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Integration of contextual exercises in computer-aided design education

Ke Liu[1], Xiaobo Peng[1], Prentiss McGary[1], Bugrahan Yalvac[2], Elif Ozturk[2], Michael D. Johnson[2] and Lauralee Valverde[2]

[1]Prairie View A&M University; [2]Texas A&M University

ABSTRACT

The authors have implemented a series of contextual CAD modeling exercises in a freshman CAD class to transform adaptive expertise in the CAD education. The students were interviewed before and after the exercises to capture their manifestation of adaptive expertise. At the end of semester, a CAD modeling test was given to the students. The CAD modeling procedures were evaluated based on the model attributes and students' screen-recordings. The data analyses examine the role of learner-centered contextual exercise in CAD modeling process, and the correlations between the adaptive expertise in CAD modeling procedure. The findings show that the contextual exercises have positive effects on improving students' adaptive expertise and CAD skills.

KEYWORDS

CAD; adaptive expertise; education method

1. Introduction

The Computer-Aided Design (CAD) education is facing more challenges now because of the fast evolution of CAD industries. There are wide varieties of CAD tools available, which are updated frequently. Upon graduation, engineering students will often need to use different CAD software from the one they were trained with in college. It becomes essential that students are trained with the skill of transferring CAD skills among diverse CAD platforms. Such a skill is called adaptive expertise.

Generally, expertise can be divided into two categories as routine and adaptive [7]. The distinction between routine expertise and adaptive expertise is that adaptive experts are innovative and efficient, while routine experts are only efficient in their own domain of expertise [17]. These adaptive experts are more flexible, innovative, and creative in novel situations as they prefer to inquiry, use their metacognitive and self-regulation skills, and hold more advanced personal epistemologies [8].

Adaptive expertise was defined by Wineburg as the ability to apply, adapt, and otherwise stretch knowledge so that it addresses new situations - often situations in which key knowledge is lacking [18]. Four main dimensions of adaptive expertise: multiple perspectives, metacognition, goals and beliefs, and epistemology were proposed by Fisher and Peterson [5]. Multiple perspectives is defined as "the willingness to use a variety of representations and approaches when working within the domain". Metacognition refers to "the learner's use of various techniques to self-assess and monitor learner's personal understanding and performance". Goals and beliefs is defined as the views that students have concerning their learning goals and the nature of expertise. Epistemology relates to one's beliefs on and attitudes towards the nature of the knowledge.

The authors have been working on a funded project to apply contextual exercises to help improve students' adaptive expertise in CAD education. Contextual exercise was proved to have a positive effect on students' cognitive and affective domains [3]. Students get involved in activities with more efficiency when personal meaning included. In our previous work [11, 15], the single contextual exercise was implemented in the curriculum. In the work presented in this paper, four contextual exercises were implemented throughout the semester. This work examines the role of adaptive expertise in CAD modeling and investigates the role of learner-centered contextual exercises on CAD modeling procedures. It was also analyzed in this paper whether four contextual exercises have more impact on students' learning than single contextual exercise.

2. Related works

Few studies have been found in the literatures which examined the expertise in CAD modeling procedures. The task knowledge of the operator is divided into

CONTACT Xiaobo Peng xipeng@pvamu.edu

declarative type and procedural type for CAD by Lang et al. [10]. An experiment was conducted to understand how training and management of CAD operators could affect the task knowledge. The performance videos were recorded while two experts and two novices were performing the CAD task. The time usage and modeling procedures were evaluated from the videos. The results indicated that the design expert was able to transfer procedural knowledge from other systems to the tested one. It was concluded that the procedural knowledge of CAD expertise is transferable to other CAD platforms. Chester [4] employed a designed intervention to students. The intervention allows instructors to teach students the strategies for the development of metacognitive processes and mental imagery. It was found that the students who completed the intervention adopted more expert strategies than the students who received specific procedural command instruction. Rynne and Gaughran [16] examined the modeling strategies of novice CAD users through observing four students' modeling processes. It was noted that the quality of modeling strategies are determined by the cognitive part of modeling. A list of attributes associated with the CAD expertise was also proposed, but there was no empirical evidence for these attributes. A think-aloud modeling task was conducted by Hartman [6] to capture the modeling procedure of five practicing product designers in the creation of a specific CAD model. Then, five specific modeling procedures were distilled into one common modeling procedure for the given object. Mandorli et al. [12] introduced a new approach to facilitate the development of negative knowledge so that the student can avoid serious mistakes. It provided a framework for negative knowledge and domain knowledge related model evaluation concepts with the goal of improving learning behavior, skill acquisition, and competency building for CAD education. Paliokas [13] used video tutorials and analyzed students' screen-recordings in order to monitor and reinforce the students' metacognitive abilities in CAD education. It was found that the video tutorials were very helpful in relation to the functional knowledge. Video tutorials and video-recordings from students' screens can help improve students' metacognition. Among the works mentioned above, very little empirical work has been done to examine the role of adaptive expertise on CAD modeling.

3. Methods

In the Spring 2014 Semester, four contextual exercises as well as pre and post interviews were carried out in a freshman CAD course. In the previous four semesters, a single contextual exercise was implemented in the classes. The course is a 3-hour laboratory session where students learn engineering graphics and 3D modeling based on a CAD platform NX.

Table 1. The list of questions used in the interviews.

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?
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? Why, why not?
Post-interview Questions
1. The things you considered before you began 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 objects or being familiar with it, helpful to you in your modeling process? How and why?
5. How confident are you in your model?

3.1. Pre and post interviews

The participating students were individually interviewed before and after their contextual modeling exercise. The designated members of the research team conducted the interviews, in which the students were asked a set of questions about their proposed and actual strategies and modeling procedures. Each interview lasted 6–10 minutes. The conversations were recorded on a digital voice recorder. The list of questions used in the interviews is presented in Tab. 1.

The interviews were transcribed verbatim. The responses were coded and categorized into four dimensions of adaptive expertise defined by Fisher and Peterson [5]. This coding was based on adaptive expertise characteristics which could be found in Tab. 2. as well as their associated dimensions. It were counted how many times a student conveyed one or more of the four dimensions. The number of these codes was used in the analyses.

3.2. Contextual exercises

In the modeling exercises, students were assigned a modeling task. They were given an hour to complete the exercise. When students were creating NX models, the procedure videos were recorded by using the Camtasia screen capture program. At the end of the semester, a CAD modeling test was given to students to assess their CAD skills.

Contextual exercises were carried out in five semesters. In Spring 2012, Fall 2012, Spring 2013, and Fall 2013, students were divided into two groups: control group

Table 2. Codes extracted from the interviews and associated adaptive expertise dimensions.

Dimension	Characteristics	Codes from Interviews
Multiple Perspectives	Efficiency(consistency & accuracy)	most efficient way to model
		easiest way to model
	Innovation	N/A
	Act flexibly to novel situation	creating drawing of objects
Metacognition	Confidence	N/A
	Successfully monitor own understanding	have to pay close attention while modeling
		have a good starting point
		in hand 3D part helps
	Recognize that own knowledge may be incomplete	how to use the features
		complexity of the objects
		how to model
		forgot how to use some features
	Use different /multiple methods to solve problems	creating drawing of objects
		look object from different angles
		trying different methods
Goals & Beliefs	Seek our opportunities for new learning	try to learn better (if you had problems)
	Self-regulation strategies	have an approach
		have a way to organize model
		know what steps to take first
		have a good starting point
		have strategies to model
Epistemology	Pursue knowledge	practice
		reading more
	Others can provide information	ask someone for help

(also called stylized group) and experimental group (also called contextual group). Similar CAD skill levels distribution were guaranteed in both groups every semester. Both stylized exercise and single contextual exercise were implemented in four semesters. In the stylized exercise, students were provided with a NX model drawing contains all dimensions needed to build the model. The NX model drawing is shown in Fig. 1. This is a similar exercise which is regular used in classes. In the single contextual exercise, students were asked to model objects that they often use in their daily life. At the same time, they were given a ruler to measure dimensions of the objects during the modeling exercise. Objects chosen by students included a game controller, an USB driver, and a watch, etc. Fig. 2. shows two examples modeled by students in single contextual exercise. In the Spring 2014, students were asked to complete four contextual exercises as shown in Fig. 3. In each exercise, the students were also asked to model objects that they often use in their daily life. In the first three exercises, the objects have to be mainly consist of primitive features, remove features, and instance features respectively. In the final contextual exercise, the objects have to consist of all the features mentioned above.

3.3. *Model and procedure analysis*

The students' CAD modeling behaviors during the contextual exercises were examined by two ways. The first way was to analyze the model and feature characteristics as detailed in our previous work [9, 15]. The model attributes include the sketch plane (denotes whether the sketch for main block feature is placed on the proper datum in the model), origin (center of main block feature located at a global origin), base feature (main block as first feature), orientation (proper orientation of part in the model), correct feature sequence (should begin with main feature and end with ancillary features), number of mirrors, number of patterns, number of features, reference geometry, incorrect feature terminations, and average number of segment per feature (a bigger average number of segment per feature stands for a more complex feature). Detailed definitions of the attributes could be referred to the previous work [9, 15].

The second way of examining modeling procedure was to analyze the procedure videos. The recorded procedure videos were analyzed to compare whether students in control group and experimental group have different CAD modeling behaviors and to examine the relationship between modeling time division and both adaptive expertise and modeling attributes. The modeling time was divided into five main categories, i.e., doing, trial and error, thinking, searching, and regeneration. Doing time is defined as engaging in productive modeling activities (e.g. create a feature). Trial and error is defined as the process encompassing the making of a feature and its subsequent deletion. Thinking time is defined as the stillness of the cursor movement or circling the software window without purpose. Searching time is defined as cursor movement without productive modeling activities. Regeneration time is the time for the software to regenerate graphics or complete the model.

4. Results

Overall there are 71 students participating in this research in five semesters. 29 of them completed stylized exercise. 27 students were in single contextual exercise group. 15 students were in four contextual exercises group. In this paper, the difference is considered statistically significant when the p value is less than 0.10. Tab. 3. shows the exact number of students involved in each semester.

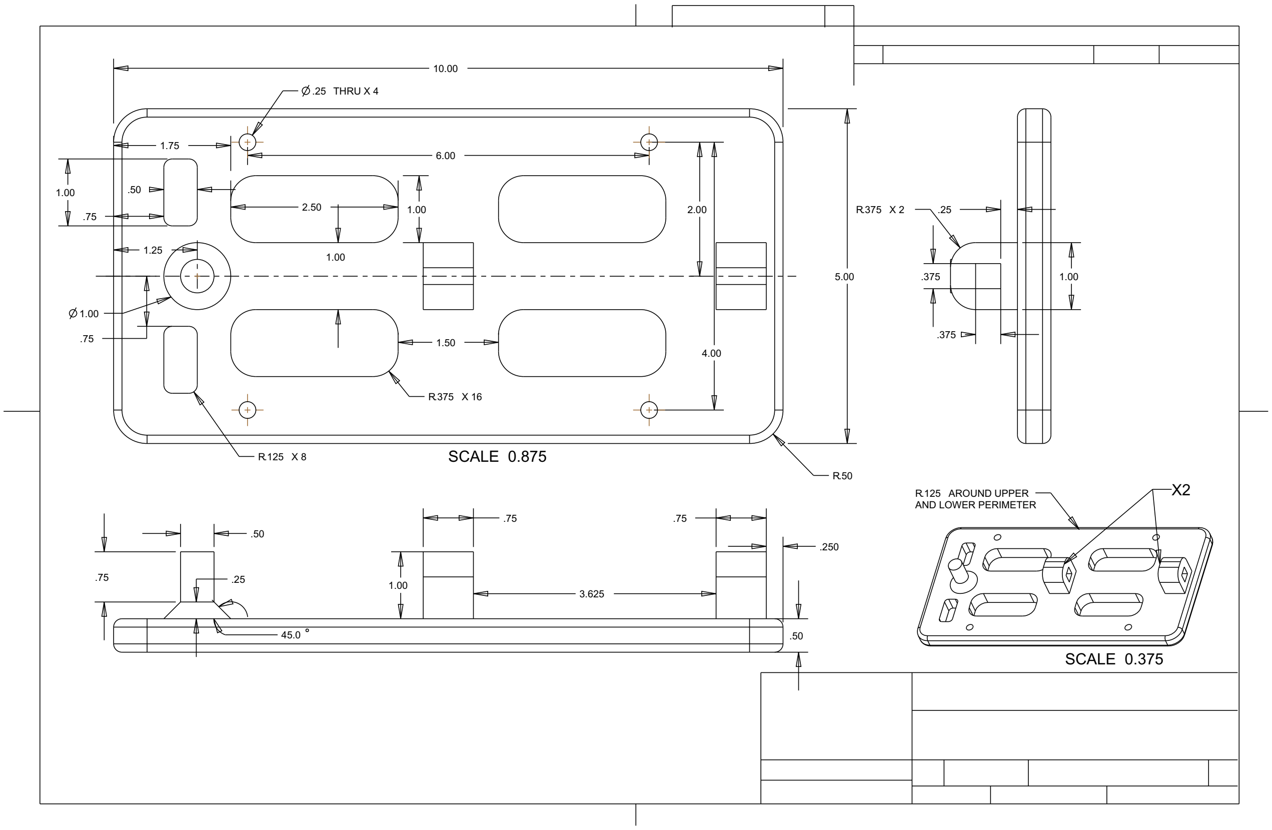

Figure 1. The NX model drawing provided in stylized exercise.

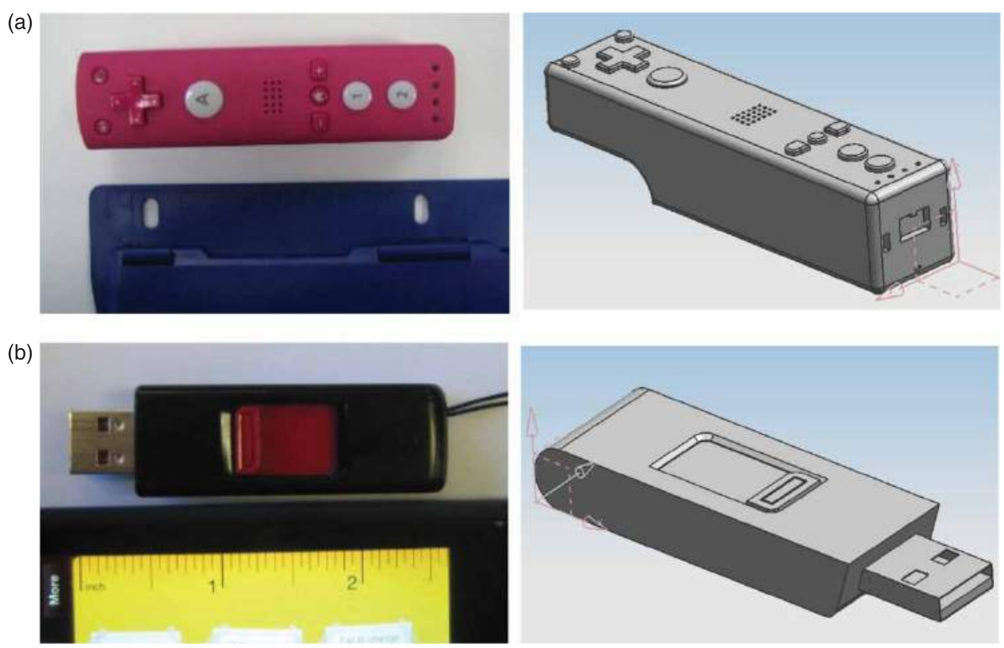

Figure 2. Examples in single contextual exercise: (a) a game controller; (b) an USB drive.

In the comparison of interview data, no significant difference was found between the stylized exercise group and single contextual exercise group. Tab. 4 shows the interview data comparison between the stylized exercise group and four contextual exercises group. Students completed four contextual exercises (N = 13, M = 0.15) have less metacognition conveyed in pre interviews than students completed stylized exercise (N = 28, M = 0.82) suggested by t-test (t = 2.891, p = 0.006*). In contrast, students completed four contextual exercises

Figure 3. Examples of students work in four contextual exercises: (a) primitive contextual exercise; (b) remove features contextual exercise; (c) instance contextual exercise; (d) final contextual exercise.

Table 3. The number of participants in each semester.

	Stylized Exercise	Single Contextual Exercise	Four Contextual Exercises
Spring 2012	7	6	–
Fall 2012	13	10	–
Spring 2013	3	6	–
Fall 2013	6	5	–
Spring 2014	–	–	15
Total	29	27	15

Table 4. Interview data comparison between stylized exercise and four contextual exercises.

	Stylized Exercise	Four Contextual Exercises	t	Sig (2-tailed)
Number of participants	28	13	–	–
Pre-Int-Metacognition	0.82	0.15	2.891	0.006*
Post-Int-Goals and Beliefs	0.32	0.77	−1.942	0.059*
Post-Int- Total AE	1.00	1.85	−1.914	0.063*

*Difference is statistically significant when the p value less than 0.10 is considered.

(N = 13, M = 0.77) have more goals and beliefs conveyed in post interviews than students completed stylized exercise (N = 28, M = 0.32) suggested by t-test (t = −1.942, p = 0.059*). Also, students completed four contextual exercises (N = 13, M = 1.85) have more total adaptive expertise conveyed in post interviews than students completed stylized exercise (N = 28, M = 1.00) suggested by t-test (t = −1.914, p = 0.063*).

The video data were compared between the stylized exercise group and the contextual exercise groups. Only one significant difference was found when comparing the video data between the stylized exercise group and the four contextual exercises group as shown in Fig. 4. Students who completed four contextual exercises (N = 15, M = 0.24) spent less time on thinking than students who completed stylized exercise (N = 22, M = 0.35) suggested by t-test (t = 2.914, p = 0.006*). As suggested in Fig. 4., in general students who completed single contextual exercise spent more time on doing and trial and error, less time on thinking than students completed stylized exercise. Students completed four contextual exercises spent more time on doing as well as trial and error than students completed stylized exercise.

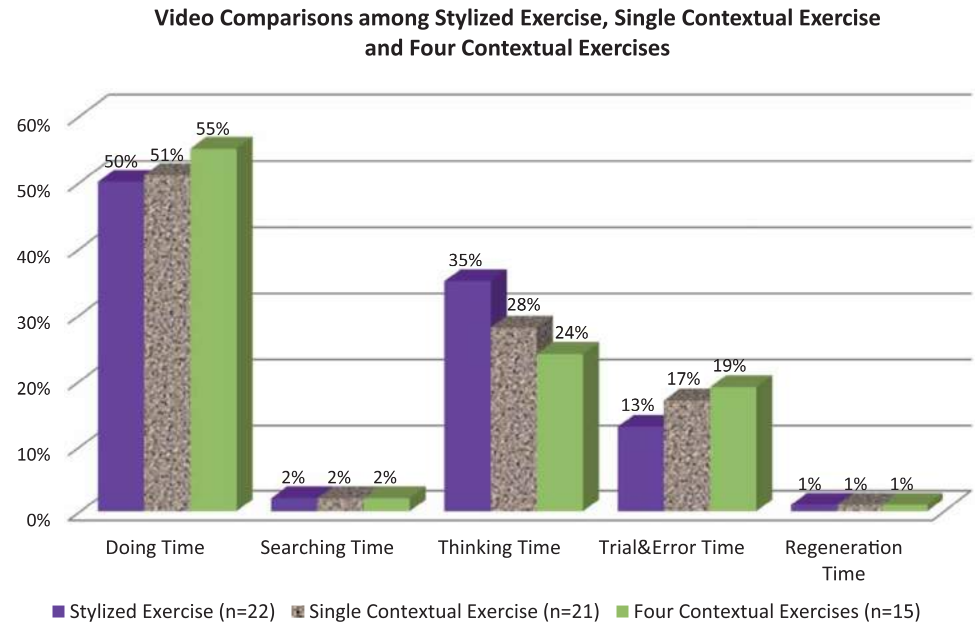

Figure 4. Video data comparisons.

Table 5. Model attributes data comparison between stylized exercise and single contextual exercise.

	Stylized Exercise	Single Contextual Exercise	t	Sig (2-tailed)
Number of students	29	27	–	–
Sketch Plane	0.90	0.89	0.091	0.928
Origin	**0.00**	**0.15**	**−2.126**	**0.043***
Base Feature	0.93	0.00	−1.440	0.161
Orientation	0.90	0.93	−0.379	0.706
Correct Feature Sequence	0.55	0.74	−1.484	0.144
Number of Features	**18.69**	**13.15**	**2.660**	**0.011***
Reference Geometry	0.59	0.52	0.199	0.843
Average Number of Segment	5.60	7.77	−1.157	0.252
Incorrect Feature Terminations	**4.24**	**0.30**	**4.456**	**0.000***
Number of Mirrors	0.66	0.26	1.078	0.288
Number of Patterns	**0.07**	**0.44**	**−1.871**	**0.071***

*Difference is statistically significant when the p value less than 0.10 is considered.

Table 6. Model attributes data comparison between stylized exercise and four contextual exercises.

	Stylized Exercise	Four Contextual Exercises	t	Sig (2-tailed)
Number of students	29	15	–	–
Sketch Plane	0.90	0.87	0.290	0.774
Origin	**0.00**	**0.20**	**−1.871**	**0.082***
Base Feature	0.93	1.00	−1.440	0.161
Orientation	0.90	0.73	1.242	0.228
Correct Feature Sequence	0.55	0.73	−1.203	0.238
Number of Features	18.69	14.47	1.557	0.127
Reference Geometry	0.59	0.13	1.503	0.142
Average Number of Segment	5.60	9.91	−1.252	0.229
Incorrect Feature Terminations	**4.24**	**1.07**	**2.689**	**0.010***
Number of Mirrors	0.66	0.33	0.643	0.523
Number of Patterns	0.07	1.27	−1.526	0.149

*Difference is statistically significant when the p value less than 0.10 is considered.

Model attributes were compared between stylized exercise and single contextual exercise as well as between stylized exercise and four contextual exercises. As shown in Tab. 5., students who completed single contextual exercise ($N = 27$, $M = 0.15$) are more likely to choose correct origin than students who completed stylized exercise ($N = 29$, $M = 0.00$) indicated by t-test ($t = -2.126$, $p = 0.043^*$). Students in single contextual group also used less number of features, less incorrect feature terminations and more number of patterns than students in stylized group. All these significant differences are expected. In the comparison between stylized exercise and four contextual exercises as shown in Tab. 6., students who completed four contextual exercises ($N = 15$, $M = 0.20$) are more likely to choose correct origin than students who completed stylized exercise ($N = 29$, $M = 0.00$) indicated by t-test ($t = -1.871$, $p = 0.082^*$). In addition, students completed four contextual exercises ($N = 15$, $M = 1.07$) are more likely to use less incorrect feature terminations than students completed stylized exercise ($N = 29$, $M = 4.24$) indicated by t-test ($t = 2.689$, $p = 0.010^*$).

The students' performance on the CAD modeling test were compared between control and experimental groups as shown in Fig. 5. Overall, students in experimental groups did better than students in control group. However, no significant difference was found.

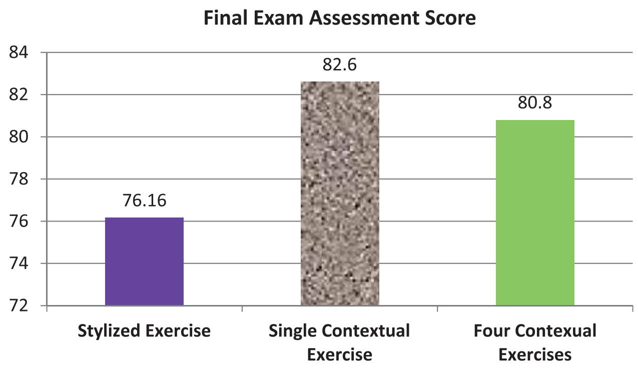

Figure 5. CAD modeling test results among stylized exercise, single contextual exercise, and four contextual exercises.

The correlations were calculated between the interviews and model attributes as shown in Tab. 7. The "metacognition" dimension conveyed in pre-interview was positively correlated with "reference geometry" attribute. The "goals and beliefs" dimension conveyed in pre-interview was positively correlated with "number of mirrors" attribute. "Total AE" dimension conveyed in pre-interview was positively correlated with both "reference geometry" and "number of mirrors" attributes. "Multiple perspectives" dimension conveyed in post-interview was positively correlated with "origin," "reference geometry," and "number of mirrors" attributes. The "metacognition" dimension conveyed in post-interview was positively correlated with "number of patterns" attribute. The "goals and beliefs" dimension conveyed in post-interview was positively correlated with "origin" and "number of mirrors" attributes. "Total AE" dimension conveyed in post-interview was positively correlated with "origin," "correct feature sequence," "number of mirrors" as well as "number of patterns." "Total AE" dimension conveyed in both pre-interview and post-interview was positively correlated with "reference geometry" and "number of mirrors."

Table 7. Correlations between interviews and model attributes.

Variable 1	Variable 2	Correlation(r)	Sig.
Pre-Int-Multiple Perspectives	Base Feature	−0.338	0.006*
Pre-Int-Epistemology	Sketch Plane	−0.208	0.094*
Pre-Int-Metacognition	Sketch Plane	−0.205	0.099*
Pre-Int-Metacognition	Reference Geometry	0.252	0.041*
Pre-Int-Goals and Beliefs	Incorrect Feature Terminations	0.318	0.009*
Pre-Int-Goals and Beliefs	Number of Mirrors	0.363	0.003*
Pre-Int- Total AE	Reference Geometry	0.228	0.065*
Pre-Int- Total AE	Number of Mirrors	0.242	0.050*
Post-Int-Multiple Perspectives	Origin	0.235	0.058*
Post-Int-Multiple Perspectives	Reference Geometry	0.241	0.052*
Post-Int-Multiple Perspectives	Number of Mirrors	0.284	0.021*
Post-Int-Metacognition	Incorrect Feature Terminations	0.211	0.089*
Post-Int-Metacognition	Number of Patterns	0.396	0.001*
Post-Int-Goals and Beliefs	Origin	0.238	0.055*
Post-Int-Goals and Beliefs	Incorrect Feature Terminations	0.241	0.051*
Post-Int-Goals and Beliefs	Number of Mirrors	0.275	0.025*
Post-Int- Total AE	Origin	0.267	0.030*
Post-Int- Total AE	Correct Feature Sequence	0.224	0.070*
Post-Int- Total AE	Incorrect Feature Terminations	0.262	0.034*
Post-Int- Total AE	Number of Mirrors	0.314	0.010*
Post-Int- Total AE	Number of Patterns	0.209	0.093*
Int- Total AE	Reference Geometry	0.228	0.065*
Int- Total AE	Number of Mirrors	0.300	0.014*

*Difference is statistically significant when the p value less than 0.10 is considered.

5. Discussions

Comparisons regarding students' coded responses in the pre and post interviews showed that no significant difference of adaptive expertise was observed between students who completed stylized exercise and those who completed single contextual exercise. In the comparison of stylized exercise and four contextual exercises, students who completed four contextual exercises showed more goals and beliefs and more total adaptive expertise in the post interviews than students who completed stylized exercise. This suggests that the four contextual exercise did help students gain adaptive expertise. Compared to single contextual exercise, four contextual exercises have more positive effects on improving students' adaptive expertise.

Few significant differences were observed in video data comparison. The only one is that students who completed four contextual exercises spent less time on thinking than students who completed stylized exercise. It has been noted that experts spend more time doing and thinking [1], while more trials and errors are used by those with limited skill [2]. Our result is not in compliance with the conclusion suggested by the literatures.

Students in experimental groups (both single contextual exercise and four contextual exercises) used more correct origins, less number of features, less incorrect feature terminations, and more number of patterns. Also, students who completed contextual exercises (both single contextual exercise and four contextual exercises) received higher score on the final CAD exam than those who completed stylized exercise. However, the differences were not statistically significant. As a result, it shows that the contextual exercises have a positive effect on improving students' CAD modeling skills.

The correlations were examined between interviews and model attributes. The results indicated that students with higher adaptive expertise used more reference geometries, more number of mirrors and patterns, more correct origins, and they are more likely to choose correct feature sequence. These modeling features are considered as better modeling strategies to convey design intent as discussed in previous works [9, 14].

6. Conclusions and futher work

This paper presents the work of implementing a serious of contextual exercises to enhance the students' adaptive expertise in Computer-Aided Design. The data were collected in five semesters, including pre and post interviews responses, CAD models, and students' screen-recordings. The analysis results showed that experimental groups used more correct modeling attributes than the control group. Also, students participated in experimental group performed better than students in control group in the end of semester CAD modeling test. However, this was not significant different. When the correlations were examined, students with higher adaptive expertise used more correct modeling attributes.

Future work will be focused on collecting and analyzing data from expert CAD users. The research team will examine the performances of industry engineers and to find their characteristics of adaptive expertise related to CAD. The study will determine the preferred modeling procedures extracted from those experts.

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ORCID

Ke Liu http://orcid.org/0000-0002-6311-9645
Xiaobo Peng http://orcid.org/0000-0002-0498-7194
Prentiss McGary http://orcid.org/0000-0001-7693-0667
Bugrahan Yalvac http://orcid.org/0000-0002-9716-126X
Elif Ozturk http://orcid.org/0000-0003-3980-3444
Michael D. Johnson http://orcid.org/0000-0001-5328-8763
Lauralee Valverde http://orcid.org/0000-0002-8415-372X

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