AC 2011-172: CAD MODEL CREATION AND ALTERATION: A COMPARISON BETWEEN STUDENTS AND PRACTICING ENGINEERS

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Abstract

Computer-aided design (CAD) is a powerful and ubiquitous tool in the modern engineering environment. CAD databases are used throughout the development process, but to take full advantage of the functionality provided by modern CAD tools requires a skilled user. Students tend to be taught CAD in a manner that focuses on declarative skills and knowledge that is limited to creating geometry in a specific program. This is in contrast to the procedural knowledge associated with experts. Comparing student modeling procedure to that of practicing and experienced engineers could inform CAD educational activities.

The results of an exercise performed by 30 practicing engineers and 107 students are presented. The exercise consisted of creating and altering a CAD model of moderate complexity. Both students and practicing engineers were split into groups and asked to create the part with altering goals: one group's goal was to create the part as quickly as possible; the other's goal was to create the part so that it could be easily altered. These initial parts were then altered by others in the opposing group. Model attributes and derived quantities for both groups are tabulated for both populations.

As expected, student modelers required more time to complete the initial modeling and alteration activities. Students used more, simpler features to create their models (in both groups). The practicing engineers tended to produce models that followed commonly described proper modeling procedures. During the alteration process, students were more likely to delete features as opposed to alter them. Exercises are suggested to encourage student modeling procedure more in line with that of the experts. Student and practicing engineers also had slightly differing opinions regarding which modeling procedures would be beneficial.

Introduction

Computer-aided design (CAD) tools are ubiquitous in industry; CAD is used throughout the development process [1]. Given the importance of CAD in the engineering process, students should be provided with a knowledge base that allows them to use these powerful tools to their full capabilities. Teaching students how to properly model components in CAD requires that they be taught the strategic knowledge [2, 3] that can easily be adapted to other programs and contexts as opposed to the declarative knowledge focused on a single CAD program [4, 5]. This strategic knowledge is associated with CAD expertise [2].

Morozov et. al, note that the practices of experts can be examined to help inform educators about which skills and procedures should be conveyed to students [6]. Other educational researchers have examined the role of expertise in general problem solving[7] and design education [8]. This work builds off of previous work examining the creation, alteration, and perception of CAD models [9-

[11]. Specifically, this work examines the differences between the modeling procedures of CAD novices (students) and CAD experts (practicing engineers). The methods used are discussed in the next section; this is followed by a presentation and discussion of the results.

Methods

The model creation and alteration in this work is done using the Pro|Engineer CAD package. Student data for this work was gathered over three semesters from a junior level design course with a CAD instruction portion during the lab. Most students did not have prior experience with Pro|Engineer. The practicing engineers were members of different teams of the Indian subsidiary of a renowned product development and services company. The average experience level of the participants with the use of Pro|Engineer CAD package was 4.9 years. In both cases participants were split into two groups: one group was incentivized to design the component shown in Figure 1 as quickly as possible (denoted incentivized for speed); the other group was incentivized to design the component in Figure 1 so that it was easily altered (denoted incentivized for ease of alteration). Originally, these two grouping were devised to examine the role of incentives on modeling procedure [9, 10], but in subsequent exercises they are used to increase the breadth of modeling procedures. In the case of the student participants, they were incentivized with extra credit in the course based on their relative performance within their respective incentive group. In the case of the practicing engineers, they were asked to complete the exercise by their management and therefore were incentivized by their normal workplace incentives.

In both cases participants were given sixty minutes to complete the initial modeling of the component. In the case of the student participants, the exercise was done in a laboratory setting and completion times were noted by the instructor and a teaching assistant. The practicing engineers self reported their completion times via e-mail. Once the initial modeling procedure was complete, those finishing in the top third of an incentive group had their models submitted for alteration by three members of the other incentive group – people who had designed for ease of alteration, altered models by those designed for speed. This was done by semester for the student participants. Again, participants were given sixty minutes to alter the original model (Figure 1) to that shown in Figure 2. Alteration times were noted. After the completion of the model (or the expiration of the sixty minutes allotted), participants were asked to fill out a survey regarding their perception of certain model aspects and what attributes they felt might improve the model they had worked with. . The perception metrics included: 1) the intuitiveness of the order of features in the model; 2) the intuitiveness of the organization of the features and the overall quality of the model; and 3) an overall rating of the model. The intuitive order and organization were rated on a seven point scale (a rating of 1 meant that the model was not at all intuitive and 7 meant very intuitive). The overall rating was also rated on a seven point scale (a

Figure 1. Drawing of original design

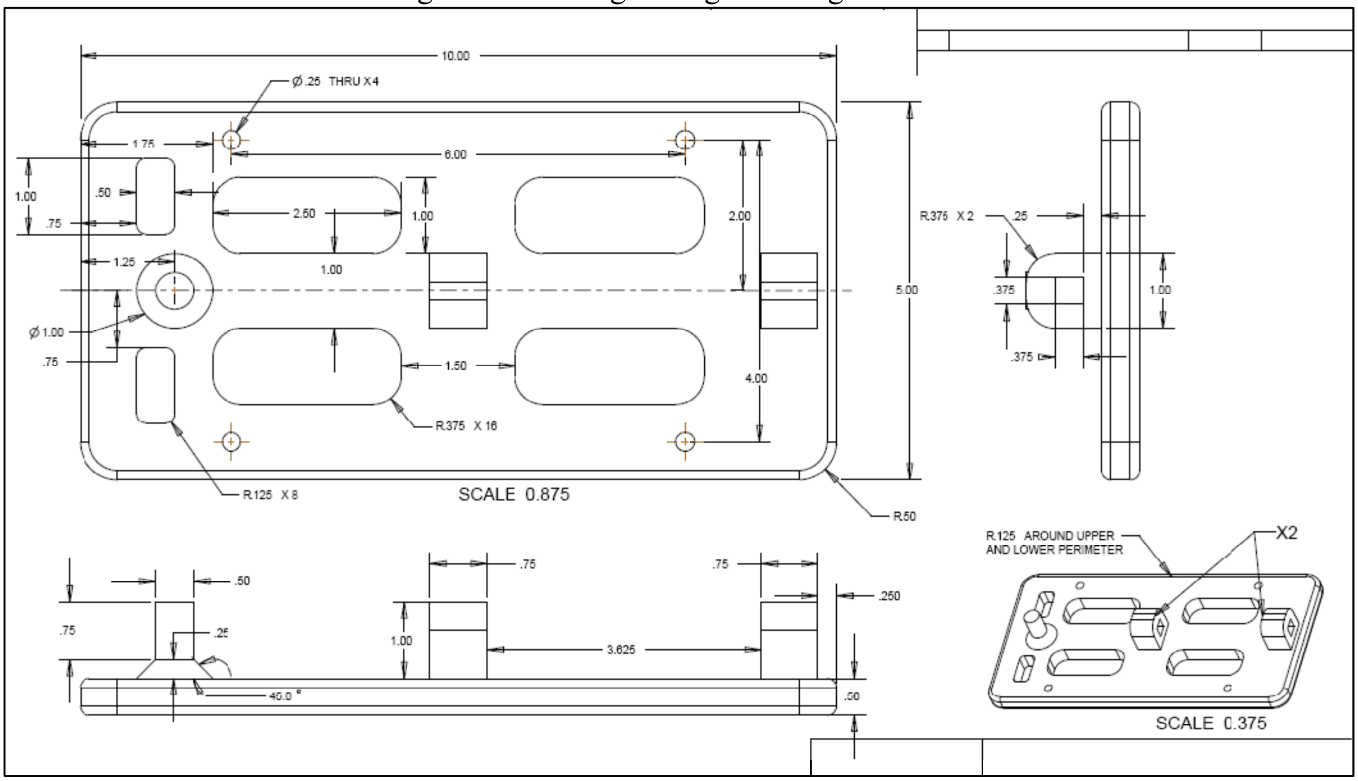

Figure 2. Drawing of altered design

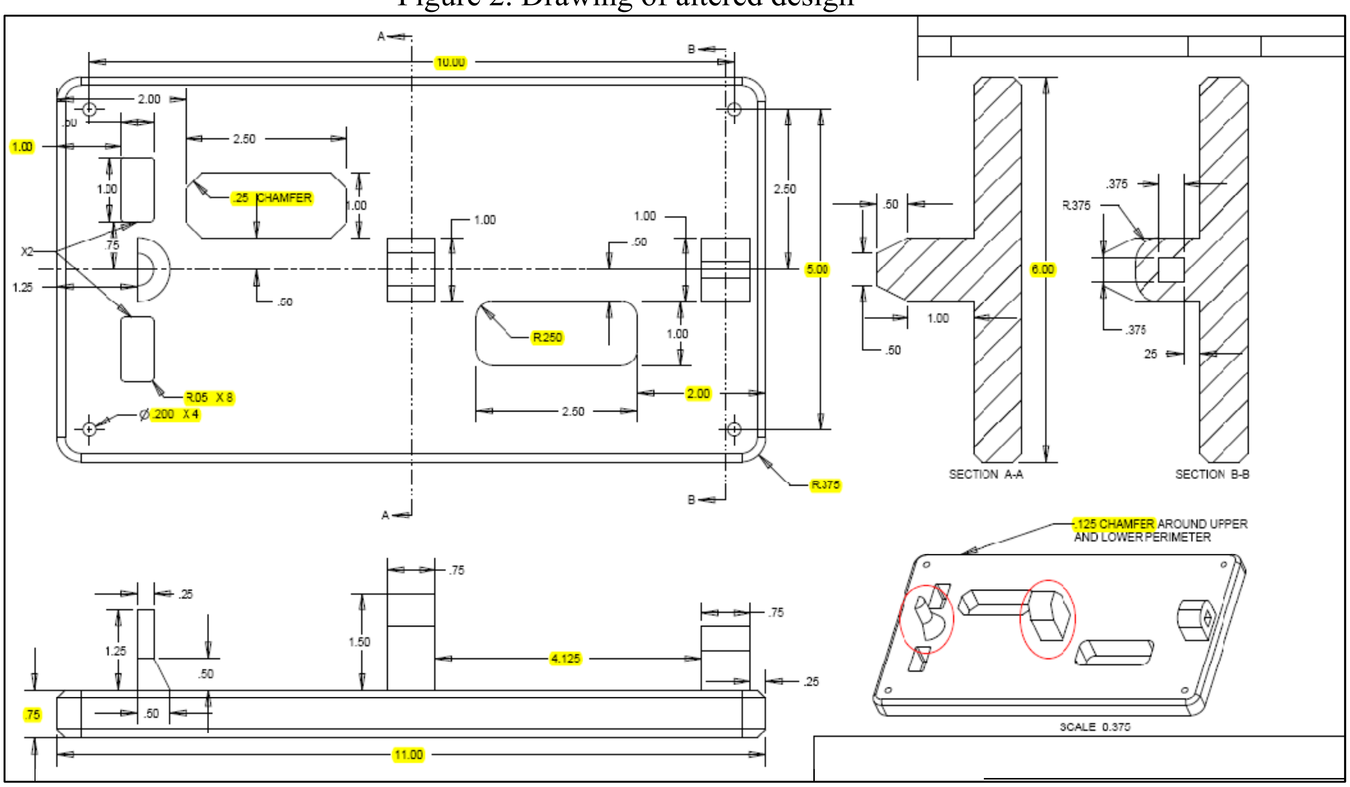

Table 1. Description of the Model Attributes and Derived Quantities

Attribute	Description	Measure
Correct Initial Sketch Plane	Denotes whether the sketch for main block feature is placed on the top datum in the altered model	Binary: 1 – yes; 0 – no.
Correct Model Origin	Center of main block feature located at global origin in the altered model	Binary: 1 – yes; 0 – no.
Correct Base Feature	Main block as first (non-datum) feature in the altered model	Binary: 1 – yes; 0 – no.
Correct Part Orientation	Orientation of part as shown in drawing in the altered model	Binary: 1 – yes; 0 – no.
Correct Feature Sequence	The altered model should begin with main block and end with chamfers and rounds	Binary: 1 – yes; 0 – no.
Number of Features	The total number of features in the altered model. 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) in the altered model	Whole number
Simple sketch and feature geometry	Average number of sketch segments per extrusion or revolve; rounds and chamfers per feature in the altered model	Real Number
Number of weak dimensions	Number of weak sketch dimensions in extrusion or revolve feature in the altered model. Weak dimensions are created/deleted without notice by the CAD program and hence the name “weak” dimension. When the user defined dimensions and constraints – using the “constructive approach” [12]– were less than the required dimensions to completely constrain the sketch, the number of dimensions required to make the sketch fully defined was counted as the number of weak dimensions.	Whole number
Correct Feature Terminations	Number of features that do not have correct feature terminations (e.g., through holes not defined as such) in the altered model	Whole number
Number of Pattern Features	All pattern features in the altered model	Whole number
Number of Mirror Features	Includes both solid and sketched mirror features in the altered model	Whole number
Relations	Whether or not mathematical relations were used in the altered model	Binary: 1 – yes; 0 – no.
Number of New Features	The number of new features added to the parent model to get the altered model	Whole Number
Number of Features Deleted	The number of features in the parent model that were deleted during alteration	Whole Number
Percentage of Features Retained	The percentage of features from the parent model that are retained with or without changes made to them in the altered model	Real Number
Number of Features Unchanged	The number of features that have been carried over to the altered model as is from the parent model	Whole Number
Number of Features Changed	The number of features in the parent model that have been modified in the altered model	Whole Number
Number of Features Inserted	The number of features that have been inserted between existing features in the model tree in the altered model	Whole Number
Number of New Mirrors	Includes both solid and sketched mirror features newly added to the parent model during alteration	Whole Number
Number of New Patterns	Only the new pattern features added to the parent model during alteration	Whole Number
Number of Mirrors Deleted	Includes both solid and sketched mirror features that have been deleted from the parent model during alteration	Whole Number
Number of Patterns Deleted	The pattern features that have been deleted from the parent model during alteration	Whole Number

rating of 1 meant that the engineers would dread to work with the model and 7 meant they would be pleased to work with the model). The goal of these metrics was to quantify aspects of model quality and its ability to be altered. The model attributes queried were also rated on a 7 point scale (1 – would make the model much worse; 7 – would be very helpful). The attributes assessed included: 1) the naming of features; 2) the use of more complex features; 3) the use of simpler features; 4) the use of patterns and mathematical relations; 5) the use of copy and mirror features; and 6) the use of datum geometry for referencing features. After the initial modeling and alteration procedure, the models were analyzed using the attributes and quantities detailed in Table 1. Some of these attributes were derived from those found in Rynne and Gaughran [13]. The results of the comparison between expert and novice CAD users are detailed in the next section.

Results

Table 2. Comparison of Results of Model Creation Exercise - Participants Incentivized for Speed

	Experts	Students	t	Sig. (1-tailed)*
Number of participants	15	53	-	-
No. completing the exercise	15	39	-	-
Time	16.64	37.27	-9.813	**0.000**
Sketch plane	0.47	0.90	-3.031	**0.004**
Orientation	0.47	0.74	-1.834	**0.040**
No. of features	12.33	16.95	-3.950	**0.000**
Reference geometry	0.80	1.13	-0.939	0.176
Avg. no. of segments	5.85	3.50	4.126	**0.000**
Total weak dimensions	0.53	4.92	-4.091	**0.000**
Incorrect feature terminations	0.33	1.23	-3.633	**0.000**
No. of mirrors	2.47	2.38	0.110	0.456
No. of patterns	0.80	2.31	-3.106	**0.002**

*α=0.100

The modeling time and attributes of the models created by the students and the practicing engineers incentivized for speed were compared. The results are shown in Table 2. While only 39 of 53 student participants were able to complete the modeling task all experts were able to complete the modeling exercise. The students required more than twice as much time to complete the modeling task compared to the experts; the difference was statistically significant. Significantly more students chose the correct sketching plane and their models were oriented according to the drawing; this could be a result of several previous exercises that were provided to the students in a similar drawing format. Models created by experts had fewer features and more segments per feature; both of these differences were statistically significant. This is in agreement with the works of Hamade et al., that equate CAD skill and experience with more complex and fewer features [4, 14]. Student models contained about nine times more weak dimensions and three times more incorrect feature terminations; both attributes were statistically significantly different between the groups. These two attributes are typically associated with poor modeling procedure; they were much more prevalent among the novices than the experts.

Table 3. Comparison of Results of Model Creation Exercise - Participants Incentivized for Ease of Alteration

	Experts	Students	t	Sig. (1-tailed)*
Number of participants	15	54	-	-
No. completing the exercise	15	42	-	-
Time	20.85	39.18	-6.823	**0.000**
Sketch plane	0.60	0.81	-1.449	**0.081**
Orientation	0.60	0.64	-0.290	0.386
No. of features	12.73	16.88	-5.645	**0.000**
Reference geometry	0.53	1.19	-1.962	**0.027**
Avg. no. of segments	5.14	3.02	7.728	**0.000**
Total weak dimensions	0.00	5.14	-5.150	**0.000**
Incorrect feature terminations	0.20	1.14	-3.822	**0.000**
No. of mirrors	3.13	2.67	0.849	0.201
No. of patterns	0.93	2.12	-2.757	**0.005**

*α=0.100

The modeling time and attributes of the experts and students incentivized for ease of alteration are summarized in Table 3. As in the group incentivized for speed, all experts completed the exercise while only 42 of 54 students were able to. The experts modeled the component in less time than the students and the difference was statistically significant. Models created by students had significantly more features than those created by experts. The amount of reference geometry in student models was more than twice that in expert models. There were no weak dimensions in expert models while 5.14 weak dimensions per model in the student models. Each student model contained almost six times more incorrect feature terminations than the expert models. Overall, the differences between the experts and the students were similar for both incentive groups.

The results of a comparison of attributes and derived parameters of parent models that were created by participants who were incentivized to create the models as quickly as possible and altered by students and experts are summarized in Table 4. As expected, all experts who participated completed the alteration exercise while less than 60% of the students who participated completed the exercise. The difference between the alteration times was statistically significant. The student models had a significantly greater number of features. The altered student models contained significantly more reference geometry as well. The altered student models contained over 8 times more weak dimensions than the expert models. Surprisingly there were more incorrect feature terminations in the models altered by experts. However, the difference was not statistically significant. During alteration, students deleted more features from the parent models and created more new features compared to experts. Both differences were statistically significant. Experts changed significantly more features when compared to students; students were more likely to delete a feature or leave it unchanged. This would suggest that experts are more aware of the capabilities and efficiency associated with parametric CAD modeling tools. Models created by experts received significantly higher intuitive organization, order and overall ratings. These statistically significant differences suggest that experts recognize and appreciate other experts' modeling procedures.

Table 4. Comparison of results of alteration exercise - Parent Models Incentivized for Speed

	Experts	Students	t	Sig. (1-tailed)*
No. of participants	15	53	-	-
No. completing the exercise	15	29	-	-
Alteration time	18.98	42.55	-11.001	**0.000**
Sketch plane	0.40	0.93	-3.776	**0.001**
Orientation	0.40	0.86	-3.105	**0.003**
No. of features	15.07	18.00	-4.101	**0.000**
Reference geometry	0.47	1.71	-3.875	**0.000**
Avg. no. of segments	4.42	3.46	4.722	**0.000**
Total weak dimensions	0.47	3.89	-4.360	**0.000**
Incorrect feature terminations	0.80	0.79	0.039	0.485
No. of mirrors	1.60	1.32	0.632	0.266
No. of patterns	0.67	0.96	-1.161	0.126
No. of new features	7.33	9.29	-2.028	**0.025**
No. of features deleted	3.60	7.82	-4.236	**0.000**
Percent Retention	68.75	51.62	2.781	**0.004**
No. retained w/o change	0.73	2.61	-3.548	**0.001**
No. of features changed	7.07	6.00	1.097	0.143
No. of new patterns	0.07	0.18	-1.126	0.134
No. of new mirrors	0.40	0.29	0.438	0.332
No. of mirrors deleted	0.80	0.79	0.045	0.482
No. of patterns deleted	0.40	1.68	-3.504	**0.001**
Intuitive organization	5.07	3.70	2.788	**0.006**
Intuitive order	5.13	4.01	2.697	**0.007**
Overall	4.87	3.82	2.481	**0.011**

*α=0.100

A summary of the results of a comparison between models originally incentivized for ease of alteration altered by students and experts is presented in Table 5. Not surprisingly, all experts and only 36 of 51 students completed the alteration exercise. Experts completed the exercise significantly quicker than students. Again, there were significantly more new features and more features deleted from the parent models by students during alteration. Models created by experts were again rated statistically significantly higher in intuitive order and overall ratings compared to those created by students.

Table 5. Comparison of Results of Alteration Exercise - Parent Models Incentivized for Ease of Alteration

	Experts	Students	t	Sig. (1-tailed)*
No. of participants	15	51	-	-
No. completing the exercise	15	36	-	-
Alteration time	18.23	37.51	-7.423	**0.000**
Sketch plane	0.60	0.74	-0.936	0.177
Orientation	0.60	0.65	-0.309	0.379
No. of features	15.33	17.97	-4.319	**0.000**
Reference geometry	0.60	1.97	-4.696	**0.000**
Avg. no. of segments	4.21	3.51	4.050	**0.000**
Total weak dimensions	0.53	4.91	-5.577	**0.000**
Incorrect feature terminations	0.13	0.71	-2.818	**0.004**
No. of mirrors	1.67	1.32	0.844	0.201
No. of patterns	0.53	1.06	-1.721	**0.046**
No. of new features	6.60	8.26	-1.621	**0.056**
No. of features deleted	3.20	7.44	-4.620	**0.000**
Percent Retention	72.67	59.75	2.283	**0.014**
No. retained w/o change	1.27	3.15	-3.256	**0.001**
No. of features changed	7.33	6.56	1.409	**0.083**
No. of new patterns	0.07	0.18	-1.167	0.125
No. of new mirrors	0.07	0.44	-2.172	**0.018**
No. of mirrors deleted	1.20	1.26	-0.164	0.435
No. of patterns deleted	0.73	1.59	-2.765	**0.004**
Intuitive organization	5.00	4.53	1.816	**0.038**
Intuitive order	5.20	4.65	2.081	**0.021**
Overall	5.40	4.63	2.646	**0.006**

*α=0.100

Table 6 details the responses of which attributes would improve the original model altered for both student and expert participants. These are the combined results for both incentive groups. The desire to have features named received a statistically significantly better rating by the students than experts. Experts might have a superior ability to navigate between features and tended to have models that contained fewer features. However, the ratings by the students and the experts were high, given that the ratings were on a scale of 7. It should be noted that some students had assigned meaningful names to their features while no expert renamed any feature during model creation. Also, neither the students nor the experts modified the names of features during alteration. Both students and experts felt that complex features should be avoided and this was indicated by a low rating for the use of complex features. Experts stated a greater preference for simpler features; the difference in the rating was statistically significant. Expert users tended to alter models that had more complex features. There was no significant difference between the ratings for the use of patterns and relations or mirror and copy features by both experts and students. Experts felt more strongly the need for referencing features from datum planes and the difference was statistically significant. This could be a result of the higher usage of reference geometry by student participants.

Table 6. Comparison of Survey Results

	Experts	Students	t	Sig. (1-tailed)*
Naming Features	5.333	5.859	-1.776	**0.050**
Complex Features	2.833	2.818	0.053	0.483
Simpler Features	5.567	5.222	1.134	**0.099**
Patterns and Relations	4.533	4.707	-0.502	0.371
Mirror and Copy	4.500	4.192	0.827	0.135
Referencing Datum Planes	5.900	5.424	1.658	**0.014**

*α=0.100

Discussion

The goal of this work was to determine which modeling and alteration procedures differed between expert and novice users of CAD; this study examined 30 expert users and 107 student users of the Pro|Engineer software program. This work stems from the premise that identifying expert behavior can inform which procedures should be taught to students [6]. During initial model creation, both expert incentive groups tended to use more complex features. This could be a result of the time related incentive to model quickly; others have shown a relationship between increased feature complexity and reduced modeling time [4]. Students should be introduced to this relationship and taught how to use more complex features; focused exercises detailing the methods to reduce features should be introduced. Expert users also used fewer incorrect feature terminations and weak dimensions. While this falls under the category of common modeling procedure, expert users may be better placed to know the detrimental effects of these attributes. These detrimental effects should be highlighted for students, so that they better understand the rationale behind proper modeling procedure.

During the alteration procedure expert users were more likely to alter features and less likely to delete features. While this could be a result of general CAD skill, it could also signal that expert users understand and appreciate the parametric nature of modern CAD tools and the efficiency associated with altering as opposed to deleting and creating new features. This provides more evidence that modification exercises should be incorporated into the CAD curriculum[15]. Expert models received higher ratings for intuitive order, organization, and higher overall ratings. Expert users thought more highly of their fellow experts' original models than novice users thought of their cohort's models. Overall there was general agreement as to which modeling attributes would improve the model alteration process. Student participants showed a greater preference for naming features, but this could be due to a lack of ability locate and identify features using other tools within the program or the lack of any expert using this particular attribute. Expert users thought that simpler features and more reference geometry would be slightly more helpful than novice users. Again, this was consistent with a lack of usage by expert modelers. Expert original models had more complex features and used less reference geometry. Overall, expert modelers are more likely to follow procedure associated with "proper" CAD modeling mores such as those found in Rynne and Gaughran [13].

This conclusions associated with this work should be viewed in light of some limitations. One limitation of this work was the lack of sharing of models for alteration between the expert and novice users. Having novice users alter and assess expert original models might provide a more informative analysis. This is an opportunity for future work. Another limitation of this work is the lack of explicit rationale behind the modeling and alteration procedures. The data are used to infer what may have been the rationale, but this is not as explicit as using the "think aloud" method to capture what thought process led to certain decisions. To better understand the skill development of expert users, future work should tabulate their pre-professional education and training with regards to CAD. Future studies will attempt to rectify these limitations.

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