling Activity



a.

b.

Figure 2. Example of Contextual Exercise Component (a.) and CAD Model (b.)

Table 1. Number of participants and the activities they completed

	# of students at TAMU (Fall 11- Spring 14)	# of students at PVAMU (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

Analyses

A total of 317 interview-recording pairs (pre and post) were transcribed verbatim. Pre and post interviews were coded to identify student attributes and manifestations of adaptive expertise in the contextual and stylized CAD modeling activities. Over the course of the

project activities, changes were made to the interview questions. In the final data collection phase, the interview protocol was primarily intended to capture the four AE dimensions-- multiple perspectives, metacognitive self-assessment, goals and beliefs, and epistemology-- summarized by Fisher and Peterson ¹³.

According to the literature and the four dimensions defined ¹³, participants' responses were categorized. In the analysis of the interview transcriptions, constant comparative method ²³ and open, axial, and selective coding strategies ^{24, 25} were used. After the categories were determined with the selective coding method ²⁶, the transcriptions were coded and the frequencies of the selected responses were compared with the students' AES scores to explore if there is any meaningful correlation and if there are some group differences in manifestations of AE between the pre and post interviews.

Findings

To determine if there are significant differences between the control and experimental groups, one-way ANOVA analyses were run using the IBM SPSS Statistics 22. This compared the students and engineers' pre and post interview and their AE scores with one another. Because there were more than two groups, a Scheffe post-hoc test was also run to do the multiple comparisons and to be able to specify which groups were different from each other.

Results from the one-way ANOVAs showed that during the pre-interviews engineers who had professional experiences and years of work in industry ($N=14$, $M=1.79$, $SD=1.42$) possessed more "metacognitive self-assessment" manifestations of adaptive expertise behavior than PVAMU students who were mostly freshmen and had very few to no years of experience in the industry at the time the study data were collected ($N=92$, $M=.92$, $SD=.92$, $F(2, 242)=4.594$, $p=.014$). Post interview analyses revealed that Engineers ($N=14$, $M=1.43$, $SD=1.16$) possessed statistically significantly more "multiple perspectives" manifestations than the PVAMU students ($N=92$, $M=.54$, $SD=.69$, $F(2, 242)=7.729$, $p=.001$) as well as the TAMU students who were mostly seniors ($N=139$, $M=.72$, $SD=.82$, $F(2, 242)=7.729$, $p=.007$) at the time the study data were collected. Furthermore, engineers ($N=14$, $M=3.21$, $SD=1.97$) had more overall manifestation of adaptive expertise than PVAMU students ($N=92$, $M=1.67$, $SD=1.35$, $F(2, 242)=10.165$, $p=.006$).

The total AE manifestations in both pre and post interviews were also compared. Results indicated that in general, TAMU students (who were mostly seniors) and engineers had more AE manifestations than PVAMU students who were mostly freshmen. TAMU students ($N=139$, $M=7.23$, $SD=4.05$) had more overall manifestations of adaptive expertise behavior than PVAMU students ($N=92$, $M=4.95$, $SD=2.84$, $F(2, 242)=11.468$, $p=.000$). TAMU students ($N=139$, $M=1.89$, $SD=1.67$) also had more "multiple perspectives" manifestations of adaptive expertise behavior than PVAMU students ($N=92$, $M=1.36$, $SD=1.29$, $F(2, 242)=3.492$, $p=.033$). In addition, TAMU students ($N=139$, $M=2.71$, $SD=2.03$) had more "goals and beliefs" manifestations than PVAMU 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” manifestations than PVAMU students ($N=92$, $M=1.49$, $SD=1.21$, $F(2, 242)=6.370$, $p=.006$).

Discussion and Conclusion

The main purpose of this paper was to compare students’ and practicing engineers’ manifestations of AE at pre- and post- interviews responses as well as their AES scores. Results indicated that engineers had more “multiple perspectives” and more overall manifestations of adaptive expertise than students. As expected, engineers were more experienced with the modeling practice and their AE characteristics were enhanced. Fisher and Peterson ¹³ also reported a similar pattern . According to their findings, the average adaptive expertise score of the engineering faculty was higher than that of the engineering freshmen.

In these findings, among all four dimensions, only the multiple perspectives characteristic of AE was significantly higher in engineers. Hence, it can be concluded that with experience and years of work in industry, engineers multiple perspective characteristics were enhanced. However, besides having significant results, the number of the participating engineers ($N=14$), which was a relatively small sample, was a limitation of that work. Future studies with an increased number of engineers should generate more precise and clear results.

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Appendix – Survey Instrument

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"/> Junior	<input type="checkbox"/> Senior
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		

Please go to next page for survey questions

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

		Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
		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.

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
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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
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