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Analyzing Adaptive Expertise and Contextual Exercise in Computer-Aided Design

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ABSTRACT

The fast changing pace of modern CAD tools has demanded the users to be more adaptive to apply their CAD skills. This paper presents the initial work to transform adaptive expertise in the CAD education. An adaptive expertise survey (AES) and a contextual exercise were implemented in a freshman CAD class. The students' responses to the survey and interviews were analyzed. The CAD models were evaluated based on the attributes. The statistically significant relationships among the variables are reported. The analyses examined the role of adaptive expertise in CAD modeling and the role of learner-centered contextual exercises on CAD modeling procedures. The findings suggest some differences between the students' demographics and their adaptive expertise characteristics and positive effect of the contextual exercise on students' CAD modeling procedures.

Keywords: CAD, adaptive expertise, contextual exercise, NX, attributes.

1. INTRODUCTION

Today's engineering education must graduate engineers who are prepared with the skills of using appropriate modern Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Computer-Aided Engineering (CAE) tools. A student who is not knowledgeable in using CAD/CAM/CAE tools will be placed in a distinct disadvantage after graduation in this highly competitive environment [12]. Today the CAD industries are evolving dramatically: wide varieties of CAD tools are available and they are updated frequently. The fast changing pace of these CAD tools has demanded engineering curricula to educate students to allow their CAD skills to be transferable to other CAD platforms and new versions. To achieve this goal, it is essential to transform adaptive expertise in the CAD education.

Unfortunately most current CAD instructions are focused on teaching declarative knowledge – the key strokes and button picks required to perform certain tasks in specific software platforms [5]. Very limited attention has been devoted to teach students to be more adaptive in using CAD tools. According to a survey conducted by Ye et al. [22] on how industries evaluate the current CAD education in colleges and universities, 74 percent of the participants from the industries indicated that current CAD education is inadequate. The CAD expertise students develop at the undergraduate level should be adaptive in nature and be extendable to engineering design in general. Wineburg 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" [21].

To address the deficit of the CAD education, the authors have implemented a funded project on two campuses. The primary goal of the project is to use and evaluate contextualized and student-centered activities to help improve students' adaptive expertise in CAD. This paper presents the initial work of implementing an adaptive expertise survey and contextual modeling exercise in a freshman CAD class on one campus. This work examines the role of adaptive expertise in CAD modeling and investigates the role of learner-centered contextual exercises on CAD modeling procedures.

The rest of the paper is organized as follows. In Section 2, background and related works are reviewed. Section 3 presents details on methodology.

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Analyses and results are discussed in Section 4. Discussion and limitations are presented in Section 5. Conclusions and future works are described in Section 6.

2. BACKGROUND

Expertise is defined as the ability to complete the domain specific tasks effectively and quickly [3]. Hatano and Inagaki characterized two kinds of expertise: routine and adaptive [7]. Adaptive experts are able to innovate and be efficient in their domain, while routine experts are only efficient in their domain. Schwartz et al. [19] defined the trajectory of adaptive expertise as a balance between efficiency and innovation. They proposed that innovation and efficiency should be developed together and learning experiences should promote these two dimensions to grow and develop simultaneously. Adaptive experts possess the subject specific knowledge and technical proficiency similar to that of routine experts. In contrast to routine experts, adaptive experts inquire for new learning in their domain expertise, successfully monitor their understanding and thinking, and conceive of knowledge as dynamic rather than static [19]. In other words, adaptive experts tend to be more open to inquire, use their metacognitive and self-regulation skills, and hold more advanced personal epistemologies. These characteristics make the adaptive experts flexible, innovative, and creative particularly in novel situations [8].

Feltovich et al. [3] provided an apt definition of expertise as it relates to CAD: "amassing considerable skills, knowledge, and mechanisms that monitor and control cognitive processes to perform a delimited set of tasks efficiently and effectively". Research work has been performed to assess the adaptive expertise characteristics in the context of students' regular academic coursework [15,20]. Martin et al. [14] implemented a summer program to improve teachers' adaptive expertise. They defined the adaptive expertise as comprising two dimensions: innovation and efficiency. Fisher and Peterson distilled four main constructs of adaptive expertise: multiple perspective, metacognition, goals and beliefs, and epistemology [4]. Multiple perspective refers to "the willingness to use a variety of representations and approaches when working within the domain". Metacognition is defined as "the learners' use of various techniques to self-assess and monitor his/her personal understanding and performance". Goals and beliefs relate to the views that students have concerning their learning goals and the nature of expertise. Epistemology is defined as one's beliefs on and attitudes towards the nature of the knowledge.

Few studies have been found in the literatures which examined the expertise in CAD modeling procedures. Lang et al. [13] conducted an experiment to determining the procedural knowledge of CAD users with different skill levels. Two experts and two novices were videotaped while performing the CAD modeling. The time usage and modeling procedures were evaluated from the videos. The results showed that the design expert had an efficient modeling procedural even though he was not familiar with the CAD system. It was concluded that the procedural knowledge of CAD expertise is transferable to other CAD programs. Hartman [6] used the "think aloud" method to capture the modeling procedure of five CAD experts in the creation of a specific CAD model. One common modeling procedure was then generated from five specific modeling procedures for the given object. Rynne and Gaughran [18] examined the modeling strategies of four student (relatively novice) CAD users by observing their modeling processes. They noted that the cognitive part of modeling determines the quality of modeling strategies. Also a list of attributes associated with the CAD expertise was proposed, but no empirical evidence was provided for these attributes. Chester [1] employed the intervention to the students including teaching them the strategies for the development of metacognitive processes and mental imagery. The research found that the students who completed the intervention adopted more expert strategies than the students who completed the regular instruction. Paliokas [16] used video tutorials and analyzed students' screen-recordings in order to monitor and improve the students' metacognition in CAD education. The video tutorials were found very helpful in relation to the functional knowledge. When a student saw his/her video-recording of CAD modeling, he/she became aware of the metacognitive strategies employed through the instructor's guidance. Very little empirical work has been done to examine the role of adaptive expertise on CAD modeling in the previous works.

3. METHODS

The adaptive expertise survey and contextual modeling exercise were carried out in a freshman CAD course in Mechanical Engineering. The course is a 3-hour laboratory session where the students learn engineering graphics and 3D modeling based on a CAD platform NX.

3.1. Adaptive Expertise Survey (AES)

An Adaptive Expertise Survey (AES) developed by Fisher and Peterson [4] and a demographic questionnaire were administered to all students in the class early in the semester. The research team designed the demographic questionnaire. The original AES included 42 items on a 6-point Likert-scale [4]. The survey includes four main constructs of adaptive expertise: metacognition, goals and beliefs, epistemology, and multiple perspectives. The survey is to assess

Demographic Questionnaire	
1	Name – Last Name (write in)
2	Gender (check)
3	Age (write in)
4	Rank/ level in college (check)
5	Major (write in)
6	Are you the first generation college student in your family?
7	Have you had a professional work experience related to engineering (e.g., internship, co-op, etc.)?
8	Have you had any technical employment and research experience related to engineering (e.g., machines shops, labs, project tasks, etc.)
Multiple Perspectives Sub-dimension Items in the modified AES	
5.	Usually there is one correct method in which to represent a problem.
13.	I tend to focus on a particular model in which to solve a problem.
34.	I solve all related problems in the same manner.
36.	When I solve a new problem, I always try to use the same approach.
39.	There is one best way to approach a problem.
Metacognition Sub-dimension Items in the modified AES	
2.	As I learn, I question my understanding of the new information.
6.	I often try to monitor my understanding of the problem.
10.	As a student, I cannot evaluate my own understanding of new material.
14.	I rarely monitor my own understanding while learning something new.
26.	I monitor my performance on a task.
30.	As I work, I ask myself how I am doing and seek out appropriate feedback.
Goals and Beliefs Sub-dimension Items in the modified AES	
3.	I feel uncomfortable when I cannot solve difficult problems.
7.	I am afraid to try tasks that I do not think I will do well.
23.	To become an expert in engineering, you must have an innate talent for engineering.
27.	Experts in engineering are born with a natural talent for their field.
38.	When I struggle, I wonder if I have the intelligence to succeed in engineering.
41.	I feel uncomfortable when unsure if I am doing a problem the right way.
Epistemology Sub-dimension Items in the modified AES	
12.	Scientists are always revising their view of the world around them.
33.	Scientific knowledge is developed by a community of researchers.

Tab. 1: The demographic questionnaire and the 19 AES items used in the analyses.

the students' beliefs and cognition in relation to the constructs of adaptive expertise. In the previous work, the authors discussed the reliability and validity of the AES [10,11]. Confirmatory factor analysis was performed to examine if the items grouped under each sub-dimension with the data collected matched with the items grouped in Fisher and Peterson's work [4]. The results showed that there are 19 matching items as listed in Tab. 1. Those 19 items were used in computing the students' AE characteristics in four dimensions and the total adaptive expertise score.

3.2. Contextual Exercise

In the week after the survey, the students in class were divided into two groups: experimental group and control group. The students were selected based on their performance in the class so that the two groups had similar CAD skill level distribution. The experimental group completed a learner-centered and contextual exercise. The students in the experimental group were asked to bring a real-life object of their choice to the classroom. Students measured the dimensions of the object and modeled it in NX during the class. The students in the control group were asked to create a model in NX based on a drawing provided to them. This is similar to a regular exercise that they usually do. Students in both groups were given an hour to complete the CAD modeling. The objects brought by the students in the experimental group included an iPad case, a keyboard, a cell phone, a comb, and an usb drive. In Fig. 1. the pictures of two objects and their models designed by the students in the experimental group are shown.

The students in both groups were interviewed before and after their modeling exercises. The designated members of the research team conducted the interviews. The course instructor did not interview the students, which was a requirement in our Institutional Review Board (IRB) approval. Each interview lasted around 6–10 minutes. The conversations were recorded on a digital voice recorder. In the interviews, the students were asked a set of questions about their proposed and actual strategies and modeling procedures. The list of questions used in the interviews is presented in Tab. 2.

The interviews were transcribed verbatim. The transcriptions were analyzed using the constant comparative method [2]. The incidents students described

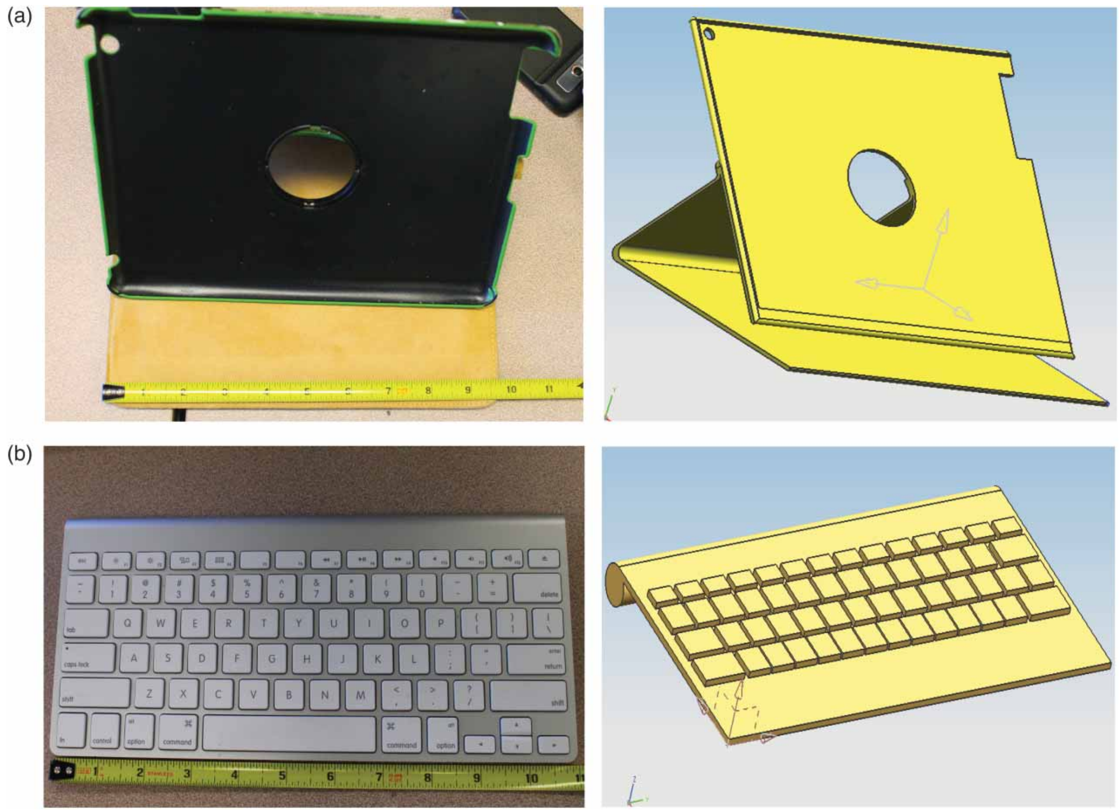

Fig. 1: Examples of student work in the experimental group: (a) iPad case; (b) keyboard.

Pre-interview Questions

1. What are the things you consider first when you are asked to model an object? Why?
2. What are the challenges you often encounter in the modeling process?
   a. How do you plan to overcome these challenges?
   b. Which strategies do you anticipate using?
3. Are you familiar with the object you are going to model today?
4. How important it is to know about the object you are going to model?
   - 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? Why, why not?

Post-interview Questions

1. The things you considered before you began modeling the object, were they helpful to you in the process? How and why?
2. What challenges did you encounter during the modeling process?
3. How did you overcome the challenges you faced during the modeling process?
4. Was knowing the object or being familiar with it, helpful to you in your modeling process? How and why?
5. How confident are you in your model?

Tab. 2: The list of questions used in the interviews.

were coded and categorized. The codes illustrated the AE characteristics of the students as proposed by Fisher and Peterson [4], i.e., metacognition, multiple perspectives, epistemology, and goals and beliefs. It were counted and recorded how many times a student conveyed one or more of the four dimensions. The number of these codes was used in the analyses.

The following examples explain how the transcripts were coded. For example, one student described that "Since this is my first semester learning about the program, I may not know about all the tools, how to use the tools as properly as I should". This sentence was associated with the "metacognition" dimension because metacognition refers to the learners' use of different techniques to self-assess the

Attribute	Description	Measure
Correct Initial Sketch Plane	Denotes whether the sketch for main block feature is placed on the proper datum in the model	Binary: 1 – yes; 0 – no.
Correct Model Origin	Center of main block feature located at global origin	Binary: 1 – yes; 0 – no.
Correct Base Feature	Main block as first (non-datum) feature	Binary: 1 – yes; 0 – no.
Correct Part Orientation	Proper orientation of part in the model	Binary: 1 – yes; 0 – no.
Correct Feature Sequence	Should begin with main feature and end with ancillary features (e.g. chamfers and rounds)	Binary: 1 – yes; 0 – no.
Number of Features	The total number of features. Sketches are not counted as additional features; pattern features include the pattern, the original feature, any additional required geometry; mirrors are counted as a single feature; all datum features (outside default planes and coordinate system) are included	Whole number
Use of Reference Geometry	All datum features (outside default planes and coordinate system)	Whole number
Simple Sketch and Feature Geometry	Average number of sketch segments per extrusion or revolve; rounds and chamfers per feature	Real Number
Incorrect Feature Terminations	Number of features that do not have correct feature terminations (e.g., through holes not defined as such)	Whole number
Number of Pattern Features	All pattern features	Whole number
Number of Mirror Features	Includes both solid and sketched mirror features	Whole number

Tab. 3: Descriptions of assessed model attributes.

personal understanding. Individuals with high levels of metacognition are able to recognize areas where their knowledge may be incomplete or insufficient [4]. Another student stated that "I look for answers, I might ask my teacher." This sentence was associated with the "epistemology" dimension. Students, who had the epistemology attribute, realize that others with different backgrounds can provide useful intuitions and guidance for their work [4]. One other student said "usually at least there is no one right way to do it." This response was coded with the "multiple perspectives" dimension, which illustrated the student's willingness to use a variety of representations. Students conveying the multiple dimension attribute recognize that there may be more than one way to solve a problem [4,20]. A student told that he usually wrote down the process he follows and tried to organize the steps using bullet points or numbers. This response was coded with the "goals and believes" dimension because self-regulation strategies help detecting goals to create ideas or improve an existing idea [15].

All students' NX models were analyzed in order to examine the modeling procedures and the characteristics of the final design. The attributes are based on the authors' previous work [9,17] as listed and described in Tab. 3. The adaptive expertise survey responses and the pre/post-interview data were analyzed. The attributes of the models were compared for the control group and experimental group. The statistical relationships among the variables were explored. The detailed results are presented in the next section.

4. RESULTS

Among the eight students participated in the control group, seven students completed the models in the designated time. Six of the nine participating students in the experimental group completed their models. Among the thirteen students who completed their models, ten students participated in the adaptive expertise survey. Due to the unequal sample sizes, both parametric and non-parametric tests were run to explore the relations between the participating students' demographic characteristics (i.e., sex, rank, age, 1^{st} generation, work experience), their Adaptive Expertise Survey responses (multiple perspective, metacognition, goals and beliefs, and epistemology sub-dimensions and total AES), their coded responses in the pre and post interviews regarding the AE characteristics, and CAD model attributes. It is important to note that the number of students participated in this preliminary study is less than ideal.

Sex	Average		t-test		Wilcoxon test	
	Female N = 2 (SD)	Male N = 8 (SD)	t (DF = 8)	Significance	Z	Significance
Multiple Perspectives	3.90 (1.273)	3.32 (0.3219)	−1.346	0.215	0.270	0.787
Metacognition	**5.25 (0.118)**	**3.86 (0.462)**	**−4.052**	**0.003***	**1.970**	**0.048***
Goals and Beliefs	3.67 (0.236)	3.06 (0.734)	−1.104	0.301	0.919	0.359
Epistemology	5.25 (1.061)	3.94 (0.821)	−1.942	0.088	1.472	0.141
AE Total	**4.76 (0.135)**	**3.62 (0.182)**	**−8.136**	**<0.001***	**1.970**	**0.048***

*Difference is statistically significant when the p value less than 0.05 is considered.

Tab. 4: AES data comparison between the male students and the female students.

Rank	Average			F-test	
	Freshman N = 4 (SD)	Sophomore N = 3 (SD)	Junior N = 3 (SD)	F- test (2, 7)	Significance
Multiple Perspectives	3.65 (0.854)	3.40 (0.200)	3.20 (0.346)	0.493	0.630
Metacognition	4.67 (0.828)	3.89 (0.481)	3.68 (0.275)	2.523	0.149
Goals and Beliefs	**3.58 (0.319)**	**3.44 (0.585)**	**2.39 (0.585)**	**5.718**	**0.034***
Epistemology	4.87 (0.854)	3.83 (0.764)	3.66 (1.04)	1.952	0.212
AE Total	4.26 (0.615)	3.65 (0.112)	3.50 (0.086)	3.438	0.0912

*Difference is statistically significant when the p value less than 0.05 is considered.

Tab. 5: AES data comparison among freshman, sophomore, and junior students.

The AES responses of the male students and female students were compared as shown in Tab. 4. The parametric independent-samples t-test results indicated that there is a significant difference between the male students' (N =8, M =3.62, SD = .182) and the female students' (N = 2, M = 4.76, SD = .135) overall adaptive expertise scores ($t(8) = -8.136$, $p < 0.001$). In this study, the difference is considered statistically significant when the p value is less than 0.05. Female students' responses conveyed more adaptive expertise characteristics than the male students. The non-parametric test using the Wilcoxon method revealed the same conclusion ($Z = 1.97$, $p = 0.048$). When comparing the male and female students' responses to the four sub-dimensions of the adaptive expertise survey, only in the metacognition sub-dimension students' responses revealed significant differences ($N_m = 8$, $M_m = 3.86$, $SD_m = .46$, $N_f = 2$, $M_f = 5.25$, $SD_f = .12$) for both in parametric t-test ($t(8) = -4.05$, $p = 0.003$*) and non-parametric Wilcoxon test ($Z = 1.97$, $p = 0.048$*). For the multiple perspective, goals and beliefs, and epistemology dimensions, no significant difference is observed between the male and female students' responses.

When students' age, rank, and first-generation statuses were compared to their overall adaptive expertise survey responses, no significant difference is observed ($p > 0.05$). Similarly, for the multiple perspective, metacognition, and epistemology sub-dimensions, the students' age, rank, and first-generation statuses did not show significant differences ($p > 0.05$). Only in the goals and belief sub-dimension, parametric F-test ($F(2, 7) = 5.72$, $p = 0.034$) indicated a significant difference among the students' ranks as shown in Tab. 5.

Because there were three groups compared in Tab. 5, post-hoc tests were run to identify the significant differences between the each two pairs. For the "goals and beliefs" dimension in the AES, the post-hoc Tukey-Kramer HSD test indicated that freshman students' responses ($N = 4$, $M = 3.58$, $SD = 0.319$) were significantly different from junior students' responses ($N = 3$, $M = 2.39$, $SD = 0.585$) at $p < .05$. Non-parametric comparisons for each pair using Wilcoxon method revealed the same result between the freshman and junior students ($Z = -1.961$, $p = 0.0497$). This indicates that freshman students have more adaptive expertise oriented goals and beliefs than the junior students. The comparison of freshman and sophomore students and sophomore and junior students were not significantly different from one another.

In the pre-interviews with the students, the opposite pattern was observed in the overall adaptive expertise characteristics. For the total adaptive expertise characteristic conveyed in the pre-interview, the post-hoc Tukey-Kramer HSD test indicated that junior students' responses ($N = 3$, $M = 5.67$, $SD =$

First-generation?	Average: Yes N = 4 (SD)	Average: No N = 6 (SD)	t-test: t (DF = 8)	t-test: Significance	Wilcoxon test: Z	Wilcoxon test: Significance
Pre-Interview –Multiple Perspectives	**0.25 (0.050)**	**2.16 (1.329)**	**2.712**	**0.026***	**–2.236**	**0.025***
Pre-Interview - Metacognition	0.500 (0.577)	1.66 (1.211)	1.770	0.114	–1.808	0.070
Pre-Interview - Goals and Beliefs	0	0	–	–	–	–
Pre-Interview - Epistemology	0.25 (0.255)	0.33 (0.208)	0.253	0.806	–0.133	0.893
Pre-Interview - Total AE	**1.00 (1.154)**	**4.166 (2.041)**	**2.784**	**0.023***	**–2.103**	**0.035***
Post-Interview - Multiple Perspectives	0	0.33 (0.167)	1.264	0.241	–1.071	0.283
Post-Interview - Metacognition	0	0.50 (0.547)	1.788	0.111	–1.469	0.141
Post-Interview - Goals and Beliefs	0	0	–	–	–	–
Post-Interview - Epistemology	0	0.16 (0.408)	0.800	0.446	–0.612	0.540
Post-Interview - Total AE	0	1.00 (0.894)	2.190	0.059	–1.815	0.069
Pre and Post interview - Total AE	**1.0 (0.680)**	**5.16 (0.555)**	**4.740**	**0.001***	**–2.474**	**0.013***

*Difference is statistically significant when the p value less than 0.05 is considered

Tab. 6: Coded pre and post-interview data between first-generation and non-first-generation students.

1.527) significantly differed from both freshman students' responses ($N = 4$, $M = 2.00$, $SD = 1.527$, $p = 0.033^*$) and sophomore students ($N = 3$, $M = 1.33$, $SD = 1.154$, $p = 0.021^*$) at $p < 0.05$. However, in non-parametric comparisons for each pairs using Wilcoxon methods revealed no statistical differences for the juniors and freshmen ($Z_{j-f} = 1.800$, $p = 0.071$) and juniors and sophomores ($Z_{s-j} = 1.77$, $p = 0.076$).

Significant differences were observed when comparing the first-generation students' interview responses with non-first-generation students' interview responses as shown in Tab. 6. Students who were first-generation ($N = 4$, $M = 0.25$, $SD = 0.50$) conveyed fewer multiple perspective oriented statements than the students who were not first-generation college students ($N = 6$, $M = 2.16$, $SD = 1.32$) as revealed by the parametric t-test ($t(8) = 2.71$, $p = .026^*$) and non-parametric test ($Z = -2.23$, $p = .025^*$) results. Similarly, first-generation students' overall adaptive expertise embedded responses ($N = 4$, $M = 1.0$, $SD = 1.15$) were significantly less than non-first-generation students' ($N = 6$, $M = 4.16$, $SD = 2.04$) in the pre-interview ($t(8) = 2.78$, $p = .023^*$, $Z = -2.1$, $p = .035^*$). For the overall pre and post interview conversations recorded, first generation students ($N = 4$, $M = 1.0$, $SD = 0.68$) used significantly fewer adaptive expertise embedded incidents than the non-first generation students ($N = 6$, $M = 5.16$, $SD = 0.55$) as revealed by parametric t-test ($t(8) = 4.74$, $p = .001^*$) and non-parametric Wilcoxon test ($Z = -2.47$, $p = .013^*$).

When the AES responses were compared between the control group and the experimental group, no statistically difference were found. It suggests that the students' adaptive expertise characteristics were not different among the groups assigned in the class. The attributes of the NX models created by the control group and experimental group were then evaluated. The data were analyzed to examine any statistically significant difference between two groups as shown in Tab. 7. None of the students in both groups used the right origin. The experimental group used more "correct feature sequence" than the control group. The experiment group had less "incorrect feature terminations" in their model than the control group. Also noticeable differences ($p < 0.1$) were observed that the experimental group used more "correct base feature", more "correct orientation", more "reference geometries", and more "patterns" than the control group.

Using the data from all the participants ($N = 10$), the correlations were calculated to examine how the CAD modeling attributes correlate with the students' adaptive expertise survey responses and the coded adaptive expertise characteristics in the pre and post interviews. Only those correlations that were statistically significant at $p < 0.05$ level are reported in Tab. 8. "Number of features" that students used within CAD exercises was positively correlated with the "multiple perspectives" dimension of AES scores, while "number of features" were

Group	Control	Experimental	t-test	P value
Total students participating (N)	8	9	–	–
Students Completing Exercise (N)	7	6	–	–
Sketch Plane	0.71	0.83	0.47	0.323
Origin	0	0	–	–
Base Feature	0.71	1	1.43	0.091
Orientation	0.71	1	1.43	0.091
Number of Features	10.29	10.5	0.11	0.456
Reference Geometry	0	0.5	1.59	0.070
Segments/Feature	3.97	5.08	0.75	0.234
Correct Feature Sequence	**0.14**	**0.67**	**2.11**	**0.029***
Incorrect Feature Terminations	**3**	**0.33**	**−3.04**	**0.006***
Number of Mirrors	0	0	–	–
Number of Patterns	0	0.83	1.39	0.096

*Difference is statistically significant when the p value less than 0.05 is considered

Tab. 7: Statistical t-test between control group and experimental group model attributes.

Variable 1	Variable 2	Correlation (r)	Sig (2-tailed)
Number of features	AES - Multiple Perspectives	0.686	< 0.05
Number of features	Post-interview - Metacognition	−0.840	< 0.01
Reference geometry	AES - Epistemology	0.647	< 0.05
Reference geometry	Total AES scores	0.691	< 0.05
Correct feature sequence	Pre-interview - Epistemology	−0.775	< 0.05
Segments/feature	Post-interview - Epistemology	0.709	< 0.05
Number of patterns	Post-interview - Epistemology	0.100	< 0.01
Orientation	Sketch-plane	0.764	< 0.05
Correct feature sequence	Incorrect feature termination	−0.802	< 0.01
Number of patterns	Segment features	0.714	< 0.05

Tab. 8: Correlations among attributes of the models, AES, and interviews.

Variable 1	Variable 2	Correlation (r)	Sig (2-tailed)
Sketch-plane	Pre-interview - Multiple Perspectives	0.962	0.038
Orientation	Pre-interview - Multiple Perspectives	0.962	0.038

Tab. 9: Correlations among attributes of the models, AES, and interviews for the control group.

negatively correlated with the "metacognition" dimension conveyed during the post-interview. "Reference geometry" attribute was correlated with both "epistemology" dimension of AES and "total AES scores". "Correct feature sequence" attribute was negatively correlated with the "epistemology" dimension conveyed during the pre-interview. This is not expected. "Segments/feature" attribute was positively correlated with the "epistemology" dimension conveyed during the post-interview. "Number of patterns" used during the CAD exercises was also positively correlated with the "epistemology" dimension conveyed during the post-interview. As expected, use of "orientation" and "sketch-plane" attributes were positively correlated. "Correct feature sequence" and "incorrect feature termination" attributes were negatively correlated. "Number of patterns" and "segments/feature" were positively correlated. These findings are in consensus with the previous work [9,17].

Similar correlation analyses were run for the control group ($N = 6$) and contextual group ($N = 4$) separately, as shown in Tab. 9. and Tab. 10. This is to examine if the adaptive expertise characteristics have different effects on the modeling process of the students in two different groups. It should be noted that these analyses may not allow the authors to draw robust conclusions because of the very small sample size. The analyses were still run as the reference for future data collections. For the control group, the "correct sketch plane" and "correct orientation" were both positively correlated with the "multiple perspectives" dimension conveyed during the pre-interview. For the experimental group, "reference geometry" attribute was positively correlated with "total AES

Variable 1	Variable 2	Correlation (r)	Sig (2-tailed)
Reference geometry	Interview - Total AE	0.968	0.032
Number of features	Interview - Total AE	–0.968	0.032
Number of features	Post-interview - Multiple Perspectives	–0.968	0.032
Number of features	Post-interview - Epistemology	–0.968	0.032
Segment/features	Post-interview –Metacognition	0.954	0.046

Tab. 10: Correlations among attributes of the models, AES, and interviews for the experimental group.

scores" conveyed in Pre- and Post-interviews. "Number of features" attribute was negatively correlated with the "Multiple Perspectives" and "Epistemology" dimensions conveyed during the pre-interview and "Total AE". "Segments/feature" attribute was positively correlated with the "Metacognition" dimension conveyed during the post-interview. Those correlations were in consistency because using more complex features (meaning higher "segments/feature") will result in less number of features.

5. DISCUSSION

The students' responses to the AES and interviews were analyzed to explore if the students in different demographic groups (i.e., sex, rank, age, 1st generation college students, with/without work experience) possess different adaptive expertise characteristics. The results suggest that female students conveyed more AE characteristics than male students. When the freshman students were compared to junior students, the AES showed that freshman students have more adaptive expertise oriented goals and beliefs than the junior students. However, junior students conveyed more adaptive expertise responses than freshman students in the pre-interview. As expected, when the students were more mature and experienced, their adaptive expertise characteristics were enhanced. In another comparison, non-first-generation college students reported significantly more adaptive expertise characteristics than the first-generation college students. This suggests that the parents' education levels may correlate with the development of their children's adaptive expertise.

In the contextual modeling exercise, the NX model attributes of the control group and the experimental group were compared to examine if students use different modeling procedures. The analyses showed that the students completing the contextual exercise used more correct modeling processes and attributes than students completing the regular exercise. The experimental group showed better performance choosing the correct feature sequence, used less incorrect feature terminations, and used more correct base feature, more correct orientation, more reference geometries, and more patterns than the control group. Examining the AES responses and the interview data of the two groups revealed that the adaptive expertise characteristics of the students in two groups were not different from each others. The adaptive expertise can be excluded from the factors causing the differences. It suggests that the contextual exercise has a positive effect on improving students' CAD modeling procedures.

The correlations were examined between the model attributes and AE responses from survey and interviews. The correlations showed that students with higher adaptive expertise (mainly epistemology sub-dimension) used more reference geometries, more complex features (i.e., feature with more segments), and more pattern features (i.e., instance features in NX). Those features are considered as better modeling strategies to convey design intent as discussed in previous work [9,17]. These findings show that adaptive expertise especially epistemology sub-dimension is associated with positive effects in CAD modeling. When the correlations were examined individually for the control group and experimental group, the experimental group revealed more significant correlations than the control group. This is an indicator that the contextual exercise is a good way to enhance students' adaptive expertise on CAD modeling.

It should be noted that any findings or conclusions from this study are constrained by the small sample size of the student participants. Another limitation of this work is that the evaluation of the modeling process was limited on analyzing only the model attributes data. The time used on the modeling and how each student spent time on modeling were not captured. These limitations will be addressed in the future work.

6. CONCLUSIONS AND FUTURE WORK

This paper presents the initial work of implementing an adaptive expertise survey and contextual modeling exercise in a freshman CAD class. The intension of the present work is to help improve students' adaptive expertise in CAD. It examines the role of adaptive expertise in CAD modeling and investigates the role of learner-centered contextual exercises on CAD modeling procedures. The adaptive expertise instrument and interviews were implemented to assess students' adaptive expertise characteristics in four sub-dimensions, such as, multiple perspectives, metacogition, goals and beliefs, and epistemology. Significant differences were found between different demographic groups, namely female and male students, freshman and junior, first-generation and non-first-generation students.

The students in class were purposefully assigned to experimental group and control group according to their course performance. The students in the experimental group were asked to model a real-life object chosen by students. The students in the control group were asked to create a model NX based on a drawing provided to them. The analyses show that the students doing contextual exercise used more correct modeling processes and attributes than students doing regular exercise. The results suggest that the contextual exercise has a positive effect on improving students' CAD modeling procedures. Correlations between the modeling attributes and AE responses were evaluated. The results suggest that adaptive expertise has positive effects in CAD modeling.

Future work will be focused on involving expert CAD users and more students in the study. The research team will work with practicing engineers working in the industries to examine their characteristics of adaptive expertise related to CAD. The study will determine the preferred modeling procedures extracted from the adaptive experts. A series of learner-centered and contextual exercises will be implemented in the two campuses to further explore the adoption of preferred modeling procedures in the context of adaptive expertise in CAD. The ultimate goal is to help students develop more adaptive expertise characteristics. .

ACKNOWLEDGEMENTS

The work is supported by the National Science Foundation under EEC Grant Numbers 1129403 and 1129411. Any opinions, findings, conclusions, or recommendations presented are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors also thank the PACE program (Partners for the Advancement of Collaborative Engineering Education) for providing NX software.

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