Using Think-Aloud Exercises to Reveal Students' Solid Modeling Strategies

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Abstract

This paper describes the results of a think-aloud exercise wherein students describe the modeling strategy that they would use to create a 3D feature-based solid model of a simple part. Eleven students were asked to articulate their modeling decisions while sketching the intermediate solid shapes resulting from each feature creation step. The results show that students tend to select the easiest modeling methods based on their visualization of the part, using either additive or subtractive approaches. Most students did not tend to plan ahead, identify alternative strategies, or consider ease of alteration or other downstream uses of the model.

Introduction

Think-aloud protocols ask participants to verbalize their thought processes during problem solving activities (Taraban et al, 2007). This study sought to reveal which factors are considered when students create models of simple parts using feature-based 3D solid modeling (CAD) software. The modeler must make a wide range of modeling decisions such as selecting the base feature and subsequent features, choosing sketching planes and sketch position/orientation, and establishing dimensional and geometric constraints. While there may be many possible methods for creating a specified geometry, best practices should be used to create a robust model that captures design intent and facilitates downstream use of the model (Chester, 2008; Rynne and Gaughran, 2008).

Methodology

Students enrolled in a second year solid modeling course at XYZ University were invited to participate in the think-aloud study. Participants were asked to solve typical solid modeling problems and explain their strategies and methods. Students were shown isometric sketches of the selected parts (Figure 1; red lettering not included) and asked to describe the modeling procedures that they would use while sketching the resultant models at each step in the modeling process. Students were asked to identify and sketch each feature profile and placement, and explain their choices. The students' sketches and verbal responses were captured on video tape and transcribed for analysis.

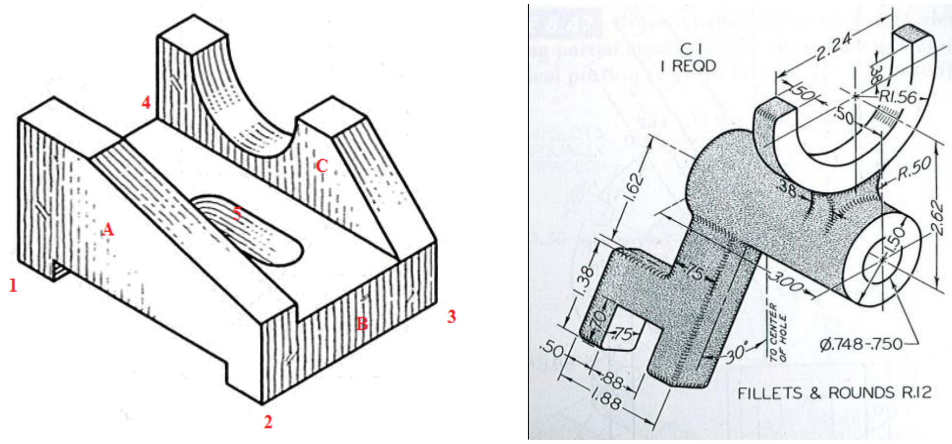

Figure 1. Parts used for think-aloud modeling study.
Block, left (Luzadder, 1993) and Shifter Fork, right (Giesecke, 2000).

Results

Eleven students participated in the think-aloud study (four sophomores, 2 juniors and 5 seniors). Only the results of modeling the Block are reported here. All of the students had completed a first-year graphics course which included sketching as well as both 2D and 3D CAD. Student majors included mechanical engineering, aerospace engineering, and computer graphics technology. In addition to different majors, students reported varying levels of CAD experience; five reported using solid modeling in high school (such as Project Lead the Way), five had used solid modeling during internships that lasted from 3 months to 2 years, and four reported using solid modeling for project work in other courses. A preliminary analysis of the data reveals three basic decisions that students made during the modeling procedure for this simple part: selection of the base feature, placement and orientation of the part in the global coordinate system, and use of constraints for sketches and terminal conditions.

Base Feature Selection: The first decision typically made is the choice of the base feature; the Block has a range of base features from which one could choose. The most common base features were a full-sized rectangular prism used by three of the students, and a full-sized U or inverted U shaped feature used by three of the students. See Figure 2. All six of these students then used similar cut features to remove material as needed to model the part, with rectangular sketches to create the U or inverted U cuts, then typically working from front to back using simple triangles and arcs for the cut features on the vertical protrusions. All of the students completed the part using an extruded cut for the central slot (Figure 1, feature 5). This subtractive strategy is sometimes taught at the secondary school levels in order to guide students to create models that are physically possible to manufacture (PLTW Inc., 2012). Some of these students mentioned manufacturing considerations when explaining their choice of modeling strategy.

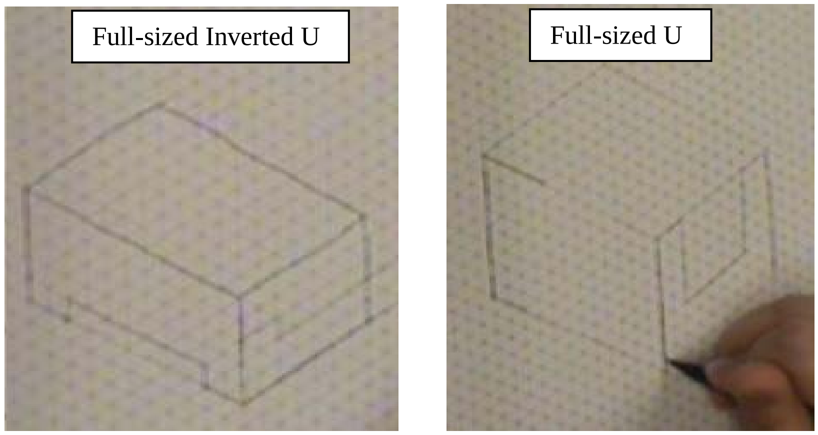

Figure 2. Student sketches of base features for the Block (subtractive strategy).

The remaining five students selected an additive modeling strategy. Four students chose a base platform in the form of a rectangular prism or the base prism with an inverted U shape as shown in Figure 3 (left). These students created the bottom cut feature if not included in the base platform, then added extrusions sketched on the front and back faces of the base platform to create the vertical features. Note that these sketches were more complex than those required for the subtractive modeling strategy. Students rationalized this modeling strategy by stating that they typically worked “from bottom to top” or “from front to back”.

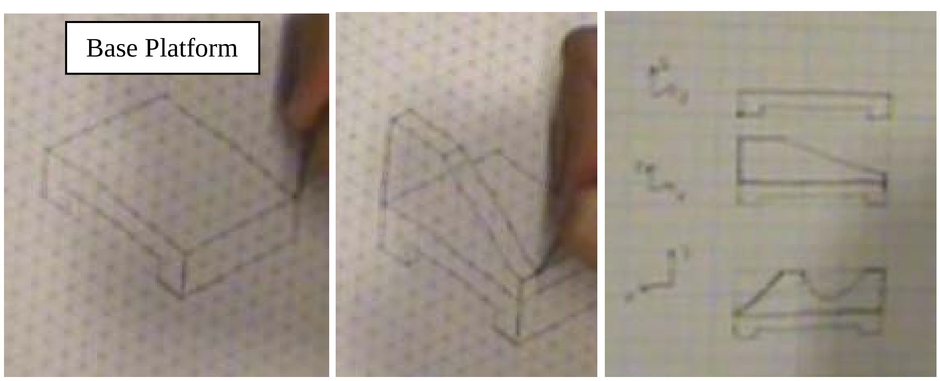

Figure 3. Student sketches of base and subsequent features (additive strategy).

The remaining student chose to extrude the front profile as the base feature; Figure 4. The student then extruded the center section as a rectangle from the right end (Figure 1, surface B), extending the rectangle to the back face of the part. The third feature, for the top of the rear vertical protrusion, was modeled using a sketch on an offset plane as shown in Figure 4. This student had the least amount of solid modeling experience of all the student participants, appeared to struggle with the decomposition of the part into model-based features, and was focused on simply reproducing the isometric sketch on paper. The student had difficulty visualizing the part and did not realize that the cut feature on the bottom of the part extends through the part.

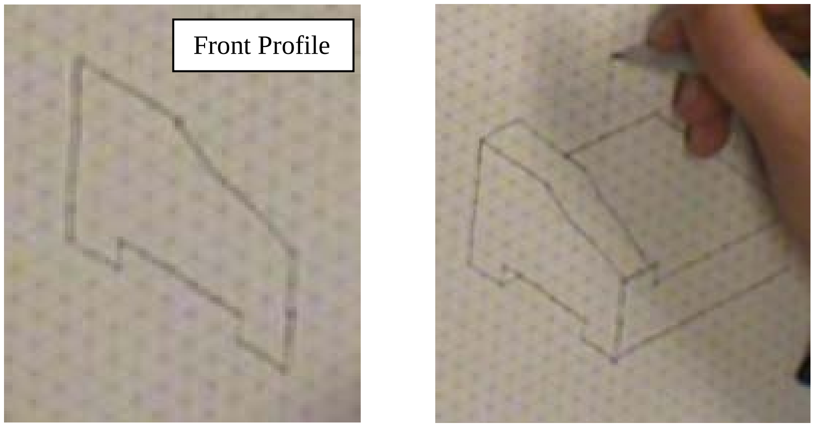

Figure 4. Student sketch of front profile for base feature (left), second feature and start of third feature sketch (right).

Placement and Orientation of Part: Six students did not discuss location and orientation. Even though base feature choice was grouped tightly, origin placement varied greatly. The three bottom corners visible in the isometric example (corners 1, 2, and 3 in Figure 1) were all cited as origin locations. These students believed their origin placement was for easy modeling. Note, however, that common solid modeling systems typically orient the global coordinate system as shown in Figure 5, and default to sketching on the x-y plane and extruding a sketch on the x-y plane in the positive Z direction. In this situation, the origin of the part would typically not be located in any of the locations cited by the students, but at the lower back corner of the part for base features shown in Figure 2 (left), Figure 3 and Figure 4. One student placed the origin in the bottom center so that he could locate the center of the slot there and that the slot would always remain centered in the part.

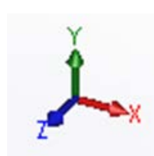

Figure 5. Orientation of global coordinate system in default isometric view.

Constraints: A common theme was the extension of sketches and cuts past the edge of the existing model geometry, as shown in Figure 6, in order to "make sure to get it all". Several students mentioned a mistrust of the software, as if the modeling software would not cut the part correctly if the sketch is made right on the edge. This indicates a lack of understanding of constraints, assuming the sketch line always automatically constrains itself to the edge without specific action by the user. In addition, it was common for dimensional constraints to be used where geometric constraints would be more suitable for capturing design intent.

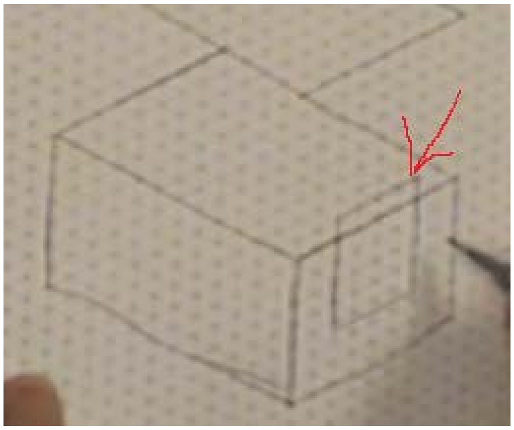

Figure 6. Unconstrained sketch geometry.

Modeling Strategy Rationale: Expert modelers often create fewer features than student modelers, which makes better use of the parametric modeling system and makes alteration easier (Chester, 2008; Johnson, 2011). Rynne and Gaughran (2007) claim that best practice strategies for solid modeling require the user to identify a base feature which will minimize the number of remaining features and facilitate alteration of the model. The majority of the students chose their base feature based on what they felt was the most prominent feature. Ease of modeling was the 2nd most popular reason for base feature choice, followed by manufacturing considerations. Ease of modeling and prominent feature were sometimes clarified with "it was the closest part" meaning that they choose the feature closest to the front in the presented isometric view, as shown in Figures 2-4. Students seem to model parts with primary consideration to simply reproducing the desired geometry without consideration of manufacturing, flexibility or relationships between features. Although this is their second SM course, and many of the students had additional high school, project or internship experience, these students did not express any strategic alternatives or planning decisions unless prompted by the interviewer. None of the students mentioned efficiency of modeling or ease of alteration, which are typically cited by experts as the basis for their modeling strategies. This is a skill that comes with learning modeling based on design intent and from experience modifying parts that have been created by other users.

Conclusions

The most popular reasoning behind any decision made by the subjects is that it made the process easy; this was followed by small minority with some manufacturing concern. Alternatives were not considered or stated; it seems like these solutions were the first ones that the students came up with rather than thinking about relationships between features and how each step will affect the usability of the final model. The forethought of design, normally shown by experts in industry is known as strategic 3dsm; the best practice is one which makes the model easiest to change (Chester, 2008). This strategic thinking should be taught in the classroom.

The brief analysis performed for this study suggests the need for expanded research. Some students demonstrated difficulty in visualizing and decomposing the parts. Although not reported here, the think-aloud exercise was also completed with additional parts such as the shifter fork shown in Figure 1. The effect of using alternative representations of the parts such as orthographic drawings vs. isometric sketches, and presence of dimensions may have some influence on the strategies used by the students. Although the use of sketching vs. directly modeling on the CAD system was intended to facilitate and expedite the study, some students were confused by the instructions and reverted to reproducing the isometric sketch rather than creating a representation of the features of the desired solid model. Thus, it would be of further interest to repeat the study using a solid modeling system rather than sketching. This could reveal modeling errors that students correct "on the fly" when these errors result in incorrect geometry or cause later modeling difficulties.

Acknowledgements

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