AC 2009-60: DESIGN UNDER ALTERNATIVE INCENTIVES: TEACHING STUDENTS THE IMPORTANCE OF FEATURE SELECTION AND ORGANIZATION IN CAD

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Design under Alternative Incentives: Teaching Students the Importance of Feature Selection and Organization in CAD

In today's global and digital environment, computer-aided design (CAD) databases are no longer solely used by individual engineers to produce detailed drawings. These databases are used for finite element simulations, tooling fabrication, and numerous other activities in the development process; in some cases these databases are transferred to engineers located around the world for global engineering projects. The use of product lifecycle management tools mean that these databases may be accessed in the future to be altered by other engineers. These trends increase the importance of designing in a manner that is both intuitively organized and amenable to change.

In most CAD courses students design components that are never altered, or in some cases only altered by the original designer. To show students the importance of designing in a manner that is intuitive and amenable to change, a design and change exercise is presented. Students are split into two groups and incentivized with differing goals. The first group's goal is to design the part as quickly as possible; the second group's goal is to design the part in a manner that can be quickly altered. The parts are then exchanged between the groups and altered.

Data is presented which shows the time required to perform the initial design as well as the alteration. The students' assessment of the design (based on how intuitive they found the design) they had to alter is reported. Student ratings of the usefulness of certain CAD tools in relation to intuitiveness and amenability to change are reported; the use of these tools broken down by group is also shown.

Introduction

Today's engineering students will enter a work environment where the use of computer-aided design tools is ubiquitous. CAD tools are used throughout the design process [1]. CAD tools are also used to facilitate global development projects with engineers located around the world all working on the same project [2]. When used in concert with product lifecycle management systems; a complete library of CAD models can be accessed by engineers around the world [3]. These trends increase the importance of designing in a manner that is both intuitively organized and amenable to change.

The design intent of a model should capture its function and allow the model to be easily altered [4-6]. Design intent is at the core of the CAD modeling process, encompassing feature[*] selection, order, and organization [4]. To produce models that are amenable to change and use modern CAD tools to their full potential, the focus of CAD courses should be around how to convey design intent. Unfortunately, most CAD modeling instruction is focused on teaching declarative knowledge – the key strokes and button picks required to perform certain tasks in specific software platforms [7-8]. Design intent would fall under the category of strategic knowledge [9]. This type of knowledge can transcend a particular CAD program or version [10]. It is important that students learn knowledge that is easily transferable, given the number of CAD programs available and the rate at which they update. Rynne et al, cite attributes such as: proper location and orientation of the base feature, use of symmetry, simple and well defined sketches, correct feature termination, and correct duplication methods as promoting proper design intent [11].

The importance of design intent is difficult to convey without some type of alteration to an existing model. Unfortunately, in most CAD courses students design components that are never altered, or in some cases only altered by the original designer. This is the case even though such exercises are viewed as beneficial in teaching students how to design [12]. To demonstrate the importance of design intent to students, a model alteration exercise is presented in the next section. The results of the exercise from one semester are presented in the following section.

Background and Exercise Description

The exercise described in this paper was prepared for a junior-level design course in a mechanical and manufacturing engineering technology program. CAD is taught as the laboratory portion of the course. The laboratory is one hour and fifty minutes long. The software used in the course is Pro/Engineer Wildfire 3.0. Most students had some experience with a CAD program previously (e.g., AutoCAD or SolidWorks). Very few students had experience with the Pro/Engineer software package (which the course uses). The laboratory is focused on creating models that are easy to alter and showing the effects of alterations when modeling using different methods. The exercise was carried out near the end of the semester after the students had been instructed in basic and intermediate part modeling.

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[*] Features are the building blocks of parametric CAD models. Depending on the software, they include basic elements (e.g., blocks, bosses, pockets, or holes) or sketch manipulations (e.g., extrusions, revolves, or blends).

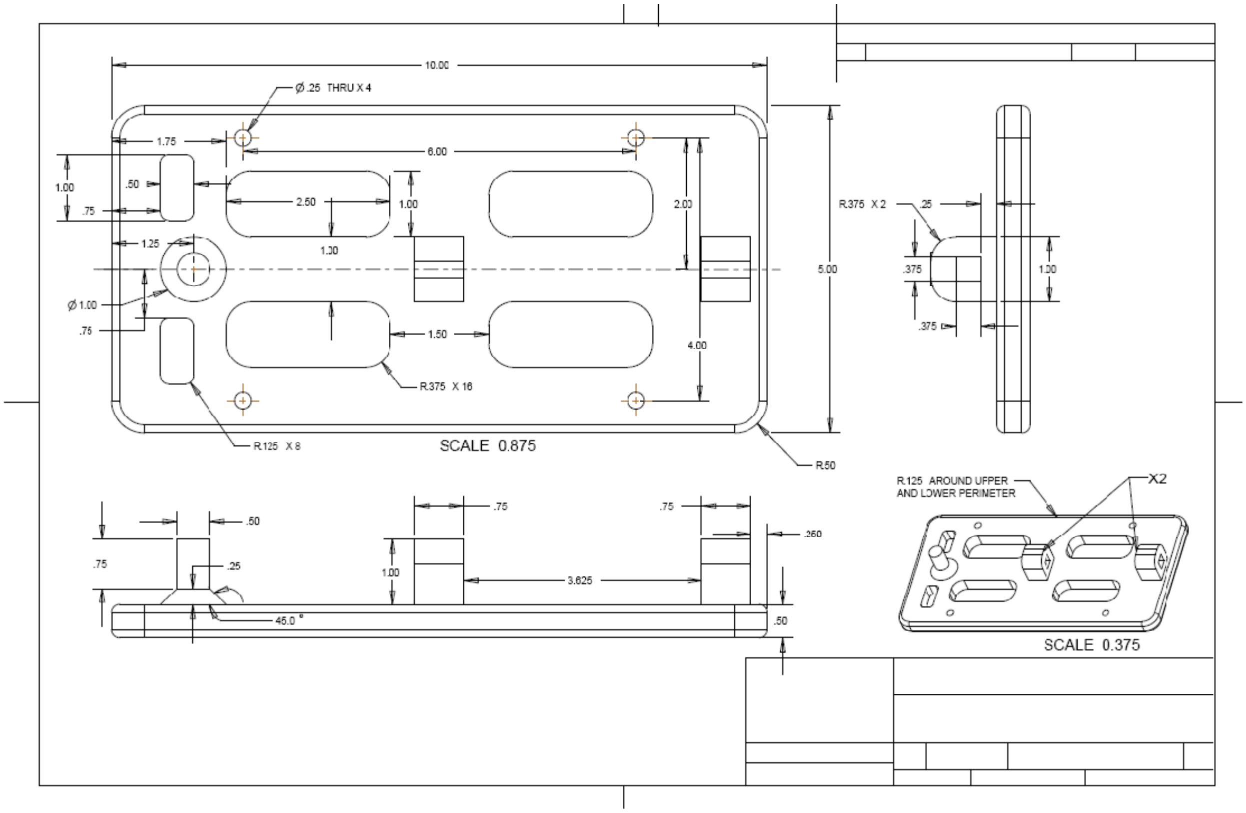

Figure 1. Drawing of the original design.

The class (containing thirty students) was split into two groups (of fifteen each based on course section). Both groups were incentivized with extra credit towards their laboratory grade. The first group was told that their goal was to model the part in Figure 1 as quickly as possible. The design is similar to one found in Chapter 4 of Toogood [5]. Those finishing in the top third of the section would get seven points of extra credit towards their laboratory grade; those finishing in the second third would get four points; those finishing in the bottom third (while putting in at least a good faith effort) would two extra credit points. Students were then asked to complete a list of steps they took (if any) to make their model more amenable to change.

The second group was told that their goal was to design the part in Figure 1 so that it could be easily changed by another member of the class. They were told that only part of their extra credit would be based on how quickly they designed the component. Those finishing in the top two-thirds of their section would get four points; those finishing in bottom third would again get two points (again assuming a good faith effort). However those finishing in the top third had a chance to receive an additional three, one, or zero points based on how quickly their design could be changed (again based on which third the average of altered design time fell into). Students were given fifty minutes to compete the modeling of the component. When students believed they had completed the exercise, they notified one of the lab instructors who then inspected their model for accuracy. Once the model was deemed accurate, the completion time was noted. These students were also asked to complete a list of steps they took to make their model more amenable to change.

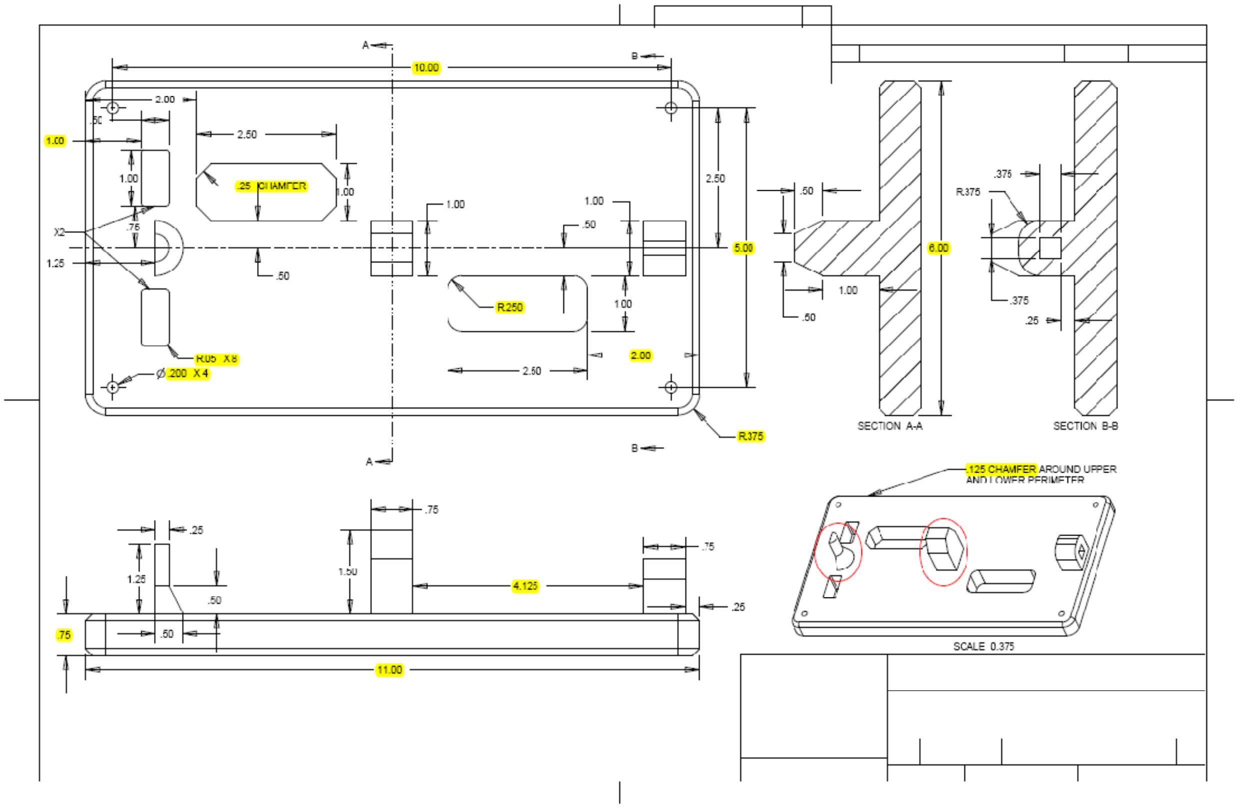

Figure 2. Drawing of the altered design.

The following week, the models of the students finishing in the top third of each group were distributed to the other group to be altered (three students worked on each of the five models). The models were distributed to the students based on their completion times for the first part of the exercise – the groups were split into thirds based on completion time. Each student in that third received one of the models to be altered. The students were given fifty minutes to complete the alteration of the model in Figure 1 to that shown in Figure 2. When the students completed the alteration of the design (or the fifty minute time limit had expired) they were asked to fill out a survey regarding the modeling and change exercise (see Appendix for a copy of the survey). Specifically, they were asked to rate the intuitiveness of organization and the feature order of the model. This was done using a seven point scale (1 –defined as not at all intuitive; 7 – defined as very intuitive). They were also asked to give an overall rating to the model. This was again done using a seven point scale (1 – signifying the student would dread working with a model like this; 7 – signifying the student would be pleased to work with a model like this). The students were also asked to rate how helpful certain model attributes would be in assisting them in understanding and changing the model. These attributes included: naming features, using more complex or simpler features, the use of patterns or relations, the use of mirror or copy tools, and the use of reference geometry (e.g., datum planes). This rating was also based on a seven point scale (1 – defined as making the model much worse; 7 – defined as making the model much better). These data were collected anonymously based on incentive group.

Once the data were collected and tabulated, it was presented during a lecture period of the course. Students were asked to sit on the same side of the room as their section, so that those sitting near them were in the same incentive group. The results presented during the lecture along with an explanation are given in the next section.

Results

In the first group, twelve of those incentivized for speed (denoted –speed group) completed the original part modeling exercise. The average time of those completing the exercise was thirty-eight minutes (the standard deviation of those times was nine minutes). Of the group incentivized for ease of alteration (denoted change group), eleven students finished with an average completion time of forty minutes (and an eight minute standard deviation). The change group had an average completion time that was 2.3 minutes greater than the speed group.

When the models of the five quickest finishers were transferred between the groups, nine students working on models originally designed by the change group completed the alteration task (out of 15). Their average completion time was thirty-six minutes (with a seven minute standard deviation). Nine students working on models originally designed by the speed group completed the alteration task. Their average completion time was thirty-eight minutes (with a nine minute standard deviation). The alteration time for the speed group's original models was 1.5 minutes longer than the average alteration time for the change group. The total (initial and alteration) modeling time for the models originally designed by the alteration group was seventy-six minutes. The total modeling time for the speed group's original models was seventy-five minutes; this was 0.9 minutes less than the alteration ease incentivized group. These results are summarized in Table 1.

Table 1. Exercise Results.

Incentivized for	Speed	Change
Total Students Participating	15	15
Number Completing Exercise	12	11
Average Time (for those completing exercise)	37.6	40.0
Minimum	23	26
Number Completing Alteration	9	9
Average Alteration Time (for those completing alteration)*	37.7	36.2
Minimum Alteration Time	24	28

*Shown as time taken to alter that model category; times shown in minutes.

In addition to showing the basic completion times for the original and altered designs, results were also analyzed for statistically significant differences between the two groups. The results of those statistical tests are shown in Table 2. These tables show the t- statistic and the one-tailed probability. The one-tailed probability is used due to the unidirectional relevance of the quantities in relation to the results. The average design time for the change group was slightly longer than that for the speed group, but the difference was not statistically significant. The average change time for the speed group's models was slightly longer than that for the change group, but again this was not statistically significant. All three perceptions ratings were lower for the speed group than for the change group; however, none of them were statistically significant at the 0.05 level.

Table 2. Statistical t Tests for Exercise.

	Goal Averages		t	Significance (1-tailed)
	Speed	**Change**		
Original Design Time (min)	37.6 (9.0)	40.0 (8.4)	-0.67	0.256
Alteration Time (min)	37.7 (8.9)	36.2 (7.1)	-0.38	0.355
Intuitive Organization	3.60 (1.40)	4.07 (1.94)	-0.75	0.229
Intuitive Order	3.33 (1.54)	4.29 (1.59)	-1.64	0.057
Overall Rating	3.50 (1.51)	4.36 (2.06)	-1.23	0.110

*Standard deviations shown below quantity in parentheses.

The survey results regarding possible model improvements are shown in Table 3. For each potential improvement the average rating and the standard deviation for that rating are shown. The number of students reporting that their original model contained this attribute are also listed; these data were collected from the list of steps students said they took to make their model more amenable to change. There was a consensus between both groups that the naming of features in the model would have been helpful. It should be noted that only one student mentioned this as something that they pursued. Both groups also showed a preference towards simpler features as opposed to more complex features. Patterns of and mathematical relations for features were both viewed as slightly beneficial. Students were somewhat neutral towards the use of mirror and copy functions. The use of datum planes was also viewed as very beneficial; this again had a low level of self-reported usage.

To relay to the students the importance of design intent and modeling components that are easily understood and changed, these data were presented during a lecture period. Some background about product lifecycle management systems and global design teams was given. Individual students were asked to discuss their experiences with altering the designs of their classmates.

Table 3 was used to convey to them that they should model components in a manner in which they would like to receive them if they had to alter them at some point.

Table 3. Helpful Improvements and Usage.

	Incentivized for	Speed	Change
Naming Features	Average	5.64	5.62
	Standard Deviation	1.08	1.33
	Usage	0	1
More Complex Features	Average	3.14	2.69
	Standard Deviation	1.79	1.03
	Usage	0	3
Simpler Features	Average	4.93	5.23
	Standard Deviation	1.54	1.17
	Usage	0	2
Patterns and Relations	Average	4.57	4.46
	Standard Deviation	1.83	2.33
	Usage	8	9
Mirror and Copy	Average	3.79	4.00
	Standard Deviation	1.37	1.68
	Usage	4	5
Referencing Datum Planes	Average	5.64	5.62
	Standard Deviation	1.45	1.66
	Usage	2	1

Conclusions

An exercise where two groups of CAD students are incentivized to model components for either speed or ease of alteration was presented. This exercise produced interesting results that agreed with the predicted trend. While the trends were not statistically significant, they were useful for class discussion purposes. The speed incentivized group produced models that were not as intuitive and that received lower overall ratings. The group incentivized for change produced models that were changed in less time than those produced by the speed group. However, this time reduction did not overcome the additional time that the change group required to produce the original models. After the exercise, students were asked what model attributes could be used to improve their modeling alteration experience. Naming features, using simpler features, and referencing datum planes were cited as being beneficial. These results were used to facilitate a discussion regarding the importance of design intent in modern CAD modeling and product development environments.

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Appendix

Student Survey:

With respect to the design change exercise (completed today), how intuitive (easy to understand the organization) would you say the organization of model you worked with was?

Not at all Intuitive 1 2 3 4 5 6 7 Very Intuitive

With respect to the design change exercise (completed today) how intuitive (easy to understand the order) would you say the order of the features in the model you worked with was?

Not at all Intuitive 1 2 3 4 5 6 7 Very Intuitive

Overall, rate the model that you were given to change:

I would dread receiving/working with a model like this.	1	2	3	4	5	6	7	I would be very pleased to receive/work with a model like this.

For the following questions, please rate the improvement (how helpful in your ability to understand and change the model) that the following changes to the model you had to modify would be.

Naming the features in the feature tree:

Would Make Model Much Worse 1 2 3 4 5 6 7 Would Be Very Helpful

Using more complex features (more geometry generated per feature):

Would Make Model Much Worse 1 2 3 4 5 6 7 Would Be Very Helpful

Using less complex features (less geometry generated per feature):

Would Make Model Much Worse 1 2 3 4 5 6 7 Would Be Very Helpful

Using more patterns and relations:

Would Make Model Much Worse 1 2 3 4 5 6 7 Would Be Very Helpful

Using more mirror, copy, and other similar feature generation methods:

Would Make Model Much Worse	1	2	3	4	5	6	7	Would Be Very Helpful

Referencing more features to datum planes/axes:

Would Make Model Much Worse	1	2	3	4	5	6	7	Would Be Very Helpful

Please use this space to provide any additional information that you think would improve the models that you were given to modify.