Examining the Constraint-Based Modeling Strategies of Undergraduate Students

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Abstract

During the Fall 2013 and Spring 2014 semesters, students completed the PSVT:R and the MCT and then were asked to complete three different modeling tasks. These tasks included modeling a part when given the object in the context of an assembly drawing (one part within the original modeling test), modeling a part when given an isometric pictorial of the object, and finally modeling a part when given a detail drawing of the object. Models were evaluated using two different rubrics. Overall scores for modeling activities and students' visualization ability were calculated. This paper presents the overall data from the modeling activities and presents a more detailed examination of the modeling strategies for a range of students. Recommendations for future work include examining the modeling activities in the introductory course for improvement, conducting a more thorough review of modeling strategies at the beginning of the semester in the second level course, and using verbal protocol analysis to gain a deeper understanding of students' modeling strategies.

Introduction

Over the last 3 years, a series of studies has been conducted to examine the engineering graphics literacy of undergraduate students (Branoff & Dobelis, 2012a, 2012b, 2013a, 2013b, 2014; Dobelis, Branoff & Nulle, 2013). Most of these studies examined how well students created constraint-based models of objects when given a 7 part assembly drawing. In addition, the relationship between students' ability to model parts was compared to their spatial visualization ability as measured by the Purdue Spatial Visualization Test: Visualization of Rotations (Guay, 1977) and the Mental Cutting Test (CEEB, 1939). One of the studies also looked at students' ability to model parts when given a pictorial and when given a detail drawing (Branoff & Dobelis, 2014). This study also introduced a new rubric for evaluating students' modeling ability. Results of these investigations revealed that the original rubric, although thorough, required a great deal of time to evaluate student models. Also, there were significant positive correlations between scores on the spatial visualization ability tests and scores on the modeling activities. The MCT appeared to have a higher correlation with the modeling activities than the PSVT:R. Recommendations from these studies encouraged using qualitative methods to gain a deeper understanding for how students modeled parts.

Review of Literature

When evaluating students' ability to create constraint-based models, several things must be considered. Design intent is a critical component of assessing students' models, but not all instructors are clear about how design intent can be assessed (Otey, Company, Contero & Camba, 2014). As students are beginning to learn how to model parts within constraint-based modelers, Otey, et al. recommend introducing design intent to students through proper modeling strategies and evaluating these models for their quality and efficiency. Ault, Bu & Liu (2014) recommend that instructors develop exercises that require students to do careful planning to build design intent into their models that reflect industry developed best practices. Company, Contero & Salvado-Herranz (July, 2013, p. 2) define quality CAD models with the following dimensions:

1. Models are *valid* if they can be opened by suitable applications, and do not contain errors or warnings.
2. Models are *complete* if they include all product aspects relevant for design purposes.
3. *Consistent* models should not crash as a result of editing tasks or design exploration.
4. *Conciseness* pursuits models that do not include irrelevant information or procedures.
5. *Effective* CAD models convey design intent.

Participants

The participants for this study were enrolled in a junior-level constraint-based modeling course at [insert university name] during the fall 2013 and spring 2014 semesters. The course consists of engineering graphics standards and conventional practices (sectional views, dimensioning, threads & fasteners, and working drawings), geometric dimensioning and tolerancing, and constraint-based modeling techniques (assemblies, advanced drawing applications, macros, design tables, and rendering). Tables 1-3 summarize the demographic information of the participants.

Table 1. Gender of Participants.

Gender	Frequency	Percent
Female	4	9.52%
Male	38	90.48%
TOTAL	42	100.00%

Table 2. Academic Year of Participants.

Year	Frequency	Percent
Sophomore	5	11.90%
Junior	21	50.00%
Senior	16	38.10%
TOTAL	42	100.00%

Table 3. Academic Major of Participants.

Major	Frequency	Percent
Agriculture & Engineering Technology	2	4.67%
Biological Engineering	1	2.38%
Civil Engineering	2	4.67%
Computer Science	1	2.38%
Electrical Engineering	1	2.38%
Mechanical and/or Aerospace Engineering	17	40.48%
Technology, Engineering & Design Education	14	33.33%
TDE – Graphic Communications	4	9.52%
TOTAL	42	100.00%

Most of the students enrolled in the course were male, in their third or fourth year at the university, and from either engineering majors or technology, engineering and design education. Engineering students were taking the course as part of a 15 credit hour minor in graphic communications. The technology, engineering and design education students take the course as part of their major requirements.

Methodology

To assess constraint-based modeling ability coming into the course, students were given 20 minutes on the second day of class to demonstrate some basic competencies learned in the introductory course. Students were given a sketch of the SPACER (Figure 1) and asked to create a fully constrained model of the part. Once their work was complete, models were saved to a server space.

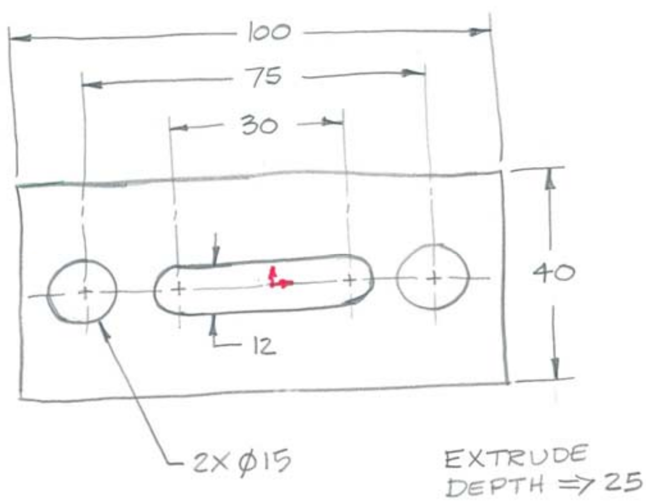

Figure 1. SPACER – Day-2 Modeling Activity.

During the latter part of the fall 2013 and spring 2014 semesters, students completed electronic versions of the PSVT:R (Guay, 1977) and the MCT (CEEB, 1939). During the next class period they were asked to model the SET SCREW (Figures 2 & 3), INDEX ARM (Figure 4), and RING (Figure 5).

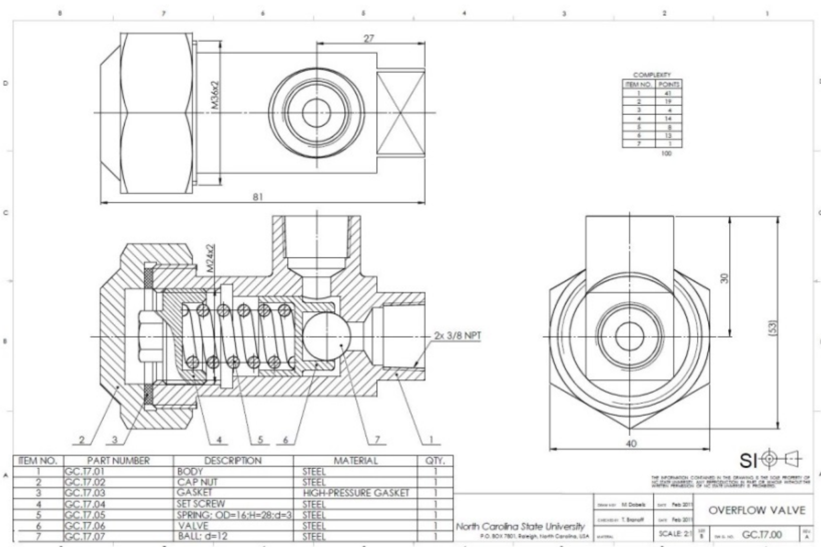

Figure 2. SET SCREW – Item 4 in Assembly.

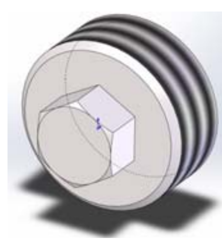

Figure 3. Model of the SET SCREW.

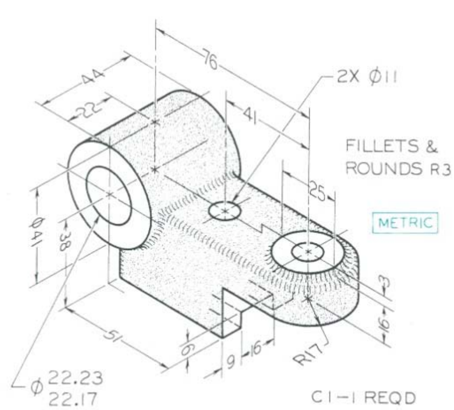

Figure 4. Model of the INDEX ARM.

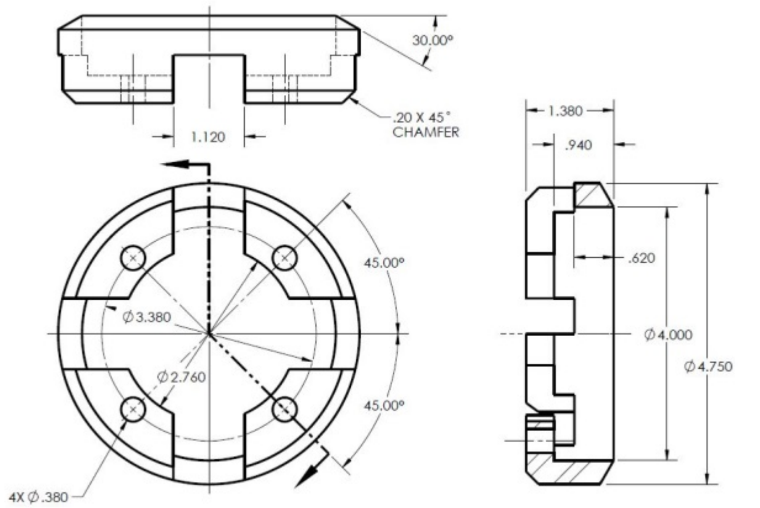

Figure 5. Model of the RING.

The SET SCREW models were evaluated using the rubric used in previous studies (Branoff & Dobelis, 2012a, 2012b, 2013a, 2013b; Dobelis, Branoff & Nulle, 2013). The SET SCREW models were also evaluated using a new rubric described in Branoff & Dobelis (2014). The INDEX ARM and RING models were evaluated using the new rubric. Once all models were evaluated, a modeling score was calculated by taking the average of the four scores. These scores were then ranked. A visualization score was calculated by taking the sum of the two visualization tests. These score were also ranked. Figure 6 displays the modeling score ranks by the visualization score ranks.

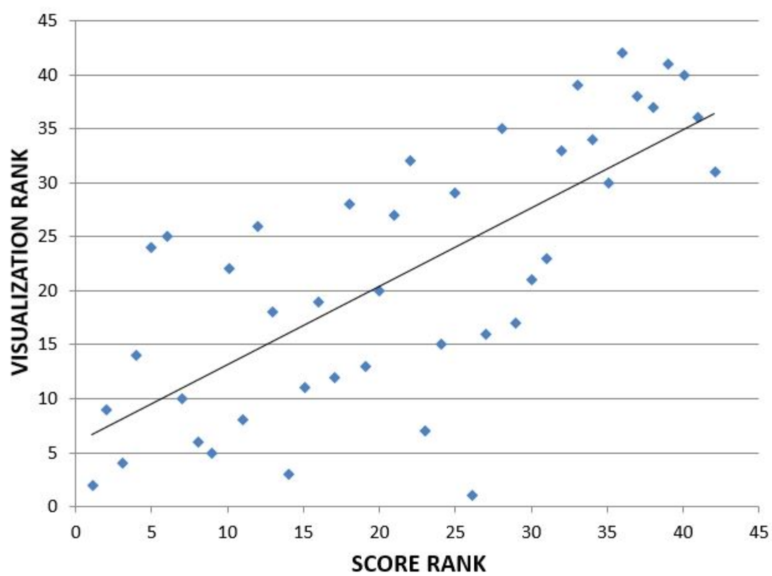

Figure 6. Score Rank by Visualization Rank.

To gain a better understanding of students' modeling strategies, a sample of models was more closely examined. The raw data for all participants (Figure 7) was arranged based on the model score ranks. Highlighted sections on the table represent students who scored at the upper end of the range, students whose models resulted in a score in the middle of the range, and students whose modeling score was at the lower end of the range.

4 - 100	SET SCREW	INDEX ARM	PACKING RING	TOTAL	SCORE RANK	PSVT:R	MCT	VIS SCORE	VIS RANK
95	99	92	93	94.75	1	30	23	53	2
90	95	96	94	93.75	2	26	22	48	9
80	91	100	98	92.25	3	30	21	51	4
90	99	85	95	92.25	4	26	21	47	14
95	97	89	86	91.75	5	26	18	44	24
95	99	85	86	91.25	6	26	18	44	25
90	89	88	92	89.75	7	28	20	48	10
90	94	85	87	89	9	29	22	51	5
90	90	86	90	89	8	29	21	50	6
95	92	86	82	88.75	10	23	22	45	22
80	90	90	89	87.25	11	29	20	49	8
80	94	80	93	86.75	12	23	21	44	26
90	86	89	80	86.25	13	27	19	46	18
70	87	89	95	85.25	14	29	24	53	3
75	93	84	84	84	15	29	19	48	11
80	88	92	74	83.5	16	26	20	46	19
70	81	89	88	82	17	30	18	48	12
65	93	92	77	81.75	18	26	16	42	28
60	86	91	89	81.5	19	28	20	48	13
80	81	72	82	78.75	20	27	19	46	20
70	89	83	72	78.5	21	28	16	44	27
60	85	89	76	77.5	22	24	13	37	32
80	85	86	56	76.75	23	28	22	50	7
55	87	83	78	75.75	24	28	19	47	15
45	85	89	82	75.25	25	28	12	40	29
80	93	54	72	74.75	26	29	25	54	1
80	75	73	71	74.75	27	26	21	47	16
50	75	87	76	72	29	25	22	47	17
50	85	88	65	72	28	21	12	33	35
60	80	75	69	71	30	30	16	46	21
50	81	80	73	71	31	24	21	45	23
30	78	94	69	67.75	32	26	10	36	33
35	81	76	64	64	33	14	9	23	39
65	74	40	73	63	34	27	9	36	34
50	80	73	46	62.25	35	25	15	40	30
50	85	63	24	55.5	36	10	2	12	42
20	65	68	48	50.25	37	17	8	25	38
10	29	58	73	42.5	38	14	13	27	37
20	76	0	59	38.75	39	10	8	18	41
20	30	70	29	37.25	40	16	6	22	40
20	30	58	23	32.75	41	21	7	28	36
0	0	64	54	29.5	42	21	19	40	31

Figure 7. Grouping of Data from Modeling Activities and Spatial Visualization Tests.

Qualitative Analyses

Day 2 Exercise – To help understand if students in the three groups took different approaches to modeling at the beginning of the semester, examples of the SPACER were examined (Figure 8-10). The example from the upper group (Figure 8) demonstrates a model that is fully constrained, uses only the dimensions given in the original sketch, and represents the design intent communicated by the instructor. The example model from the middle group (Figure 9) is not fully constrained, has extra dimensions, and is not related logically to the origin. The example model from the lower group (Figure 10) shows the origin in a good location with proper dimensions, but is missing a couple key geometric constraints that would fully define the sketch.

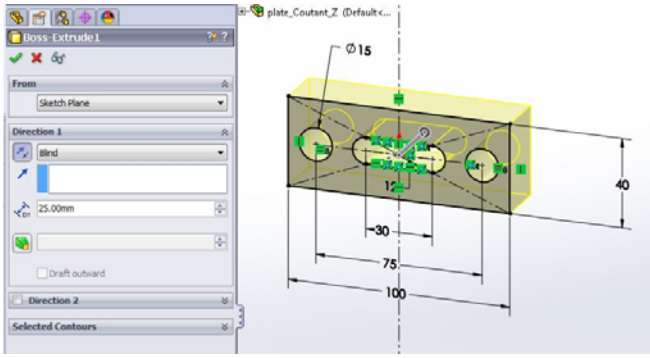

Figure 8. SPACER – Upper Group Example.

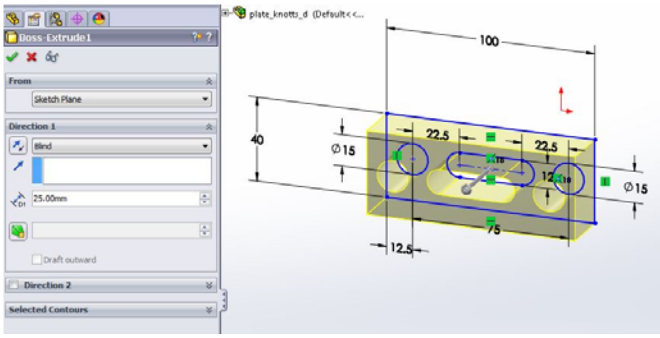

Figure 9. SPACER – Middle Group Example.

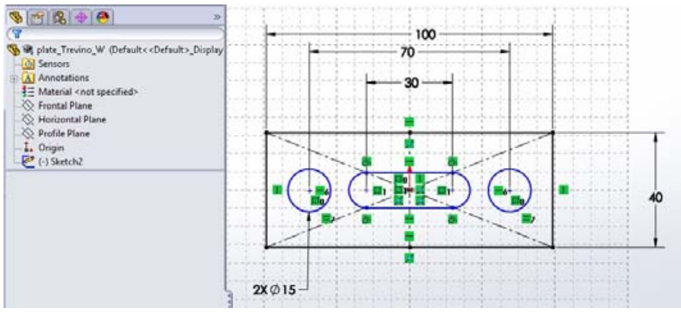

Figure 10. SPACER – Lower Group Example.

SET SCREW – Figures 11-13 show examples of the SET SCREW that was completed toward the end of the semester. The example from the upper group (Figure 11) demonstrates an efficient, fully constrained model. The only issue with this model is that the hexagon is defined by a dimension across the corners instead of across the flats. The example model from the middle group (Figure 12) is missing the chamfer feature and the cosmetic thread, defines the hexagon sketch in a non-standard way, and is not very efficient. The example model from the lower group (Figure 13) is not in the correct orientation and is incomplete.

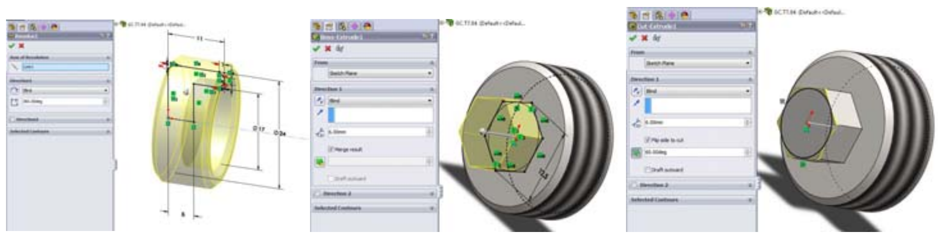

Figure 11. SET SCREW – Upper Group Example.

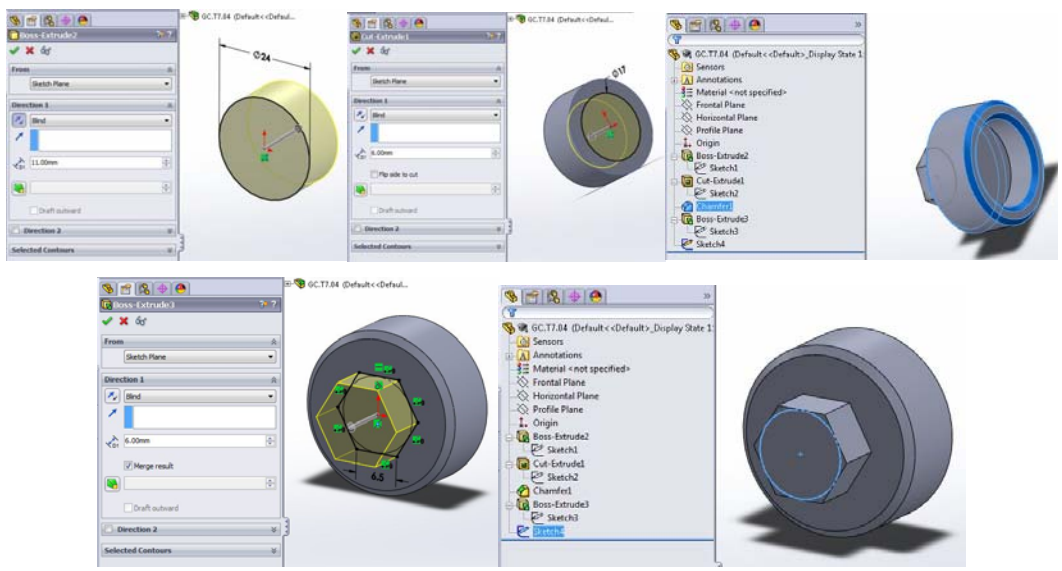

Figure 12. SET SCREW – Middle Group Example.

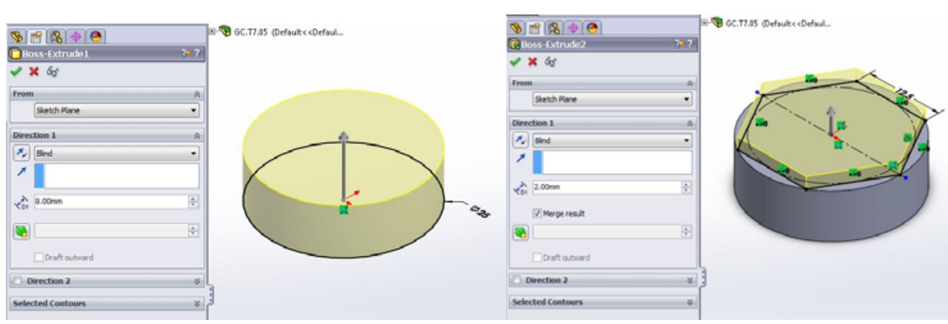

Figure 13. SET SCREW – Lower Group Example.

INDEX ARM – Figures 14-16 show examples of the INDEX ARM. The example from the upper group (Figure 14) demonstrates an efficient, fully constrained model that takes advantage of the symmetry of the model. The example model from the middle group (Figure 15) is relatively efficient, but the student did not build symmetry into the cut for the bottom slot. The example model from the lower group (Figure 16) demonstrates a very inefficient modeling strategy. Here the student added or subtracted basic individual primitives instead of looking at more complete features. Many of the sketches are under-defined, and the final volume is not correct.

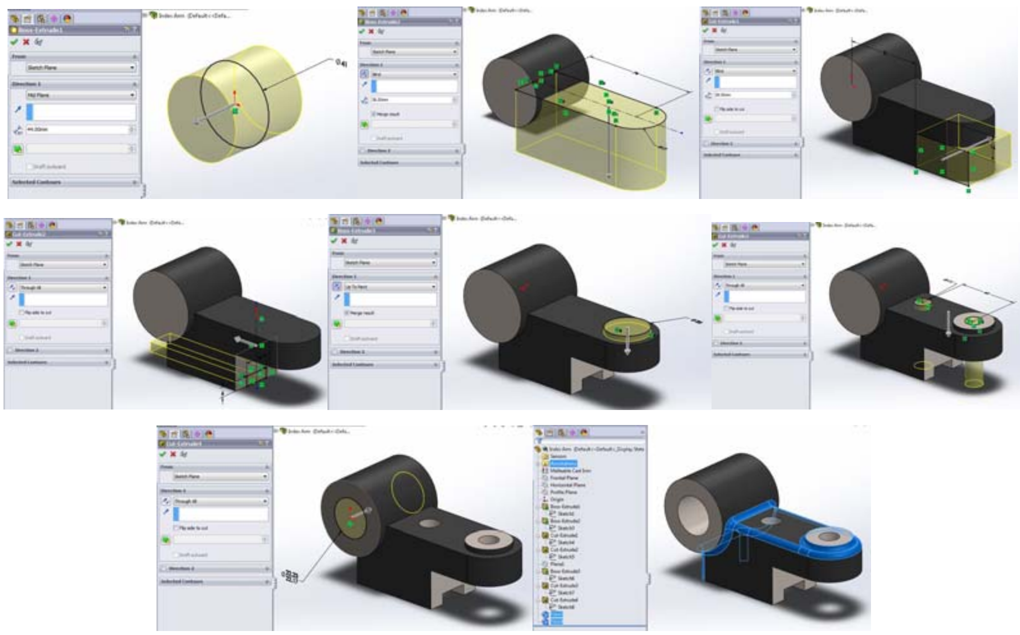

Figure 14. INDEX ARM – Upper Group Example.

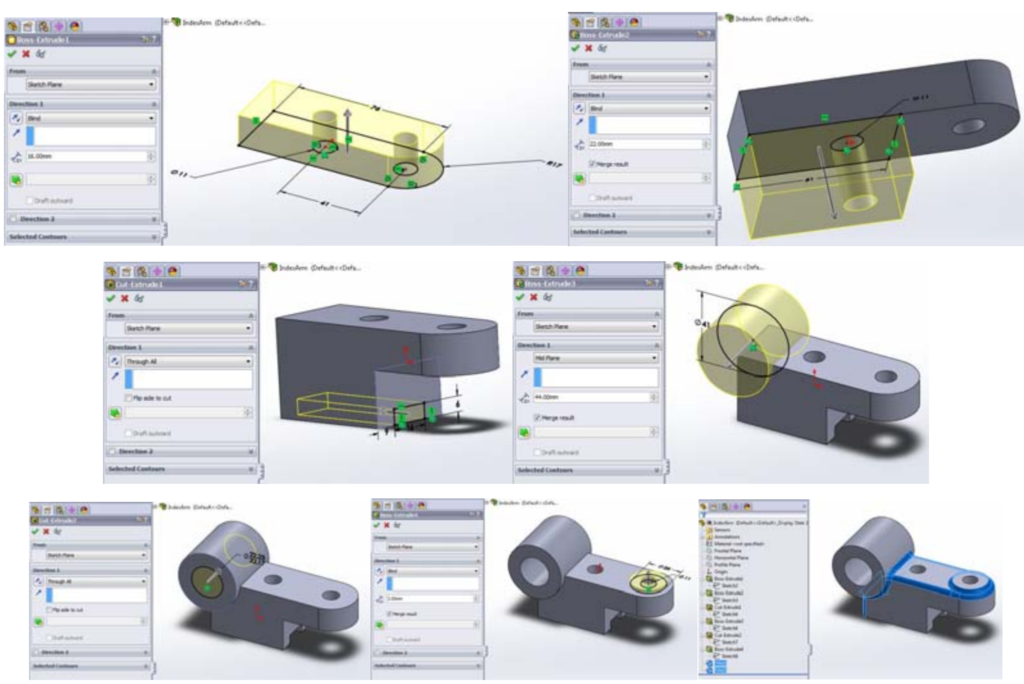

Figure 15. INDEX ARM – Middle Group Example.

Figure 16. INDEX ARM – Lower Group Example.

RING – Figures 17-19 show examples of the RING. The example from the upper group (Figure 17) shows a very efficient modeling strategy. The student completed the model in two features and built intelligent design intent into the model. The example model from the middle group (Figure 18) is much different. The student took a "sculpting" approach to modeling the part by cutting away features from an initial extrusion. The result was an incorrect and inefficient model. The example model from the lower group (Figure 19) demonstrates a similar strategy, but it appears that the student could never get past the second sketch.

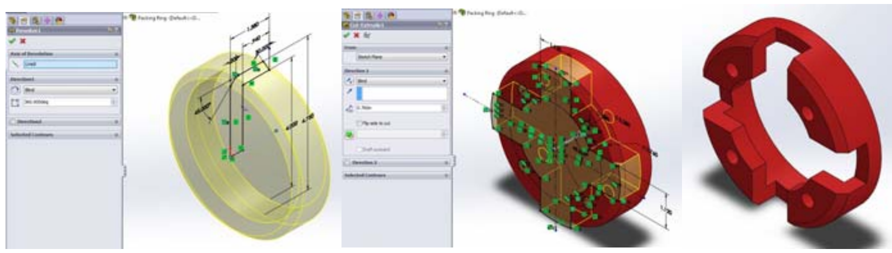

Figure 16. RING – Upper Group Example.

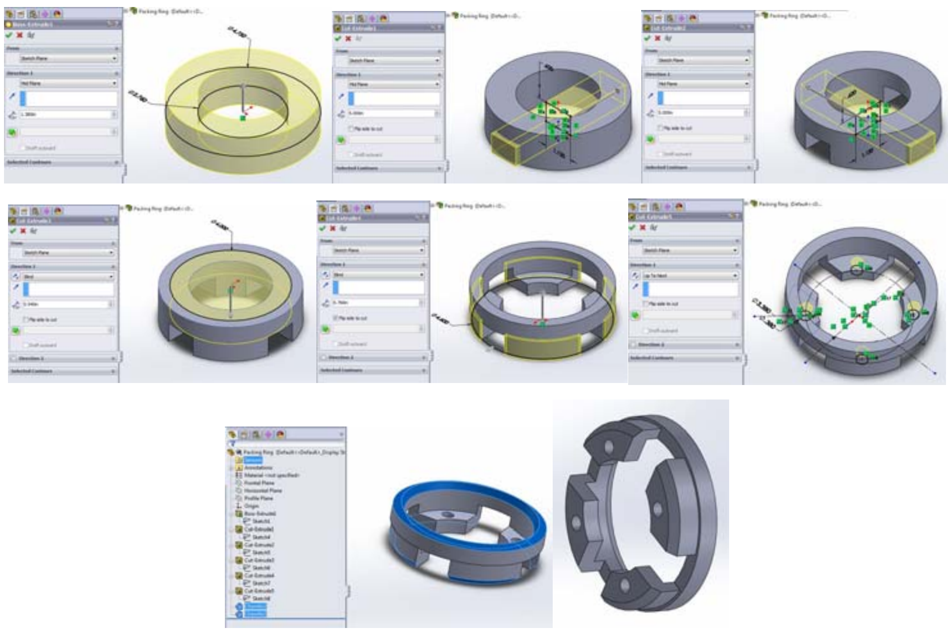

Figure 17. RING – Middle Group Example.

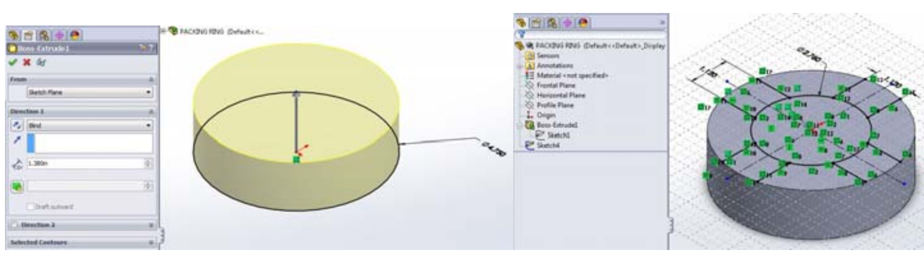

Figure 18. RING – Lower Group Example.

Conclusions

Several conclusions can be drawn from examining the modeling strategies of a sample of students in the three groups. First, spatial visualization ability plays a key role in students' ability to dissect the 3D models to interpret the correct geometry. Almost all students successfully created the SPACER since it could be created with a single sketch. Even students who created it with multiple features still created the correct 3D geometry. For the SET SCREW and the RING, students were required to read a 2D drawing, visualize the 3D part, and then plan out an appropriate modeling strategy. Those who ranked low on visualization also tended to rank low on modeling. This was evident when examining their individual models. Those in the lower group tended to misinterpret the 3D geometry more often than the students in the upper group for these two parts.

In general, students in the upper group tended to recognize design intent in the given models, and they used appropriate modeling strategies to make the models behave in a desired manner. Examples of this include building symmetry into slots to keep them centered, using appropriate end-conditions such as through-all holes, and using single fillet features for equal radius fillets instead of multiple features for each edge. Students in the middle and lower groups either took the approach of building models with a series of primitives, or they started with a large block of material and cut away features to get the final model.

There were mixed results related to the number of features used to complete models. Even in the upper group there was a wide range for the number of features used to create all of the models. For example, some students created the SPACER with one feature (an extrude based on one sketch), while others created it with three features (one extrude and two cuts). It is likely that the having more experience in a manufacturing environment might produce more efficient models.

Recommendations

Since students still enter this course with such a variety of modeling abilities, two specific items should be addressed. First, faculty need to examine the content and modeling activities required in the introductory course. Students should be able to create the SPACER model even if they took the introductory course more than a semester ago. Secondly, the instructor of this course should investigate some ways to review basic modeling strategies at the beginning of the semester to bring all students up to a minimum level of modeling competency.

Another recommendation is to introduce verbal protocol methods for examining students' constraint-based strategies. This would give a better understanding of what students are thinking about by having them verbalize their strategies as they are completing the modeling tasks.

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