ABSTRACT

Title of Thesis: SYMBOLS FOR COMPUTER-AIDED DESIGNSOFTWARE OPERATIONS: SELECTION AND EFFECT ON USER RECALL

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Computer Aided Design (CAD) software can be difficult to learn. Past research has not investigated how the selection of symbols used to represent CAD operations affects a new user's ability to learn CAD concepts. In this paper, we explore how symbol choice impacts short-term recall as measured by accuracy and response time. We performed an initial study to identify what 2D symbols users draw to perform common CAD operations. This study identified common symbols for five CAD operations and highlighted differences between symbols drawn by inexperienced and experienced CAD users. Then, we conducted a second study with three groups using different input methods: selecting Autodesk Inventor CAD operation icons, selecting 2D symbols derived from the first study, and physically drawing those same symbols. There is not a statistically significant difference between the three groups' average question accuracy. For time taken to submit responses, the group selecting Autodesk icons was lowest, followed by the group selecting the symbols, and then the group drawing the symbols. Additionally, the group drawing the symbols had a greater improvement in response time compared to the group selecting Autodesk icons. Other differences between groups were not found to be statistically significant. The results from our second study suggest a negative correlation between our set of user-created symbols and response time, and the potential for further research on other symbols from our first study.

SYMBOLS FOR COMPUTER-AIDED DESIGN SOFTWARE OPERATIONS: SELECTION AND EFFECT ON USER RECALL

by

Team Print

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Chapter 1: Introduction

Computer-Aided Design (CAD) programs are computer software used to design three dimensional (3D) models. Examples of such software that are commercially available include Solidworks®, Creo™, and Autodesk Inventor®. With any of these software, one can use a mouse and keyboard input to design a multitude of 3D objects and convert the model into a format that can be manufactured using additive manufacturing techniques. The job market for product design through additive manufacturing has expanded over the past two decades and has led to job creation in both the manufacturing and service sectors (Kianian, Tavassoli, & Larsson, 2015). As a result, the proliferation of 3D modelling and design has gained popularity with the public alongside its business uses. One of the most popular examples of additive manufacturing, 3D printers, can even be found in libraries and other public places (Hoy, 2013). However, CAD has benefits and uses outside of the manufacturing field, both for the industries and hobbyists that choose to use them. Specifically, CAD has been shown to help students improve spatial reasoning, improve academic performance, and solve problems in fields outside of engineering and manufacturing (Martin-Dorta et al., 2008; Miller et al., 2013).

CAD's required use of spatial ability and visual perception can quickly benefit the spatial reasoning of those who spend time learning it. For example, researchers at the University of La Laguna (Spain) found that civil engineering students who spent 12 hours per week for three weeks learning Sketchup significantly improved their spatial abilities as measured by a Mental Rotation Test (MRT) and Differential Aptitude Test - Spatial Relations Subset (DAT:SR) (Martín-Dorta, Saorín, & Contero, 2008). These students' spatial skills were tested before and after the course with an average observed gain of 5 points in MRT and 8 points in DAT: SR. The study found that sketch-based modeling improved their ability to perceive rotations and the unfolding of closed 3D shapes (Martín-Dorta, Saorín, & Contero, 2008). In another study, “gifted” science, technology, engineering, and mathematics (STEM) students when compared to a randomly selected control group, improved their introductory physics grades and ability to mentally rotate 3D objects after six weeks of two-hour spatial training sessions (Miller and Halpern, 2013). The training also narrowed gender differences in spatial skills when measured shortly after training (Miller and Halpern, 2013). However, eight months after the spatial training, all three benefits of the training were effectively eliminated (Miller and Halpern, 2013). These studies show a possible relationship between CAD usage and student spatial reasoning skills, in addition to a possible relationship between a consistent exposure to CAD and an improvement in scores in STEM classes.

Current Limitations of CAD Software

Despite the numerous benefits of learning and using CAD, personal 3D printers and CAD software are still not commonplace. Many people without any background using CAD software have expressed difficulties learning CAD due to its steep learning curve and use of high-level operations. (Kopp, G. A., 1999) Some setbacks that current CAD software face in terms of outreach and education include the visual complexity of its interface, the mental complexity of its workflow, and the arbitrary nature of its input methods (Piegl, 2005).

Nishino, Takagi, Saga, and Utsumiyain (2002) focused on building a 3D modeling environment for inexperienced CAD users and noted that the primary struggle of most new CAD users is the visualization of 3D objects. This inability of new users to visualize 3D objects causes a disparity in CAD learning time in favor of those with prior spatial reasoning training (Barbero, Pedrosa, & Samperio, 2017). Also, as computer systems are designed in a logical way that mimic how computers think rather than how humans think, there were limitations regarding innovative design (Piegl, 2005). Improving software for beginning CAD users would involve reducing the effect of the users' spatial reasoning abilities on their ability to learn.

Past researchers who have studied CAD sketch interfaces, particularly for novice users, often use specific symbols defined by several authors; however, it is often unclear why and how those symbols are chosen and to what extent those symbols improve understanding or learning. This is a significant problem as CAD icons are the primary method of interaction that CAD users click on to execute CAD operations. Consequentially, users learning CAD often match their 3D visualizations with corresponding CAD operations and its symbols (Hod, 1998). As a result, studying how this association affects the CAD learning process can improve CAD education. The research presented studies what symbol sketches correspond to CAD operations for first-time users by surveying those with little to no CAD experience using a symbol elicitation task (Symbol Study) and later testing the short-term recall of inexperienced CAD users being taught with these symbols (Recall Study). Results of these experiments inform researchers of 1) what symbols might be good candidates for improving future sketch-based CAD systems, and 2) if and to what degree operation symbol choice impacts an inexperienced CAD user's ability to learn CAD concepts.

Chapter 2: Related Work

Improvements to CAD Software

Past researchers attempting to incorporate sketching into CAD have typically employed one of the following methods: constructing 3D models from 2D user sketches and constructing 3D models from freehand user sketches of symbols corresponding to predefined CAD operations. In a study by Lipson and Shpitalni in 2007, scanned freehand 2D sketches were processed and converted into 3D solid shapes. A primary benefit of this software was that it allowed users who could draw but had no traditional CAD intuition, to represent 3D shapes in CAD software without having to learn a traditional user interface. However, it is currently dependent on the orientation of the sketches; for example, a cube drawn from a perspective view is easier for the software to interpret than that same cube drawn from the front, where it would appear as two squares, one slightly smaller than the other (Lipson and Shpitalni, 2007).

Another software created by Governi, Furferi, Palai, and Volpe in 2013 interpreted 2D orthographic sketches from a user and converted them into a 3D model in CAD. Because users provided a front, side, and top view, they could more carefully describe the orientation of the shape. However, there were places where the software did not interpret it accurately, such as where two curves joined together. In addition, the drawing of freehand curves on the orthographic drawings forced the software to fit a curve to the imperfect drawings of the user, including line segments that the user did not draw perfectly straight. Interpreting freehand curves and edges is still an open issue within the CAD community which may be why traditional CAD software force users to select operations rather than drawing what they want to see.

Past studies have attempted to remedy the ineffectiveness of scanning sketched objects into CAD software by developing symbols that allow users to create models on the computer. Farrugia, Camilleri, and Borg (2014) created a language of symbols to represent various 3D shapes and CAD operations. The drawings with symbols were scanned into a computer, which generated a 3D object. The researchers tested it on college undergraduates to determine if they were more effective than traditional CAD symbols. However, the participants in this study were engineering students who had prior experience with CAD software. Additionally, the language had a set of spatial rules and restrictions on what symbols were allowed and how they should be drawn, which some participants did not follow during the study (Farrugia et al., 2014).

In the system created by Cheon, Kim, Mun, and Han (2012), the researchers created a stroke-based CAD modeling system where small drawn gestures could be used to create 3D models. For example, a simple 3D model of a rectangular prism could be drawn by first drawing a rectangle and then drawing a caret representing extrude (See Figure 1). The list of the user's strokes was translated into a macro file, which was used as input to commercial CAD software to create the final solid from intermediate solids (Cheon et al., 2012). Compared to reconstruction systems, using gestures gives the user a higher degree of freedom (Cheon et al., 2012). While the researchers were successful in creating an input type for CAD with seven different operations, the symbols selected were designed to be understood by a computer rather than a human user.

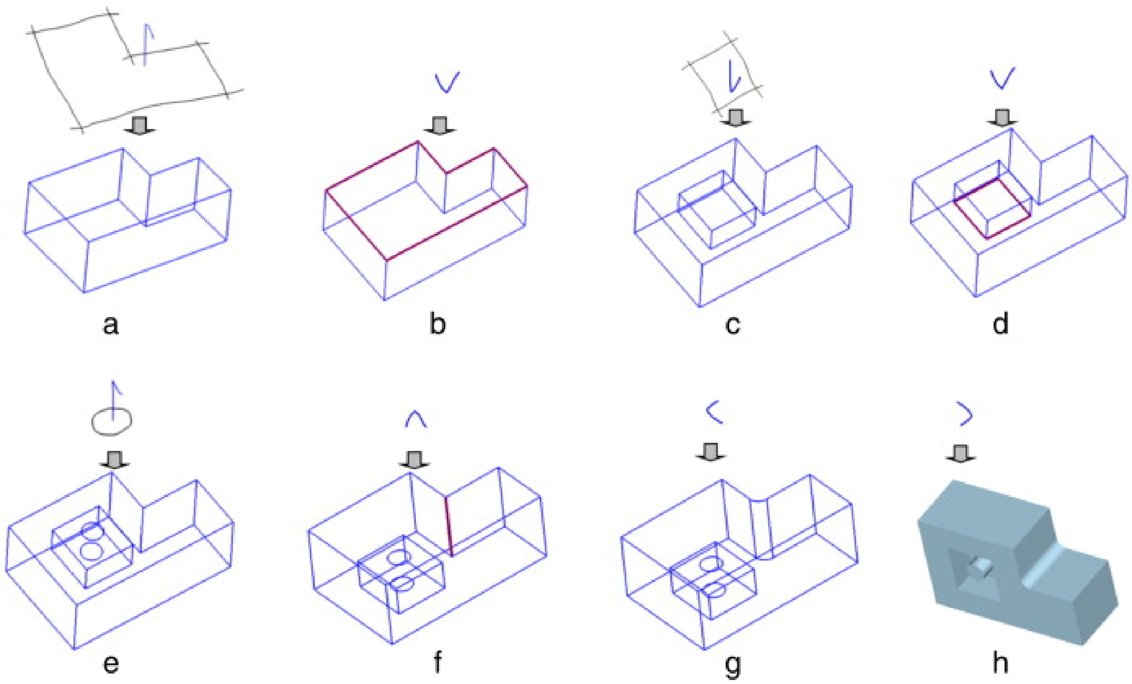


Figure 1: Symbols used in Cheon et al. (2012)

Teaching CAD

Several studies have attempted to teach CAD through a series of computer-aided instruction modules. In a study by Abdulrasool and Mishra in 2009, CAD was taught to a class of students at the Bahrain Institute of Computing and Engineering. The researchers followed a class through a series of six modules beginning with the basics of computer drawings and progressing to more difficult concepts of computer model assembly. One class was taught using computer-integrated lecture series while another class was taught with a lecture-based curriculum. Using a series of pre- and post-study rankings, the researchers found that the differences in score showed an improvement with a higher self-reported learning score in the classes with computer-integrated lectures (Abdulrasool and Mishra, 2009).

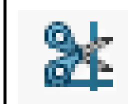
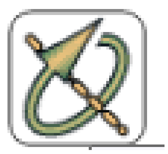
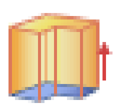
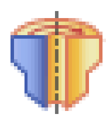
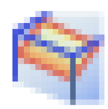
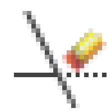
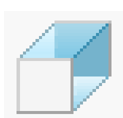
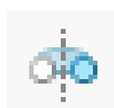
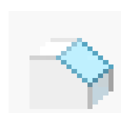
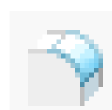
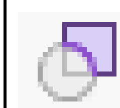
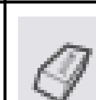
We address open questions in from past attempts to sketch 2D symbols. Specifically, the symbol sketching systems discussed do not tackle the problem of operation recall, or new users' ability to remember an operation. Quinn and Wilson (2010) showed that retention of lecture material increases when the student writes notes. In addition, Baltes and Diehl (2014) showed that students who learned architecture concepts by sketching and drawing diagrams maximized short-term recall in those students. However, it has not been researched whether sketching operations results in a more effective CAD learning experience compared to the traditional point and click method. In addition, past research has not rigorously studied the effects of symbol choice on operation recall.

Symbol Choice

As many studies on CAD research were aimed to create sketch-based software rather than a learning interface, the choice of symbols that were chosen to represent each operation has not been fully explored. In the case of Cheon et al. (2012), their system was a pen-tablet based system that created 3D systems from 2D sketches. However, the symbols that they chose to represent each CAD operation were made to be simple for the computer to recognize, rather than easy for a person to learn. In the case of Zeleznik, Herndon, and Hughes (2007), the system was a standard mouse interface which asked user to draw gestures in a certain order to perform CAD operations, but those gestures were also chosen to be easier to implement into the computer system rather than for the user to understand.

Additionally, symbols are not chosen with the average person in mind, but rather someone who is already familiar with CAD design such as an engineer. In the case of Farrugia et al. (2014), the study aimed to create 3D models from a series of 2D sketches using certain symbols to represent the different CAD operations such as linear extrusion, loft, and sweep. In these cases, using the CAD system heavily relied on the user's understanding of each operation.

Table 1: Table of icons used to represent CAD operations in various CAD programs

	Extrude	Revolve	Chamfer	Fillet	Trim
Autodesk Inventor 2018					
Solidworks					
ANSYS					n/a
NX 11					
CREO					
SketchUp Free			n/a	n/a	

Existing CAD software shows some similarity in their icon design, as shown in Table 1. Chamfer and fillet typically show some variation of a cut or rounded off edge. Trim is represented by scissors or an eraser. Extrude tends to have some representation of a flat shape, as well as having the resulting body highlighted in a different color. Most extrude symbols also include an arrow. Revolve is similar, though SketchUp does not have a revolve command. Instead it uses a “Follow Me” command that drags a profile along a separately defined path. If a circular path is used, it can function as a revolve. This command can also be used to fillet or chamfer (“Chamfer or Fillet a hole in an object”, 2017). Tinkercad, a popular low-end CAD software, is not included in Table 1 because it does not use those operations. Instead, users can drag and drop geometric shapes such as cubes, cylinders, or spheres, and then adjust the scale, aspect ratio, and rotation. There are also shape generators, which can produce more complicated shapes, but require programing knowledge to create custom ones (“How do I fillet a 45-degree corner of a rectangle”, 2016).

Open Questions in Improving CAD Software

Throughout the current literature available in the field, there are some questions that remain unanswered. According to Szewczyk (2003), a user’s first experience with CAD has a large impact on their outlook on the software. However, CAD programs tend to be complex software built on the premise of practicality and efficiency rather than learning. One question that arises is how the symbols used to represent CAD operations impact a new user’s ability to use CAD concepts. A second question that arises is whether the symbols themselves or the input method with which the user interacts with symbols is more impactful on CAD learning. In summary, if a new user was to learn CAD with traditional CAD symbols, “optimized” CAD symbols, or a new input method using “optimized” CAD operations, which learning method would result in the quickest learning and the most accurate short-term recall?

Cho, Cheng, and Lai (2009) stated that new users of an e-learning tool perceived its functionality to be greater when they were provided with multiple methods of completing the same task. In addition, changes in software's graphical user interface (GUI) increased user motivation to continue with that e-learning tool, increasing the amount of information learned. To that end, testing the role each component of a CAD interface plays in learning CAD concepts can help the community develop software with user-friendliness in mind (Cho et al., 2009).

Research Questions

Based on the prior literature, we pose three research questions.

1. What symbols do inexperienced CAD users draw when prompted to transform one shape to another?
2. How does learning CAD operations with user-created symbols versus traditional CAD icons affect short and long-term recall of CAD operations?
3. How does learning CAD operations by drawing user-created symbols versus selecting user-created symbols affect short and long-term recall of CAD operations?

For these questions to be valid, the team needs to answer two questions: what defines recall and what separates short-term recall from long-term recall?

The term recall, in past research, has been defined with two primary metrics: accuracy and time. In a study completed by Schmid and Bogner in 2015, accuracy on science and math examinations were used as a barometer to gauge the retention of information by high school students. In addition, Lee, Ko, and Kwan (2013) showed that assessments during computational learning not only increased the overall time spent on the e-learning tool, but improved students' understanding of the concepts being taught. They collected both quiz results and time spent on the quizzes to conclude that the time spent on the quizzes decreased over the course of the e-learning tool. In our studies, both these metrics were used to measure CAD understanding. Furthermore, the field of usability research covers three main categories: effectiveness, efficiency, and satisfaction (Hornbæk, 2006). For example, one measure of effectiveness is the users' ability to recall information presented in the interface, such as the memory of a button location and a measure of efficiency is time to complete a task (Hornbæk, 2006). In this thesis, the tested statistics were a variation of those two measures. However, because the CAD operations and actions are presented as independent questions instead of part of an interface or program, "recall" is used instead of the broader "usability", which may imply that a fully functional software program was constructed as part of this thesis.

With the given definition of recall, what separates long-term recall from short-term recall? A study by Souza and Oberauer in 2015 asserts that time on the scale of seconds affects the recall interval for visual working memory tasks. Unsworth, Heitz, Schrock, and Engle in 2005 created a test whose goal was to stress visual working memory. When the authors took the test themselves, all required at least ten minutes. Therefore, during the short-term recall study, participants were given this test for exactly ten minutes in between CAD concept quizzes to determine if it affected accuracy of content understanding and recall time.

Chapter 3: Methodology

Symbol Study Testing Procedure

1. The symbol study was conducted in three locations on the University of Maryland’s campus on December 13, 2016 (the day before the start of fall semester final exams): inside McKeldin Library, inside Hornbake Library, and outside the chemistry lecture halls next to the Chemistry Library. People that walked by the study tables were asked if they would fill out a quick survey related to CAD in exchange for a piece of candy. They were informed that no prior CAD experience was necessary, and the survey was projected to take no longer than 10 minutes.
2. After participants agreed to complete the survey, they were asked to fill out the IRB consent form and fill out the cover sheet of the survey. This was administered via a printed packet on a clipboard. Participants were allowed to stand or sit and move around the area of the table where the completed packets were placed.
3. The cover sheet asked participants to list any CAD software they had previously used and to select their proficiency levels in each software from one of three choices: basic, intermediate, and advanced.
4. Participants were presented with a packet of ten questions (two per page). They were informed to fill out the packet to the best of their ability.
    a. Each question contained a “Before” figure on the left, i.e. a 2D sketch or 3D solid that would exist prior to executing one of the selected CAD operations, and an “After” figure on the right, which showed the solid or

sketch after executing the operation. They were asked to draw a symbol (on the "before" figure) that they believed would turn the "before" figure to the "after" figure. Participants were not responsible for creating a shape; they simply had to indicate how they would represent the transformation. See Figure 2 for a sample symbol study question.

b. CAD Operations included: extrude, revolve, trim/cut, fillet, chamfer. There were two questions for each operation. Participants were not told which operation corresponded to which figure.

c. No time limit was enforced.

5. Participants were given wrapped candy as compensation at the completion of the survey.

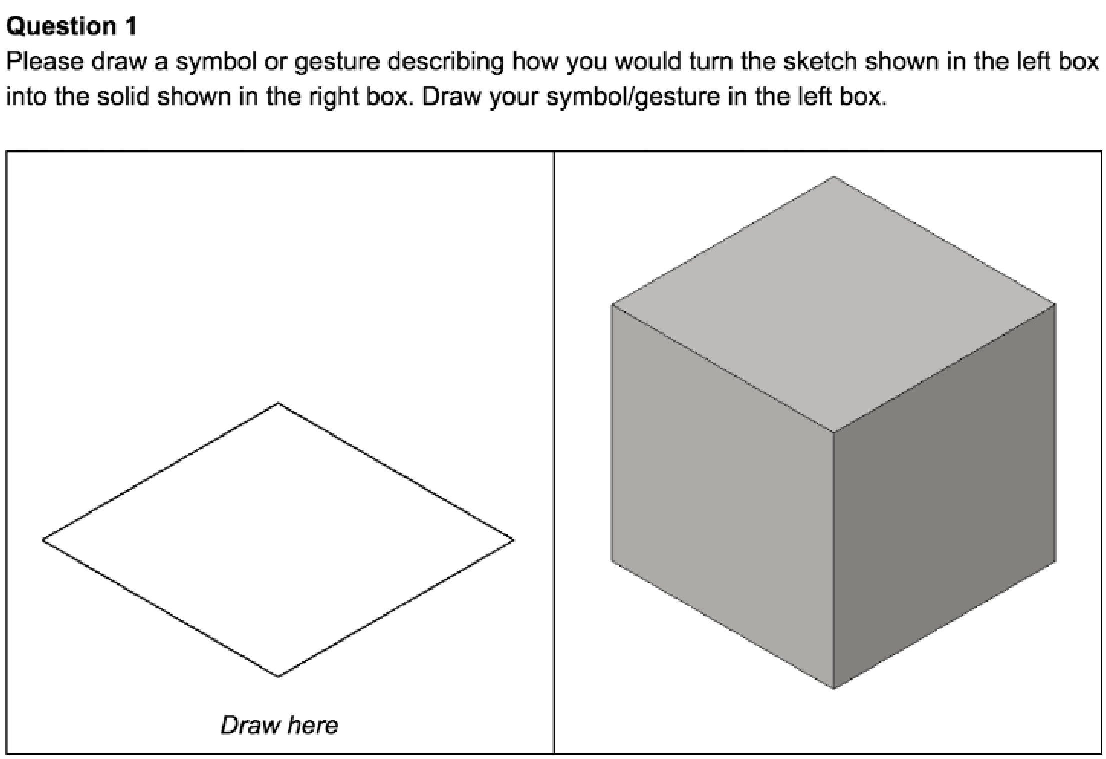


Figure 2: Sample Question in the Symbol Study

Short-term Recall Study Testing Procedure

The procedure was designed to take no longer than 1 hour (10 minutes for pre-survey process, 5 minutes for video, 15 minutes for first test, 10-minute waiting period, 15 minutes for second test, 5 minutes for post-survey).

Pre-survey process

The study took place over the course of three days in May 2017. Participants were first given a pre-assessment survey that requested the following:

- Signature for consent form
- Level of CAD experience
- Major/class standing

Participants were then divided evenly into three groups based on the order in which they came to take the test.

- CAD Icon Group: Users who selected traditional CAD (Autodesk Inventor) icons when quizzed on CAD concepts
- User-Created Symbols Group: Users who selected user-created symbols when quizzed on CAD concepts
- Drawing User-Created Symbols Group: Users who drew user-created symbols when quizzed on CAD concepts

Table 2: Testing Group Descriptions

	Testing Group A (Autodesk Icons)	Testing Group B (User-Created Symbols)	Testing Group C (Drawing User-Created Symbols)
Question type	Select Autodesk icon in multiple choice question	Select symbol in multiple choice question	Draw symbol Given icon bank
Video icons used	Autodesk toolbar icons	Symbol study icons	Symbol study icons in simplified version for drawing*

*See “Specific Group Details”.

General testing group procedure

The initial and final tests covered the same CAD operations with different 3D before and after models. The questions were randomly distributed inside each half. All questions, including pre and post assessments, were optional. Participants were given an iPad or a MacBook Pro to complete the test online. All participants in the Sketch Input Symbol Study Icons group were given iPads since they needed to draw their responses. Participants sat at a chair desk combination which faced a wall of the classroom and were separated from other participants in the testing room as to not bias any data.

1. A participant was first shown a video displaying five CAD operations (extrude, revolve, fillet, chamfer, and trim, in that order) and their associated icons (see Table 2). For each operation, the video then demonstrated the operation in action on a shape. The video was shown on the individual participant’s screen and administered via YouTube. The participant was given headphones to not distract other participants.

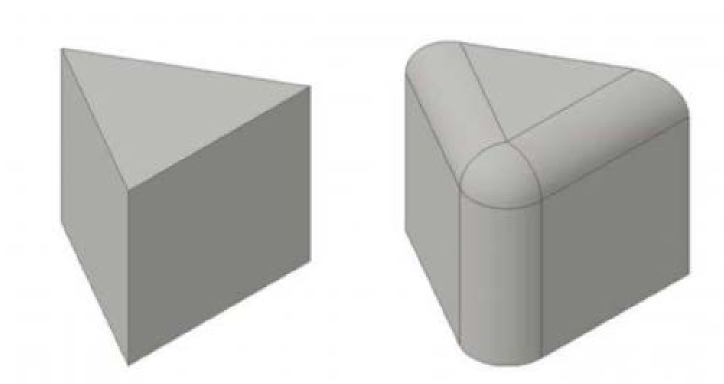
2. Immediately after the participant watched the video, he/she was asked to complete a 20-question short-term recall test asking the operation needed to transform one given shape to another. The survey did not ask for participants to construct the shape, only to indicate the operation used. Sample questions are shown in Figure 3 and Figure 4.
    a. This test was given electronically via Qualtrics on each participant's computer or iPad. The software tracked the accuracy of the user's responses and the time spent responding to each question. Participants were not shown their accuracy or time spent and were not able to reference the video when completing this exercise.
    b. Participants had to complete the tasks in question order. They were not able to return to a question after had have answered it.
3. Participants then had to complete a working memory capacity task for ten minutes to distract them from actively remembering all the symbols previously presented to them (Unsworth, et al., 2005). The test was manually started and ended by the proctor and administered on the participant's computer or iPad.
4. The participants were asked to complete a 20-question short-term recall test (same format as first test).

Select the option that best describes the statement.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
I was confident in my answers to the questions on the first test	○	○	○	○	○

Figure 3: Sample Likert Scale Question in the Short-Term Recall Study

The image below is a before and after picture for a certain CAD operation.



Which of the following CAD operation icons would perform the action in the picture above?

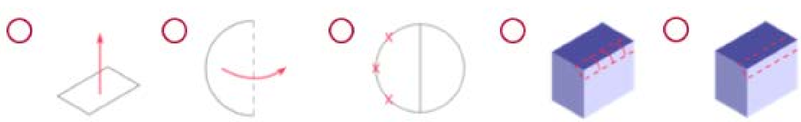


Figure 4: Sample Short-term Recall Study Question. The symbols were selected by the team (see "Symbol Study Results"). In the actual survey page, symbol choices were oriented vertically.

Specific group details

Each group had similar recognition tests but had a different set of answers to choose from. No group had text labels, ex. “Extrude”, on the quiz.

For the Autodesk Icons Group, participants learned traditional CAD icons from Autodesk Inventor and during testing selected the correct icon from a collection of icons (multiple choice).

For the User-Created Symbols Group, participants learned what each of the symbolic icons (as determined from the symbol study) meant. During testing, they selected one of those (multiple choice).

For the Drawing User-Created Symbols Group, participants learned about the same symbols as the symbol study icons group and drew them as answers for the recognition tests. Participants were given a symbol bank as shown in Figure 5.

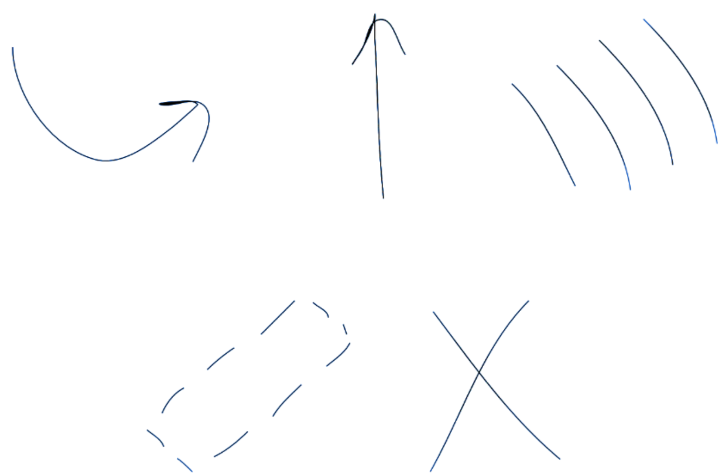


Figure 5: Symbol Key for the Sketch Input Symbol Study Icons Group.

Justification of Methodology

The symbol study was designed to allow participants to determine what icon they would use to transition a 2D shape into a 3D shape. The team analyzed the data and categorized the answers to those ten questions. The symbols used in the short-term recall study were based upon the most common responses drawn.

In setting up the experiment for the main study, the team chose to teach the participants via a video created by one of the researchers on our team. This would ensure consistency between participants of the same group as opposed to a proctor teaching the subject face to face. Literature indicates that online classes are less intimidating for the learner, at the expense of their engagement and motivation (Ni, 2013). Nevertheless, Ni indicates that in comparing data from several courses from previous investigators, it is shown that there is no statistically significant difference between online and in-class modes of learning (2013). The videos shown across the three testing groups were identical in terms of the content explaining each operation. The only difference was the image that a person would click or draw depending on their assignment group. Schwan and Riempp research showed that users with interactive videos took less time to learn the material presented in the videos then those who had a non-interactive video (2004). The interactive videos allow users to learn on their own accord and personalize their learning experience (Schwan & Riempp, 2004). In our study, while participants were allowed to pause and replay the video, they were not able to reference the video while taking the survey questions so that they only information they would use in choosing their answer would be that of what they recalled.

In the short-term recall study, there were two sections: one section tested for recognition of what the participant had just learned, and the second section tested for recall. In long surveys, researchers found that questions asked later may produce lower quality (participants giving more uniform answers, and faster) data, so participants were given 20 randomized questions per section (Galesic and Bosnjak, 2009). A working memory taxing task was given to distract users between the recognition and short-term recall sections of the study (Unsworth, et al., 2005). Participants were limited to ten minutes and moved on to the second half even if they had not finished the task. When the memory taxing task was tested on several members of the research team, they took between twelve and fifteen minutes to complete. Ten minutes was chosen to ensure the memory taxing task would fill that available time and avoid survey fatigue.

Chapter 4: Results and Discussion

Symbol Study Results

The goal of the symbol study was to answer the research question: What symbols do inexperienced CAD users draw when prompted to transform one shape to another?

A total of 92 people participated in the study: 58 did not have any experience with CAD and 34 had some experience with CAD, ranging from basic to advanced. The three most common software packages were Autodesk Inventor (5 advanced, 7 intermediate, 10 basic, and 1 participant circled multiple options), Solidworks (2 advanced, 6 intermediate, and 4 basic), and AutoCAD (1 advanced, 3 intermediate, and 2 basic).

Two members of the research team were assigned to analyze and classify all responses to a given question independently. The analysts filled out a table with the number of responses within that category. The two then compared the top symbols in their respective charts and produced a combined list of the most popular symbols for each operation and how many times they were drawn. They also selected the symbol that would best represent each operation in the short-term recall study (for groups B and C). Note that the symbol classification “Other” refers to either illegible responses or classified responses made by five or fewer participants.

1. Symbols used for extrude

Table 3: Extrude Box Response Categorization

Extrusion	Extrude Outline (a)	Arrow up (b)	Arrow and Written Extrude (c)	Outline and Arrow (d)	Other (e)
Box	41	23	10	8	10

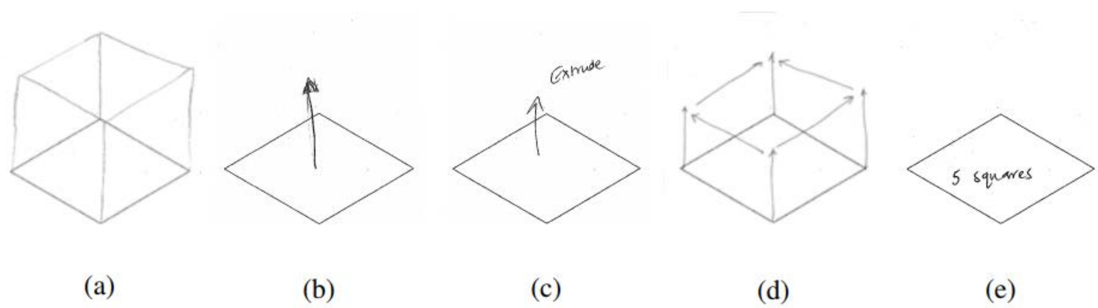


Figure 6: Sample Images of Each Category in the Extrude Box Response Set

Table 4: Extrude Cylinder Response Categorization

Extrusion	Extrude Outline (a)	Arrow up (b)	Arrow and Written Extrude (c)	Outline and Arrow (d)	Other (e)
Cylinder	34	29	11	7	11

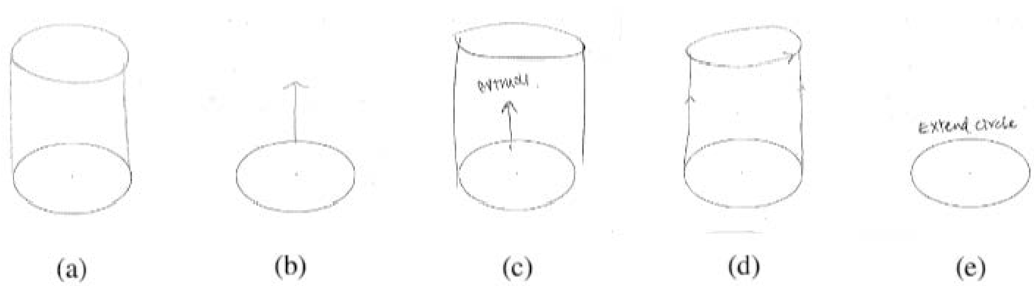


Figure 7: Sample Images of Each Category in the Extrude Cylinder Response Set

Two questions detailed an extrusion that transformed a 2D square into a 3D box and a 2D circle into a 3D cylinder. While outlining the shape itself seemed to be the most popular, an upward arrow was selected for use in the short-term recall study because the outline would be dissimilar for different shapes, and the upward arrow was the second most popular response.

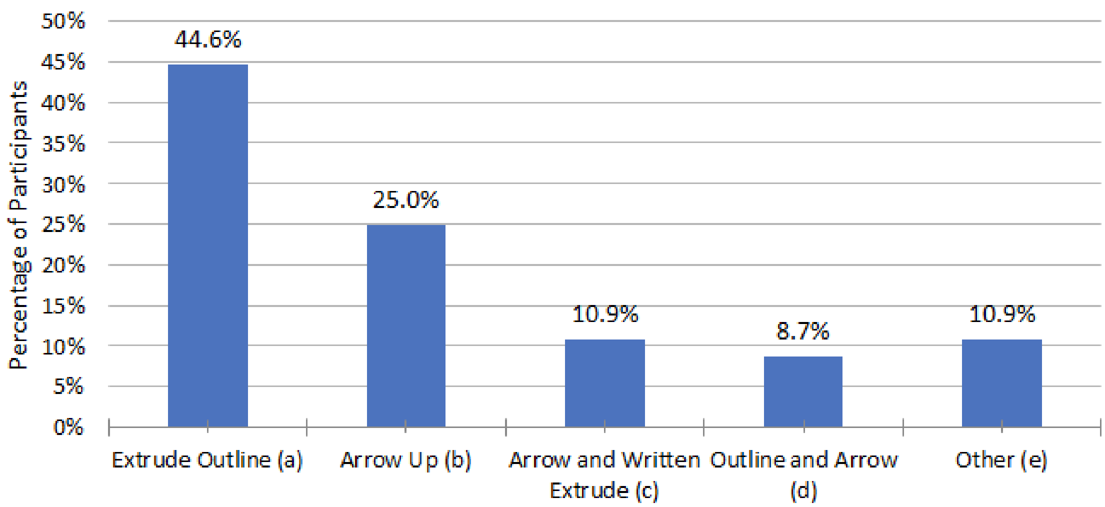


Figure 8: Percentage of participants drawing each operation for Extrude Box.

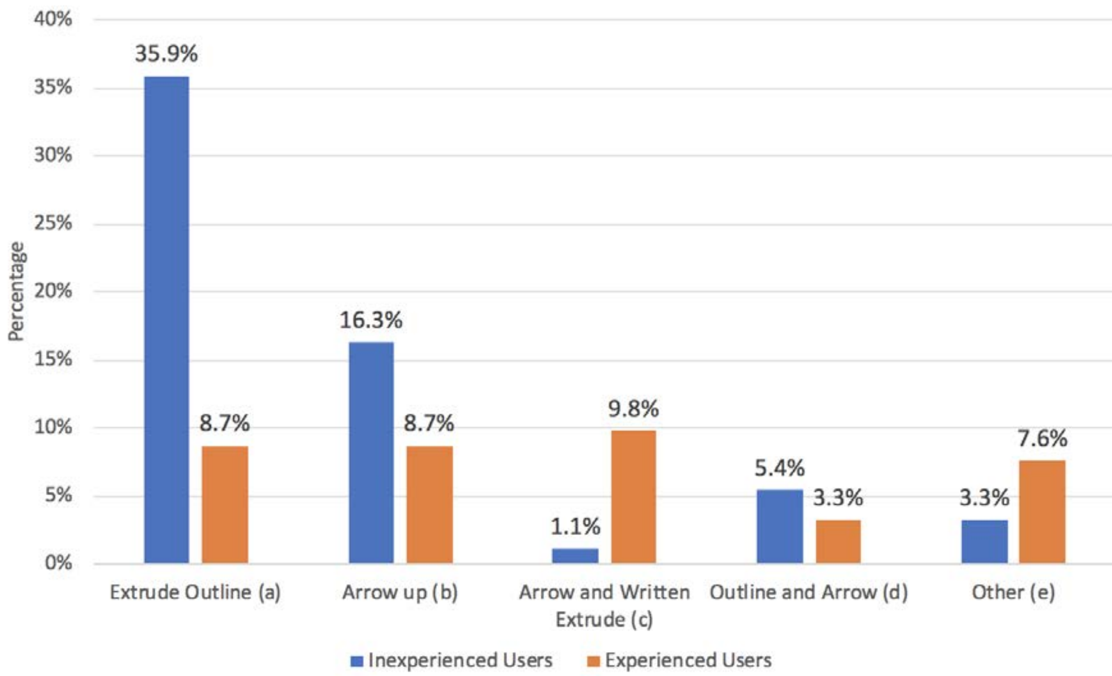


Figure 9: Percentage of participants drawing each operation for Extrude Box by experience.

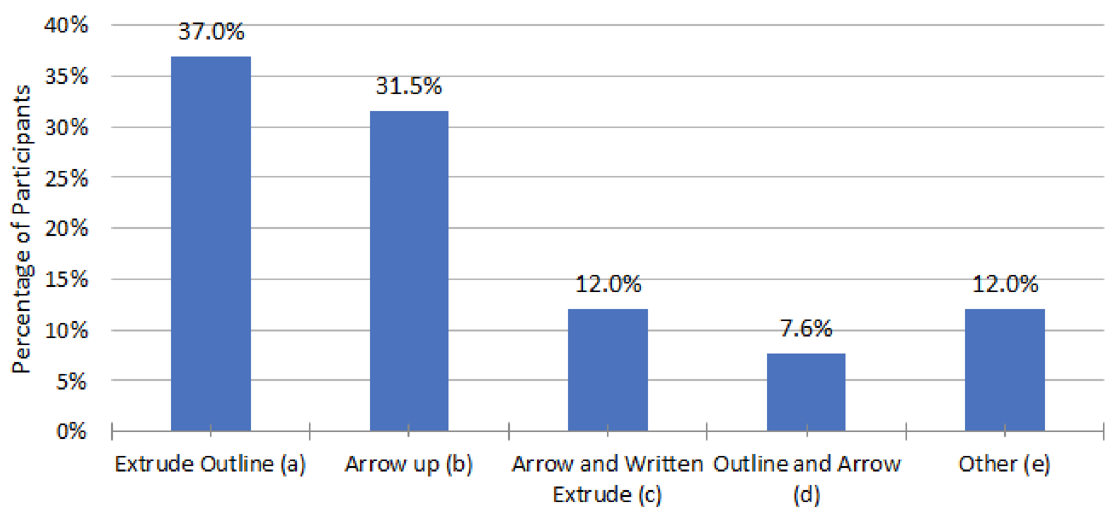


Figure 10: Percentage of participants drawing each operation for Extrude Cylinder.

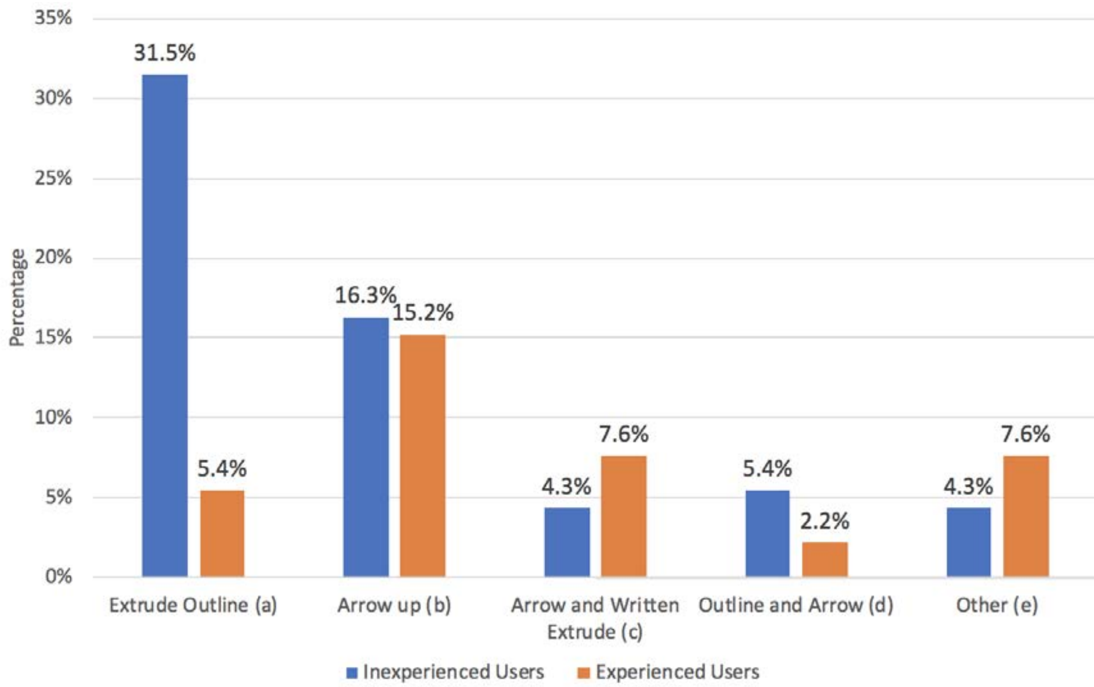


Figure 11: Percentage of participants drawing each operation for Extrude Cylinder by experience.

2. Symbols used for revolve

Table 5: Revolve Sphere Response Categorization

Revolve	Sphere by Drawing Arcs (a)	Arrow Around Axis (b)	Arrow Misc. (c)	Other (d)
Sphere	40	35	8	9

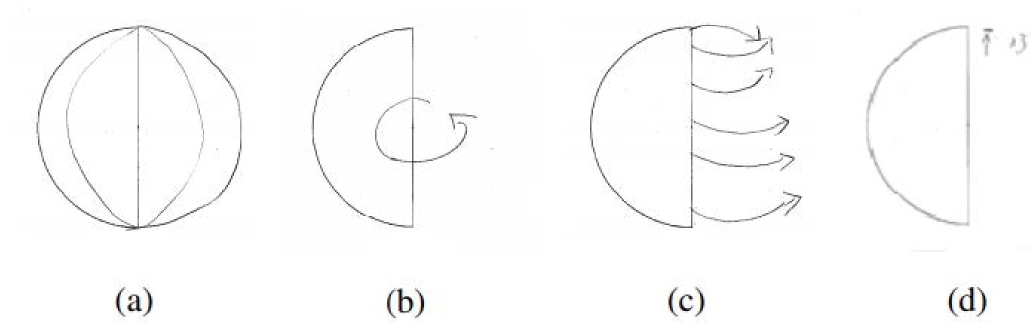


Figure 12: Sample Images of Each Category in the Revolve Sphere Response Set

Table 6: Revolve Cylinder Response Categorization

Revolve	Drawing Full Cylinder (a)	Revolve arrow symbol/words (b)	Multiple Arrows (c)	Other (d)
Cylinder	29	29	10	24

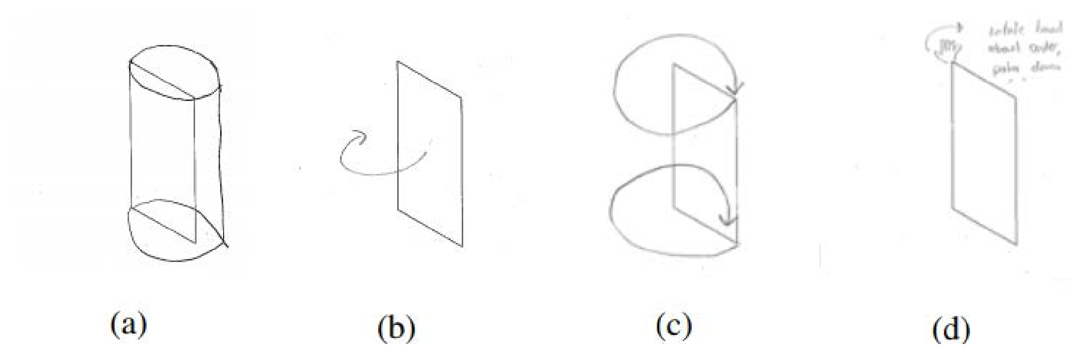


Figure 13: Sample Images of Each Category in the Revolve Cylinder Response Set

Two questions asked participants to revolve a 2D semi-circle into a 3D sphere and to revolve a 2D rectangle into a 3D cylinder. The team selected a curved revolve arrow as the symbol for the short-term recall study because it that would be the same for different shapes, despite being the second most popular response.

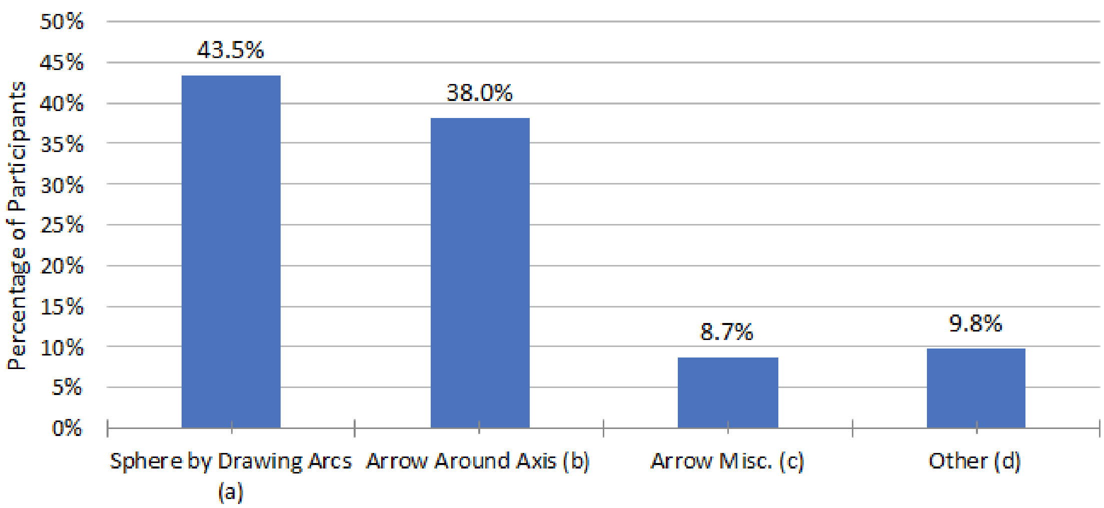


Figure 14: Percentage of participants drawing each operation for Revolve Sphere.

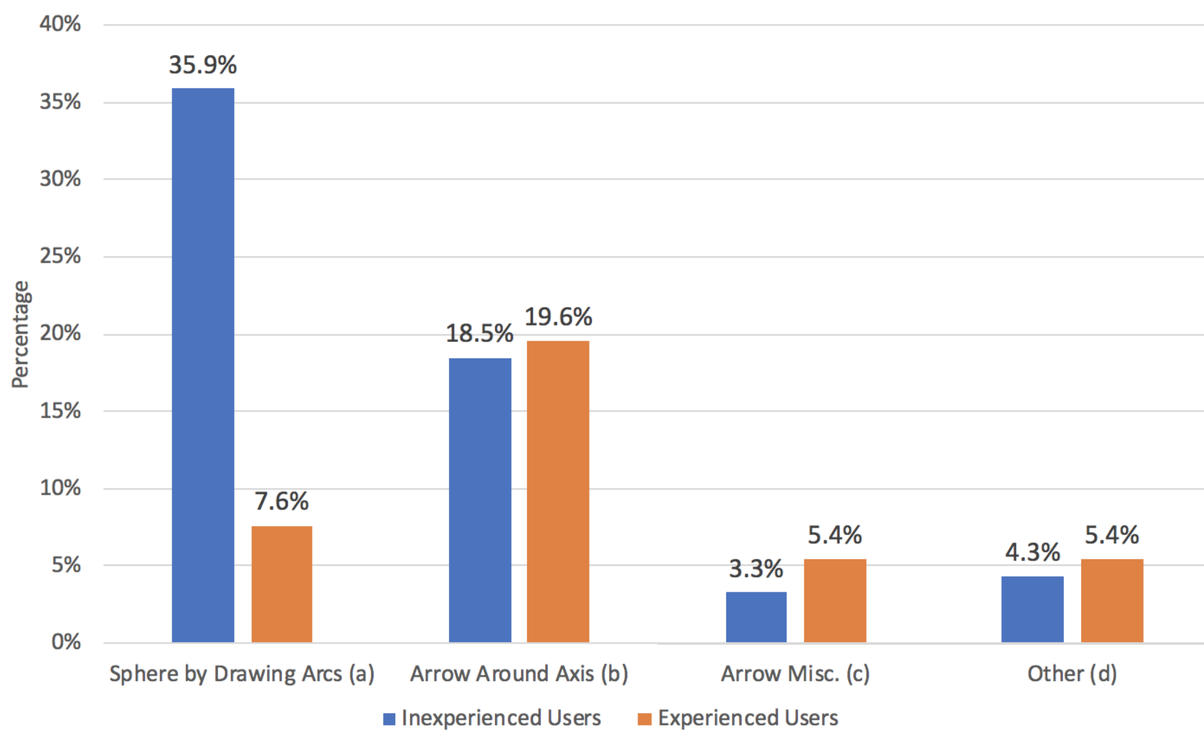


Figure 15: Percentage of participants drawing each operation for Revolve Sphere by experience.

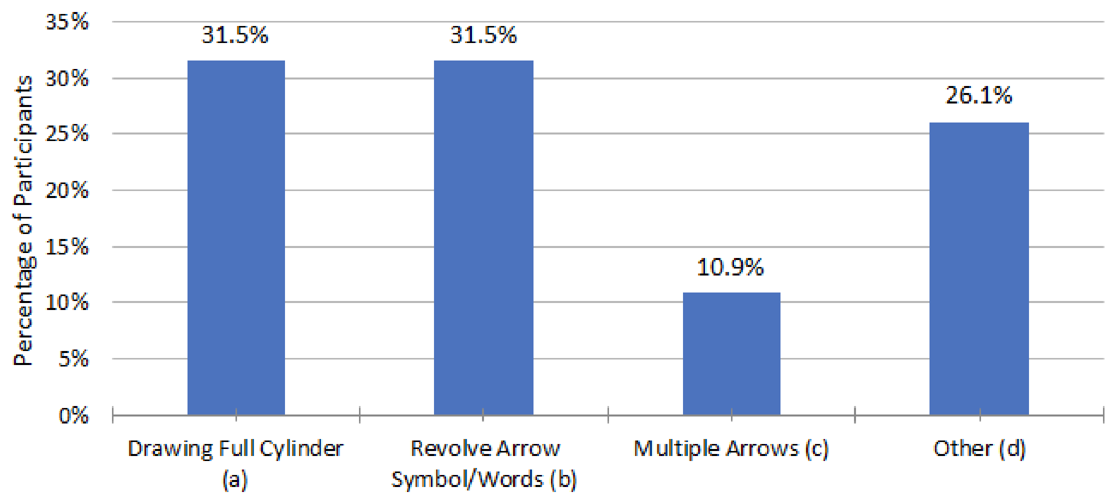


Figure 16: Percentage of participants drawing each operation for Revolve Cylinder.

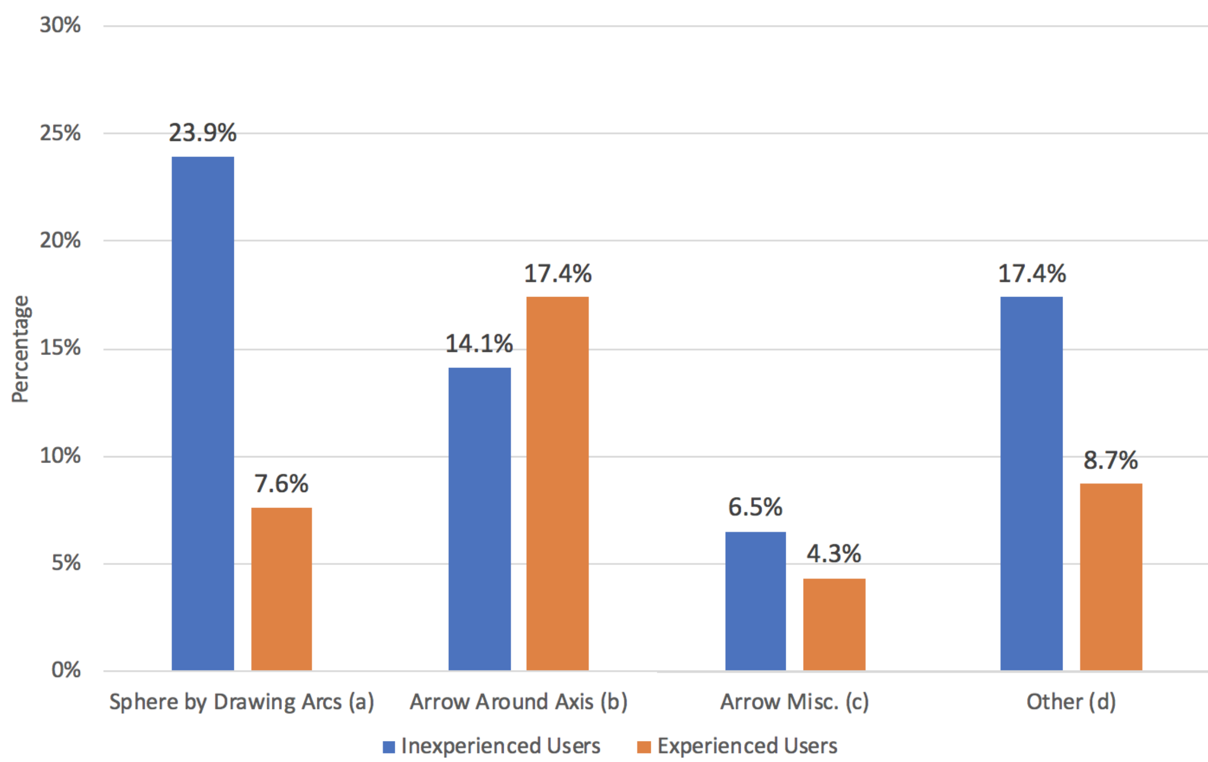


Figure 17: Percentage of participants drawing each operation for Revolve Cylinder by experience.

3. Symbols used for chamfer

Table 7: Chamfer Box Response Categorization

Chamfer	Incomplete Outline w/ words or symbols (a)	Complete Outline w/ words or symbols (b)	Incomplete Outline w/o words or symbols (c)	Only symbol (d)	Complete Outline w/ words or symbols (e)	Other (f)
Box	21	18	18	14	8	13

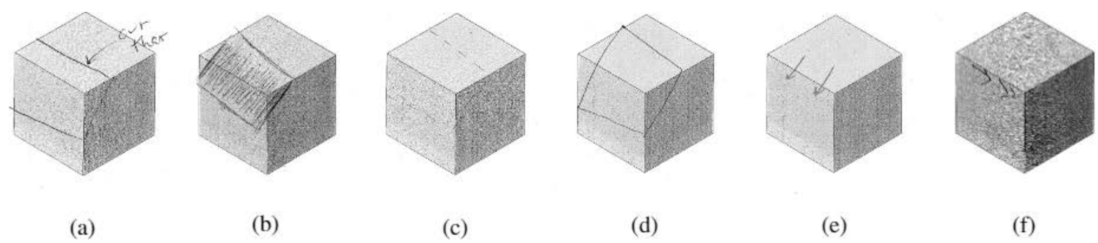


Figure 18: Sample Images of Each Category in the Chamfer Box Response Set

Table 8: Chamfer Box with Hole Response Categorization

Chamfer	Incomplete Outline w/ words or symbols (a)	Complete Outline w/ words or symbols (b)	Incomplete Outline w/o words or symbols (c)	Complete Outline w/o words or symbols (d)	Only arrows to right (e)	Other (f)
Box with Hole	27	16	15	9	7	18

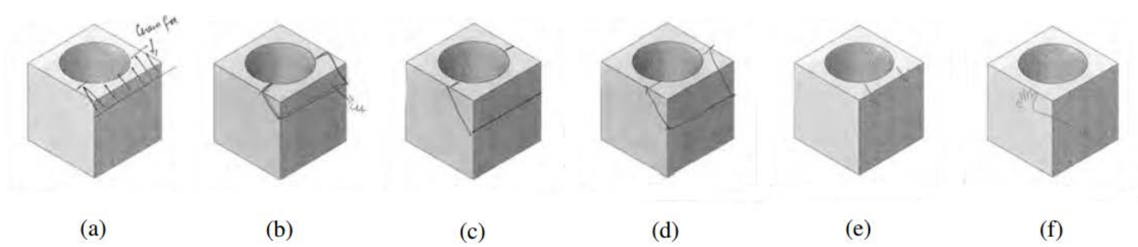


Figure 19: Sample Images of Each Category in the Chamfer Box with Hole Response Set

Two questions asked participants to chamfer a box and chamfer a box with a hole through its center. The team selected a complete outline of the chamfer as the symbol for the short-term recall study because complete outline was the most consistent and easiest to interpret (for incomplete outlines, participants varied in the sides(s) of the rectangular outline they omitted).

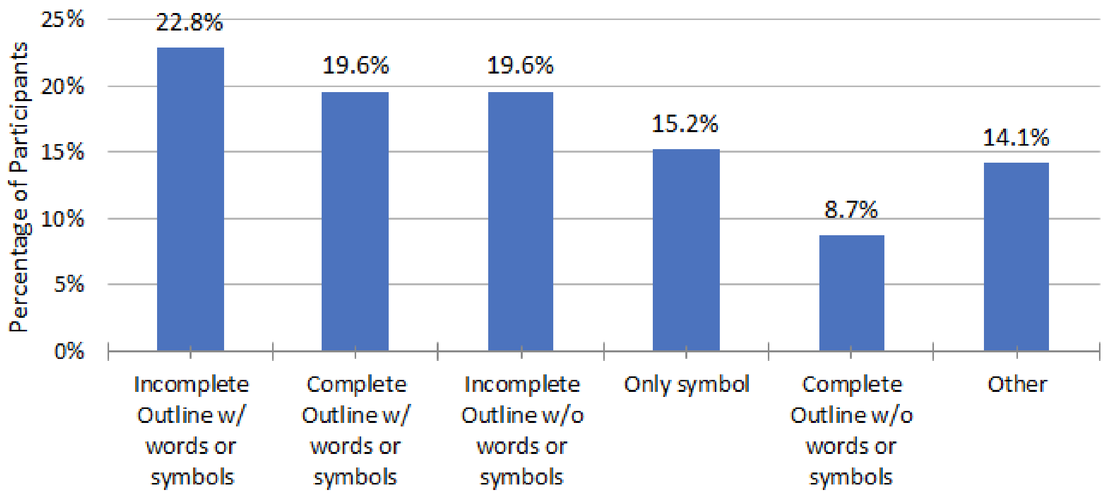


Figure 20: Percentage of participants drawing each operation for Chamfer Box.

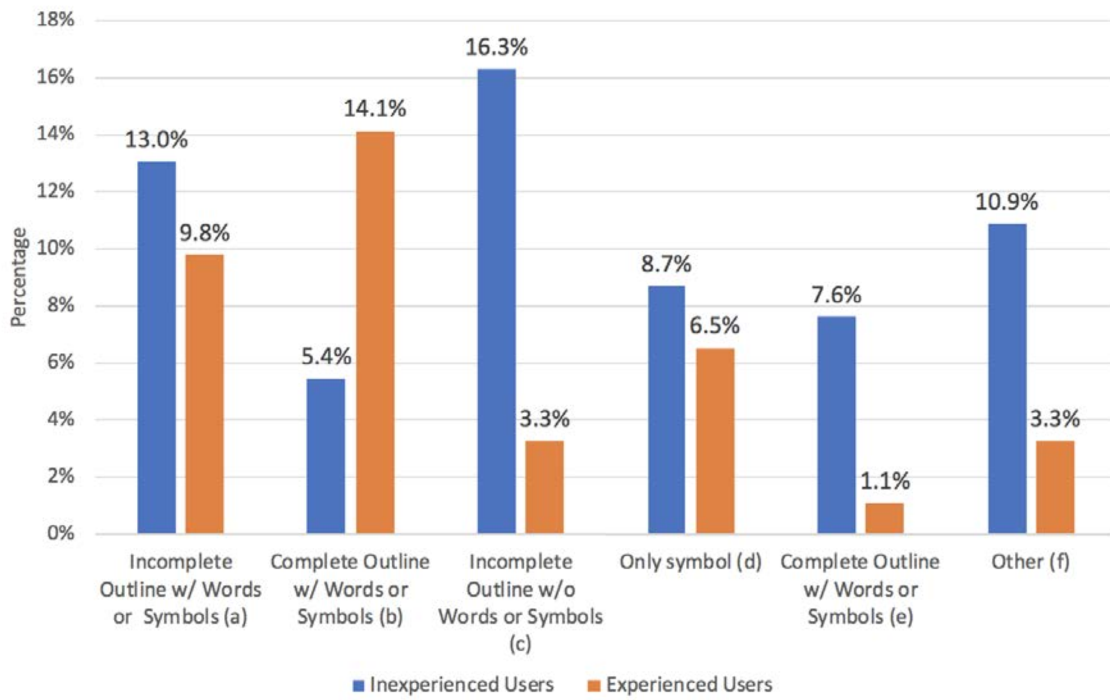


Figure 21: Percentage of participants drawing each operation for Chamfer Box by experience.

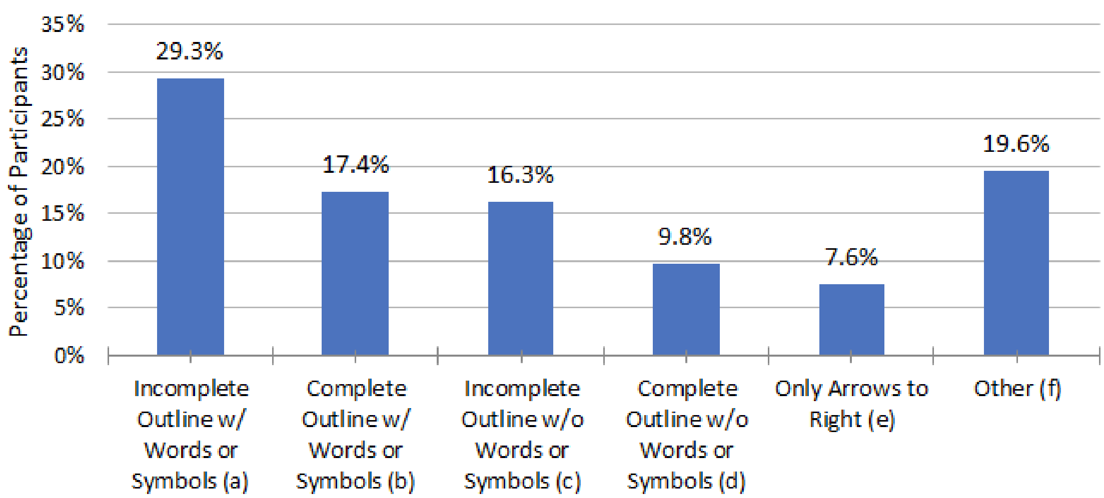


Figure 22: Percentage of participants drawing each operation for Chamfer Box with Hole.

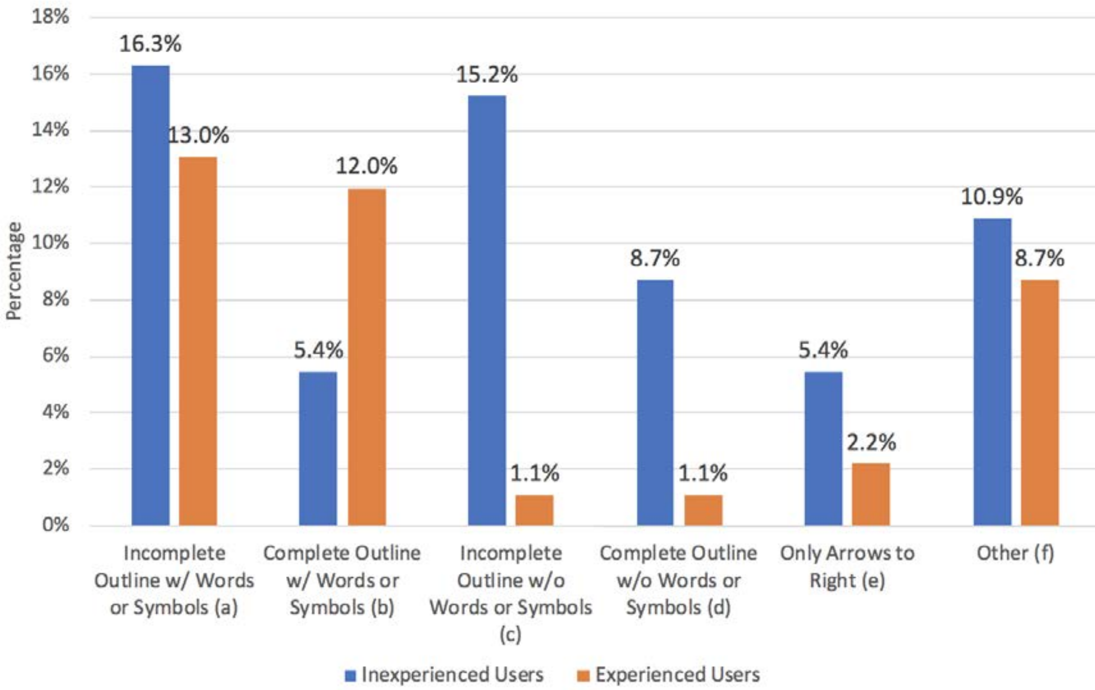


Figure 23: Percentage of participants drawing each operation for Chamfer Box with Hole by experience.

4. Symbols used for fillet

Table 9: Fillet Box Response Categorization

Fillet	Outlined Fillet (a)	Rounding marks or arrows only (b)	Icon (c)	Extrude-Like or Cut (d)	Outline with rounding marks (e)	Other (f)
Box	37	22	9	9	7	8

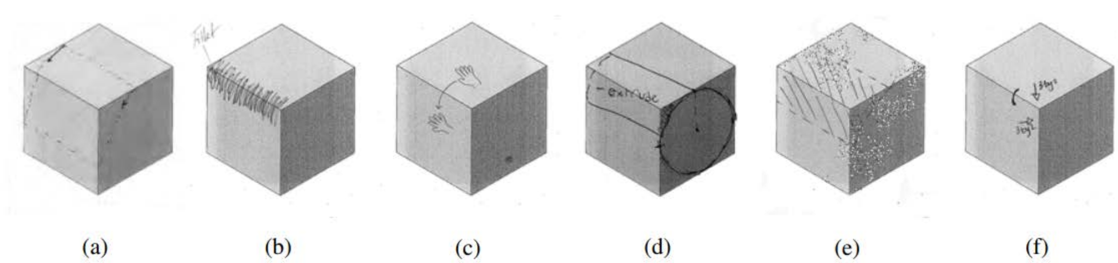


Figure 24: Sample Images of Each Category in the Fillet Box Response Set

Table 10: Fillet Cylinder Response Categorization

Fillet	Outlined Fillet, subtractive (a)	Outlined Fillet, rounding marks (b)	Revolve Cut (c)	Outlined Fillet, additive (d)	Text Only (e)	Other (f)
Cylinder	24	23	10	8	6	21

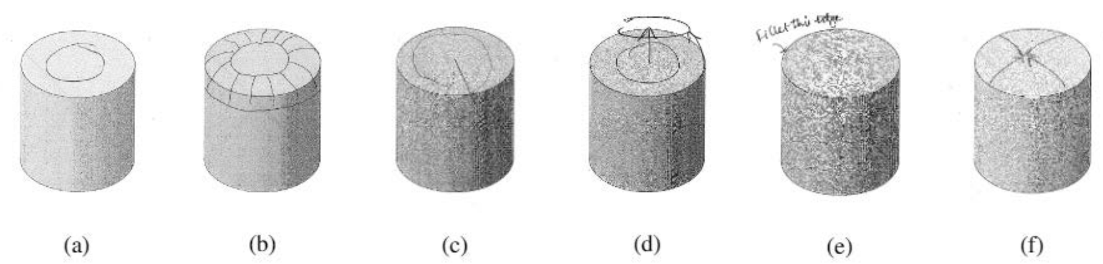


Figure 25: Sample Images of Each Category in the Fillet Cylinder Response Set

Two questions from the team's symbol study asked participants to fillet an edge of a 3D box and fillet the top edge of a 3D cylinder. The team selected curved rounding marks with outlined edges because it allows for some distinction between that and the Chamfer symbol, while combining the two most popular survey responses.

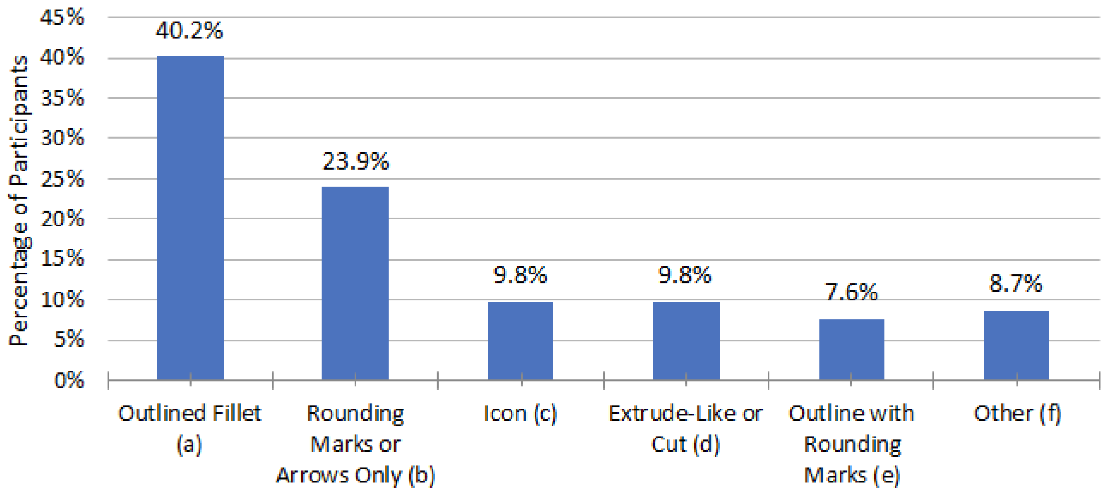


Figure 26: Percentage of participants drawing each operation for Fillet Box.

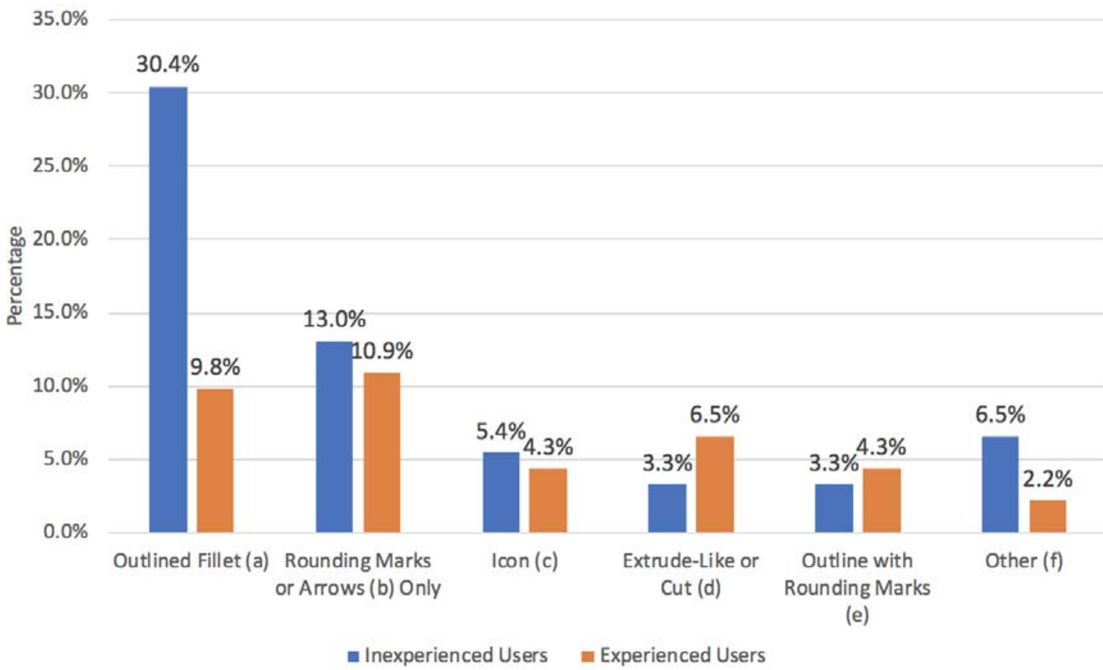


Figure 27: Percentage of participants drawing each operation for Fillet Box by experience.

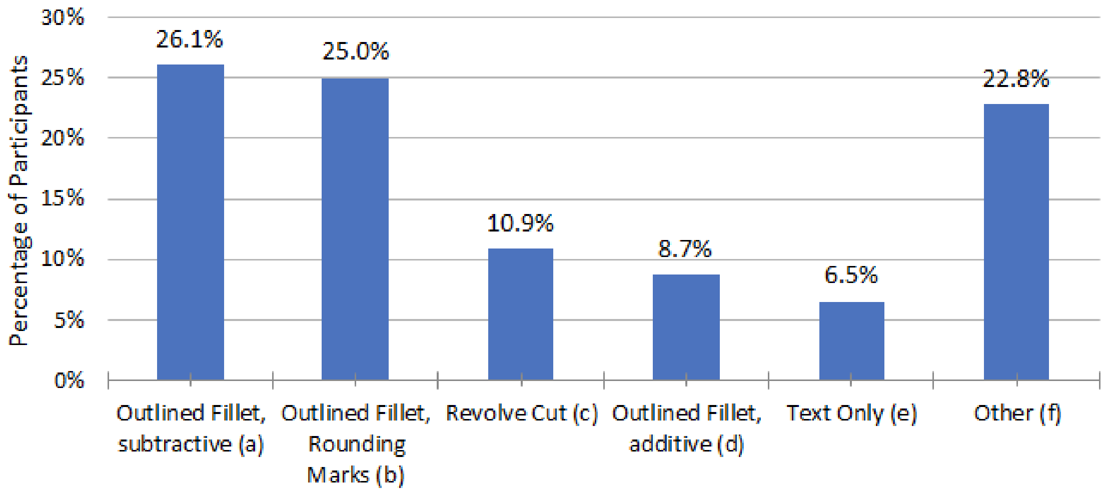


Figure 28: Percentage of participants drawing each operation for Fillet Cylinder.

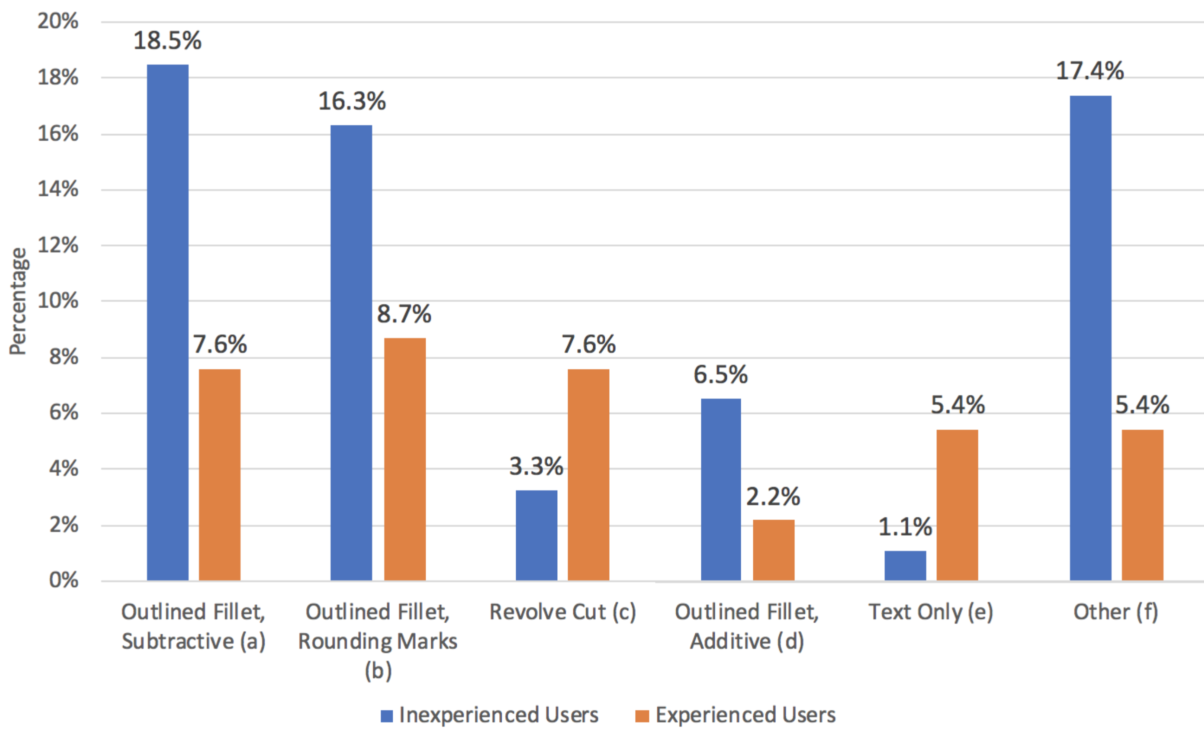


Figure 29: Percentage of participants drawing each operation for Fillet Cylinder by experience.

5. Symbols used for trim

Table 11: Trim Circle Response Categorization

Trim	Used X's (a)	Shaded (b)	Trimmed Wrong Side (c)	Arrows (d)	Words/ Misc. (e)	Crossing Out on Edge (f)	Other
Circle	16	16	16	15	10	9	10

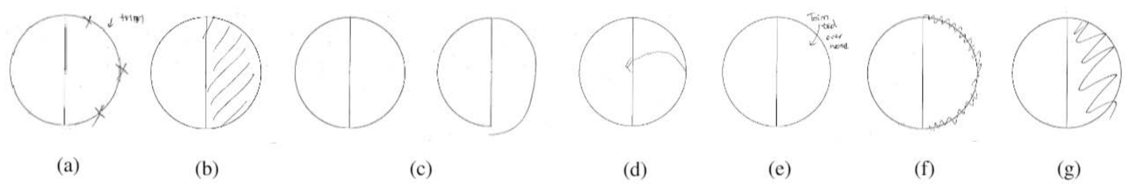


Figure 30: Sample Images of Each Category in the Trim Circle Response Set

Table 12: Trim Box Response Categorization

Trim	Crossing Out on Edge (a)	Used X's (b)	Arrows (c)	Trimmed Wrong Side (d)	Arrows top left to bottom right (e)	Other (f)
Box	28	17	9	8	7	23

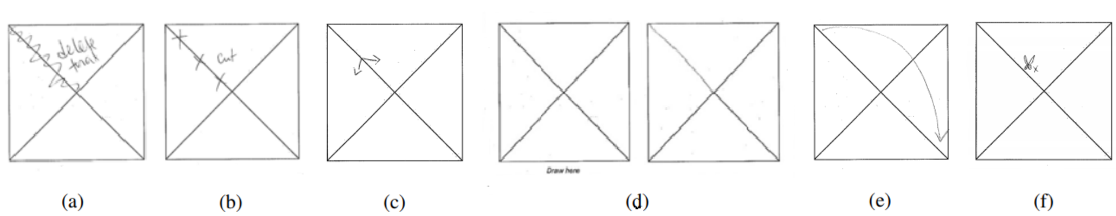


Figure 31: Sample Images of Each Category in the Trim Box Response Set

Two questions asked participants to trim half of a 2D circle and part of a 2D box. The team chose the X as the symbol for the short-term recall study because it was the most popular response for trimming the circle and the second most popular response for trimming the box.

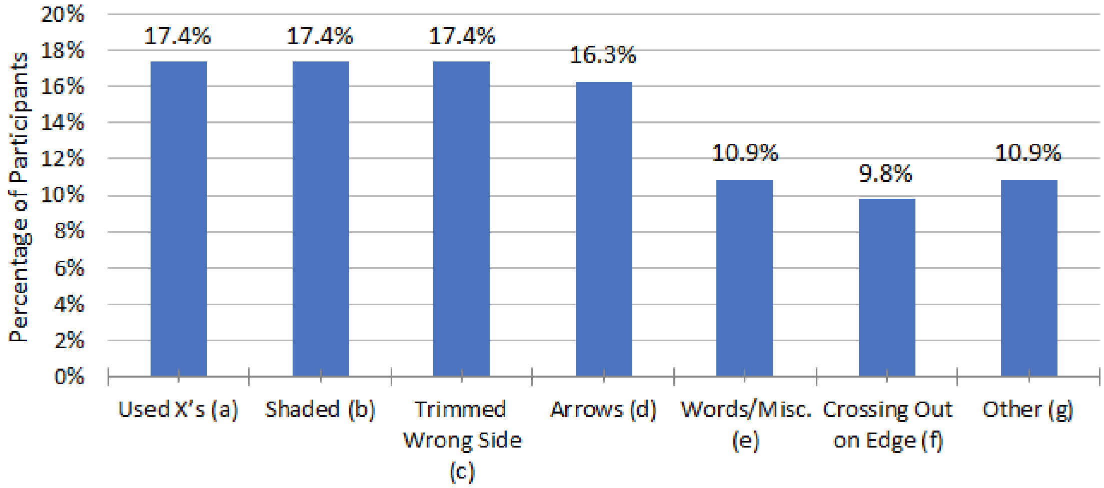


Figure 32: Percentage of participants drawing each operation for Trim Circle.

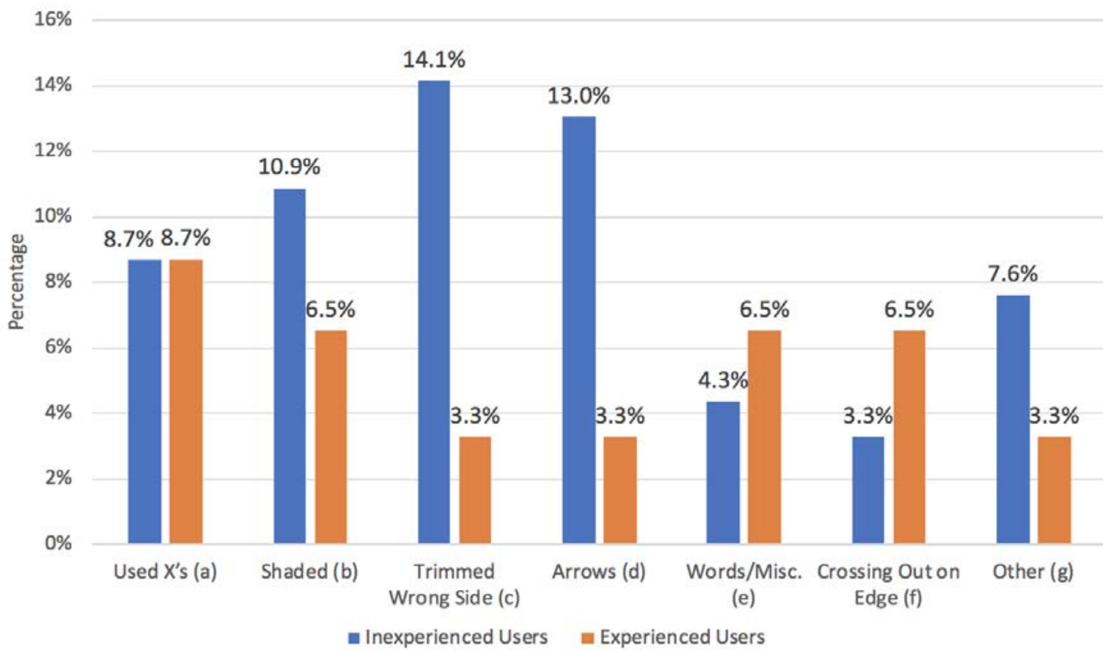


Figure 33: Percentage of participants drawing each operation for Trim Circle by experience.

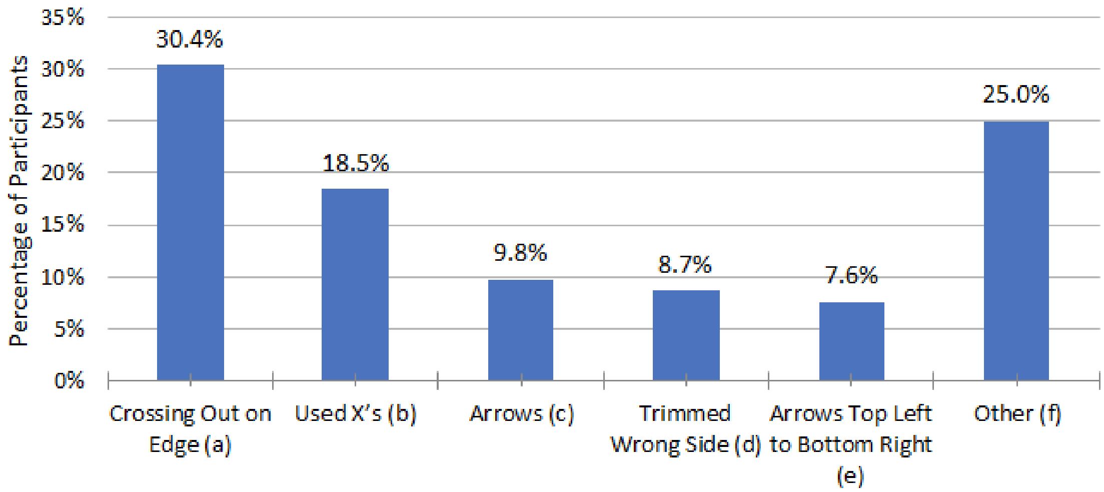


Figure 34: Percentage of participants drawing each operation for Trim Box.

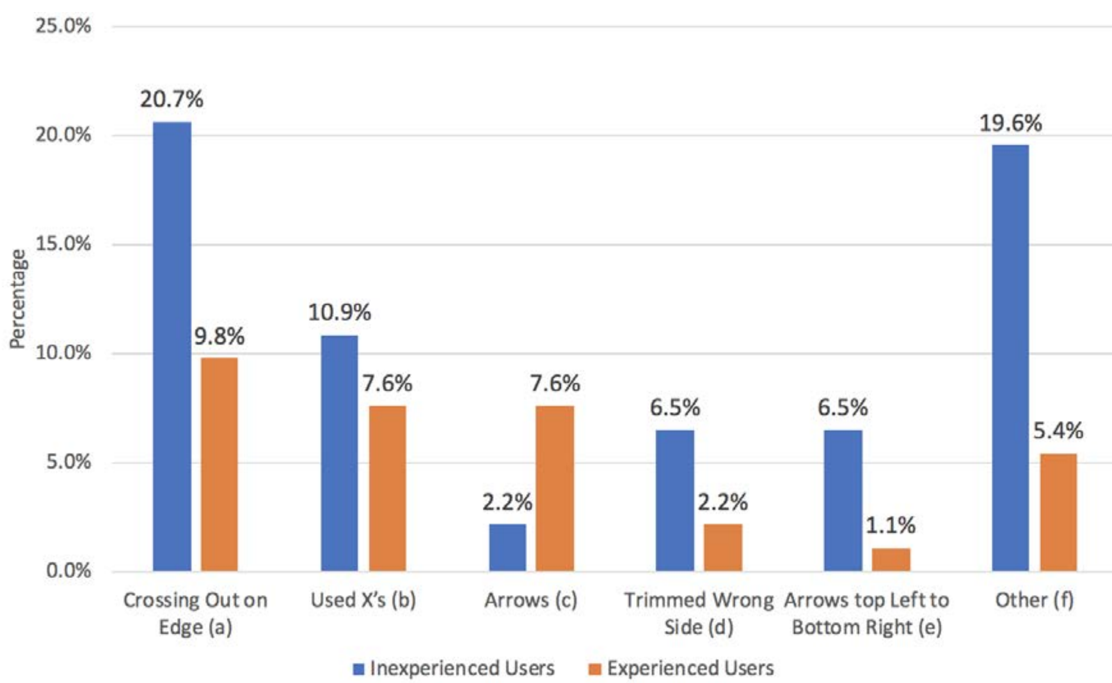


Figure 35: Percentage of participants drawing each operation for Trim Box by experience.

In summary, the symbols from our symbol study that we decided to use for the Short-Term Recall Study are shown in Figure 36.

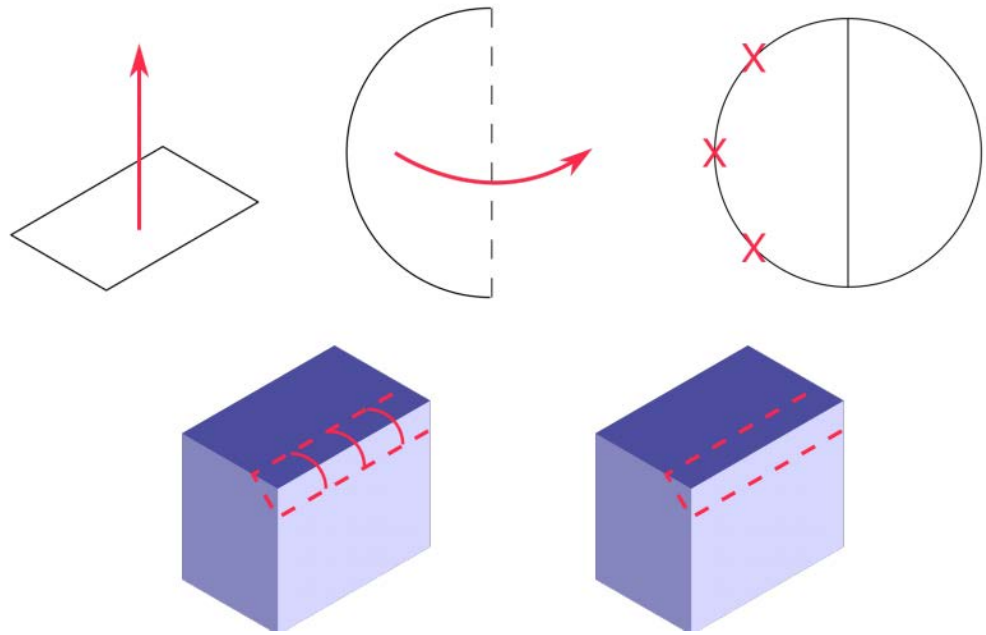


Figure 36: Symbols derived from Symbol Study for use in Short-Term Recall Study. From left to right, top row: extrude, revolve, trim; bottom row: fillet, chamfer.

Discussion

For two CAD operations (extrude and revolve), participants with prior CAD experience preferred to use arrows while those without tended to draw an outline of the additional 3D shape. For chamfer, participants with CAD experience favored using complete outlines with words and symbols whereas participants with no experience in CAD favored incomplete outlines without words and symbols. Whether the operation was additive or subtractive, inexperienced users' survey responses tended to be as close to the desired image as could be reasonably drawn on the old image. As the words and symbols category included examples of participants writing "chamfer", it is not surprising that experienced users know what this basic operation is. For fillet, those with CAD experience were divided between outlining the operation and using symbols and arrows. Those without CAD experience preferred to outline. For trim, experienced CAD users tended to prefer using X's rather than any other option whereas inexperienced CAD users' responses were diverse.

These results could mean several things. First, it could be that inexperienced CAD users prefer to draw the outline of a shape rather than drawing a different symbol representing the creation of the shape. Second, it could mean that showing participants the final shape biased their ability to think of an original symbol, so they drew the after shape on top of the before shape. Third, it could mean that the shapes we gave users were too simple, and that giving inexperienced users more complex shapes could create a wider variety of responses.

The symbol study's ability to answer the research question may have been limited in several ways. First, the survey sample may have been too small to see a significant result. In future research, increasing the size of the survey pool could allow more separation for the operations with more divided results. In addition, our categorization and selection of symbols to use in the short-term recall study was completed after reviewing each symbol, creating numerous small groups, and then combining small groups to make fewer large groups. It is possible that different grouping may be equally or more valid. A larger survey sample size, while most likely increasing the number of outlier responses, could potentially make the groupings clearer. This is particularly the case for operations like fillet and trim, which showed very divided responses.

One possible limitation comes from the prompts used for the symbol study. They were made to be clear and unambiguous, which excluded common real-world scenarios. All extrudes were made in isolation, i.e., they were not an addition to an existing complex shape. The creation of blind holes (do not go completely through shape) or through holes was not investigated. Only full revolutions were used, and the axis of revolution was an edge of the sketch. The simplicity of the forms may have contributed to the tendency for inexperienced users to attempt to exactly reproduce the result as an input.

Short-term Recall Study Results

Hypotheses and statistics tested

The short-term recall study intended to answer two questions:

1. How does learning CAD operations with user-created symbols versus traditional CAD icons affect short and long-term recall?
2. How does learning CAD operations by drawing user-created symbols versus selecting user-created symbols affect short and long-term recall of CAD operations?

The analyzed data set contained fourteen participants in Group A (Autodesk Icons Group), twelve participants in Group B (User-Created Symbols Group), and thirteen participants in Group C (Drawing User-Created Symbols Group). One Group C participant's responses were not included in the data set because that participant did not receive a symbol bank that other participants in that group received.

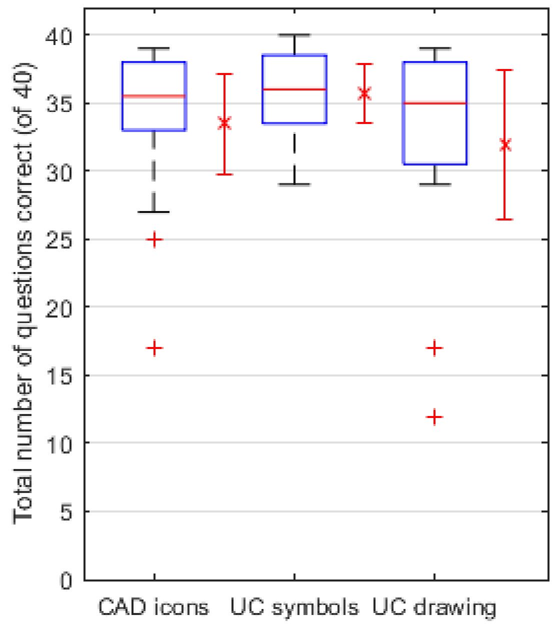
In group A, eleven participants selected None for CAD experience, two selected Beginner--Google Sketchup, and one selected Beginner--AutoCAD. In group B, all participants (except one who selected Beginner--Google Sketchup) selected None for CAD experience. In group C, eleven participants selected None for CAD experience, one selected Beginner--Google Sketchup and Beginner--Autodesk Inventor, and one selected Beginner--Autodesk Inventor and Beginner--CREO. The analyzed results include responses from all participants because the number of participants with CAD experience was small and of those with experience, all had selected beginner for experience level.

While we measured various statistics for each participant, we assessed our hypothesis with two variables: (1) the total number of questions answered correctly, and (2) the average page submission time for that participant. Each of the three test groups were considered a population, with each participant's response data as a sampled point in the population. We also measured the click count, time to first click, and time to last click for each question, but decided that they were not useful for hypothesis assessment. There is too much variability in how a participant may approach clicks when taking the quiz. For example, a participant may quickly make a random guess on their first click or click several answers while thinking about an answer. Moreover, the time to click statistics are biased against Drawing User-Created Symbols Group, as participants in that group must draw out their answer. To assess page submission time more meaningfully, we measured each participant's longitudinal change in average page submission time between the halves of the test. For example, a negative longitudinal change denotes that, on average, a participant submitted responses more quickly in the second half of the test than in the first half.

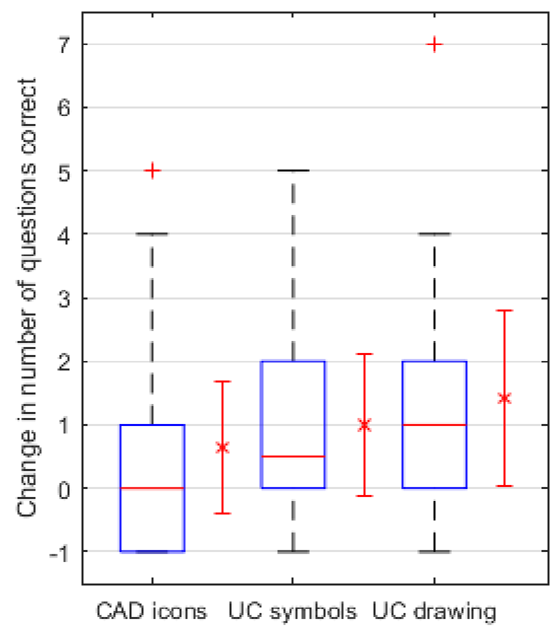
Input method's effect on question correctness

The number of questions a participant answered correctly effectively measures their short-term recall of CAD information. We hypothesized that, overall, Drawing User-Created Symbols Group would answer the most questions correctly, followed by the User-Created Symbols and Autodesk Icons Groups. To assess this hypothesis, we tested two statistics: (1) the total number of correct responses out of 40 (including both halves of the test), and (2) the longitudinal change in the number of correct responses between halves, i.e. the change in accuracy from the first half to the second half.

Figure 37 shows boxplots of the results for question correctness. While the average longitudinal differences showed our hypothesized trend, the overall question accuracy showed that Drawing User-Created Symbols Group was the least accurate of the three groups on average. Moreover, the differences in overall accuracy between each population were not found to be significantly large. We tested pairwise differences of means with the null hypothesis that the means were equal. With three pairs per statistic for two statistics and testing with and without outliers, there were twelve two-sample two-tailed t-tests in total. With a significance level $\alpha = 0.95$ we failed to reject any null hypotheses for question correctness, making the result inconclusive.



(a)



(b)

Figure 37: Question correctness box plots representing: (a) total number of questions correct, and (b) change in number of questions correct between test halves (positive indicates improvement in correctness). The red line with an x is a 95% confidence interval on that population statistic's mean as the error bar.

There are many possible explanations behind the inconclusive results. For example, the survey sample may have been too small to see a significant result. In addition, the high-test scores across all three groups could indicate that the test questions were not difficult enough to stratify the three groups. Lastly, the results could indicate that drawing or selecting user-created symbols does not significantly improve a user's accurate recall of CAD concepts compared to selecting traditional CAD icons. These limitations could potentially be addressed in future research.

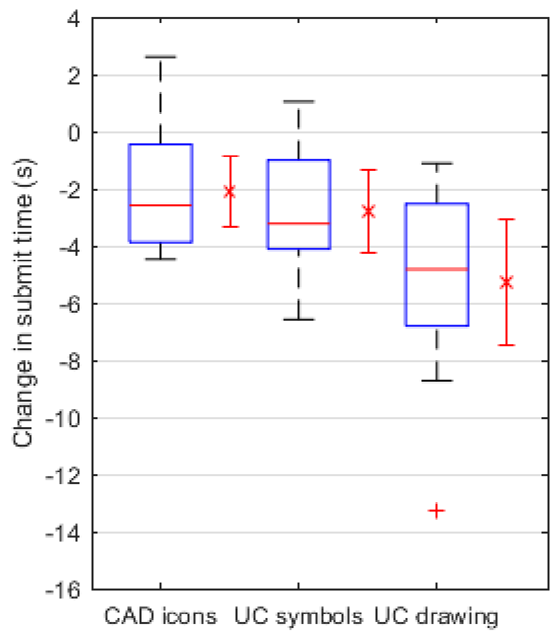
Input method's effect on page submission time

A participant's average page submission time for each test question is useful in determining the participant's short-term recall of material. The tested statistic was each participant's longitudinal change in average page submission time between the halves of the test. We hypothesized that the longitudinal change would be the lowest for Group C (Drawing User-Created Symbols Group), followed by Group B (User-Created Symbols Group) and then Group A (Autodesk Icon Group), indicating that Group C either has the most negative or least positive change in submission time. A more negative value would indicate a faster average submission time for a participant which would be an improvement in recall speed. Two different statistics were tested, one including all responses, and one using solely correct responses to observe correct recall. A participant's longitudinal change is indicated with Equation 1:

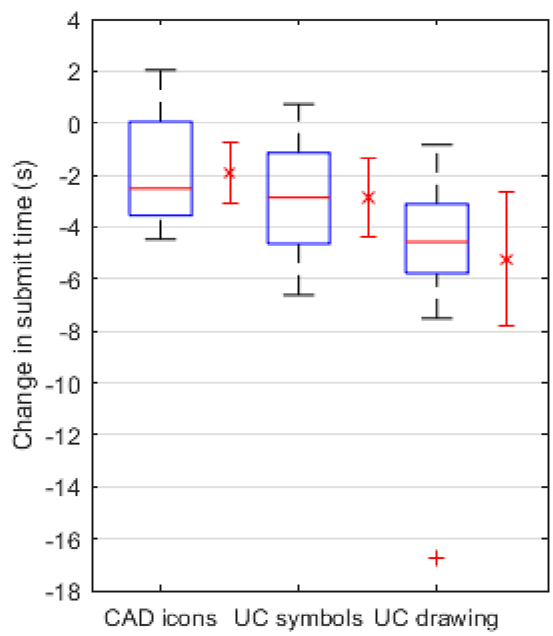
$$\overline{\Delta T_{participant}} = \overline{T_{second\ half}} - \overline{T_{first\ half}} \tag{1}$$

where $\overline{T_{first\ half}}$ and $\overline{T_{second\ half}}$ indicate an individual participant's average submission time for each test half's 20 questions (or fewer if only counting correct answers).

Figure 7 shows boxplots and error bars of the absolute change in page submission time. As was done in the hypothesis tests for question accuracy, we tested pairwise differences of means for three pairs. For pairwise tests involving Drawing User-Created Symbols Group's longitudinal changes for correct answers only, we also ran two separate tests where we either excluded or included the outlier of -16.785 s. With six tests total and two more excluding outliers, we ran eight two-sample two-tailed t-tests in total ($\alpha = 0.95$) to see if there was a statistically significant difference in the longitudinal change in submission time.



(a)



(b)

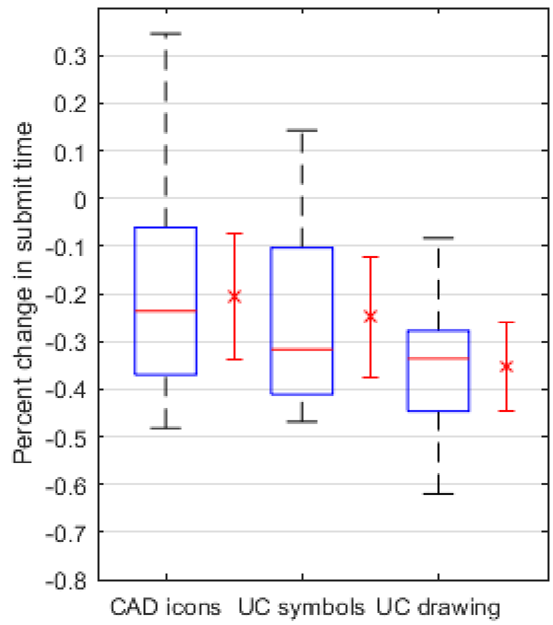
Figure 38: Absolute page submission time box plots representing: (a) change in submission time with all responses, and (b) change in submission time counting only correct responses; a negative value indicates an “improvement” with faster submission times in the second half compared to the first. The red line with an x is a 95% confidence interval on that population statistic’s mean as the error bar.

For page submission times including all responses, there is a statistically significant difference between User-Created Symbols Group and Drawing User-Created Symbols Group, with the latter having the greater decrease in submission time ($p = 0.049$), and between Autodesk Icons Group and Drawing User-Created Symbols Group with the latter having the greater decrease in submission time ($p = 0.012$). Note that the difference between Groups Autodesk Icons Group and User-Created Symbols Group was not significant ($p = 0.444$). For page submission times including only correct responses, the only statistically significant difference was between Autodesk Icons Group and Drawing User-Created Symbols Group, with Drawing User-Created Symbols Group having the greater decrease in submission time ($p = 0.02$ including the outlier and $p = 0.008$ excluding it).

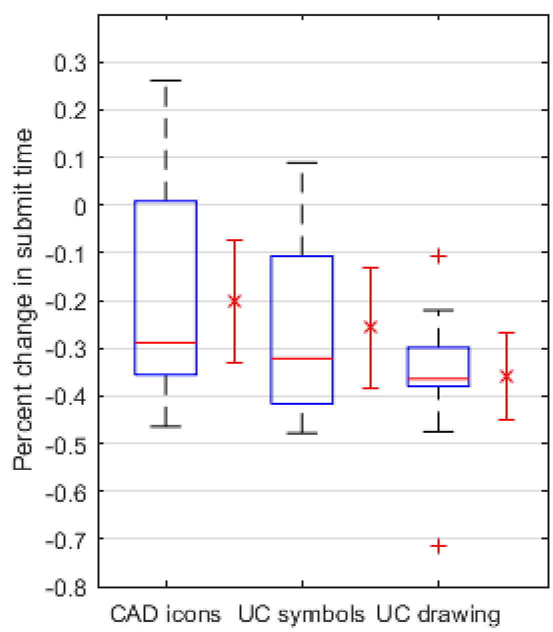
We also test the percentage change in average submission time relative to the first half of the test (Equation 2), as Drawing User-Created Symbols may have taken longer to draw out symbols:

$$\overline{\Delta T_{relative,participant}} = \frac{\overline{T_{second\ half}} - \overline{T_{first\ half}}}{\overline{T_{first\ half}}} \quad (2)$$

Figure 8 depicts the percentage change in submission time boxplots and error bars. Because the Drawing User-Created Symbols Group took more time to sketch their response compared to the multiple choice, the percentage longitudinal difference may be a more valid way of interpreting the data. When we examined the full data set, there was no significant difference for all tests ($p \geq 0.05$). When only correct answers are examined, there is a significant difference between Group A and Group C ($p = 0.04$ including outliers, $p = 0.03$ if outliers are excluded).



(a)



(b)

Figure 39: Relative (percentage) page submission time box plots representing: (a) change in submission time with all responses, and (b) change in submission time counting only correct responses; a negative value indicates an "improvement" with faster submission times in the second half compared to the first. The red line with an x is a 95% confidence interval on that population statistics' mean as the error bar.

Discussion

The results of the short-term recall study set a precedent for future researchers attempting to develop CAD software that is more accessible to new users, and this paper provides a complementary view of symbol selection by eliciting symbols that novice users would use in practice. The original hypothesis, which drew on past literature to show that writing notes relating to a concept significantly increased short-term recall of that concept, was neither proved nor disproved with the accuracy results. The measurement of question accuracy and similarity between the groups was close to 40 (a perfect score) could mean that the quiz questions were not difficult enough to stratify the groups. In the future, creating harder questions could help make the result clearer. Second, the number of students who participated in the short-term recall study could have been too low to detect an effect. Due to the high variability in test-taking strategies among students, extracting a time difference with groups of fourteen or fewer students is difficult, helping explain why the results are not statistically significant where they occur. Lastly, the time interval (ten minutes) the two parts were separated by might not have been enough for students to begin to forget the concepts they learned in the video. Increasing the amount of time between tests, even over the course of days, could help show a difference between learning methods.

For the second statistic, submit time, the group drawing symbols for each response was shown to take longer on average than either of the other two groups. That group was the only one with a statistically significant longitudinal decrease when compared to the group selecting Autodesk icons. It is likely that after drawing the same symbols eight times each, participants could have become more comfortable with the quiz process and the tablet, allowing them to draw and submit their answers more quickly.

Furthermore, the User-Created Symbols Group also had a higher page submit time than the Autodesk Icons Group. These two results indicate that there is a correlation between the symbol choice and the response time. Specifically, using the five symbols derived from the Symbol Study has a negative effect (an increase) on response time compared to traditional Autodesk Inventor icons. This finding contradicts the initial hypothesis that participants with a user-created set of CAD operation symbols would perform better than those who used a set of traditional CAD icons. However, because these five symbols had to be selected by the researchers from a larger set, an open question remains as to what symbols would best improve short-term recall.

Chapter 5: Conclusion and Future Work

In our symbol study, we asked undergraduate students with varying degrees of CAD experience to draw the symbol they felt best represented an unnamed CAD operation. After classifying the responses, we selected five user-created symbols (one for each of the CAD operations) that were popular and easy to distinguish. These symbols were then used in our later short-term recall study. The recall study, also conducted on undergraduate students, sought to determine how the type of CAD icon taught (traditional CAD icons, user-created symbols) and method (clicking user-created symbols, drawing user-created symbols) affected short and long-term recall of CAD concepts. To answer these questions, we measured question accuracy and change in response submission time across three groups: clicking traditional CAD icons, clicking on user-created symbols, and drawing user-created symbols. For correctness, there was no significant difference between any of the groups across both halves of the test. For changes in response submission time between the two halves, all groups saw a decrease, i.e., submission times were faster. The group selecting Autodesk Inventor icons was fastest, followed by the group selecting the symbols, and then the group drawing the symbols. When comparing differences between submission times, the only statistically significant difference is between the last group and the Autodesk icons group.

The two studies covered in this paper were designed to identify a set of symbols that would reduce short-term recall time for operations. Although the five symbols were selected from the data collected in the first study, because the second study did not affirm the hypothesis, this remains an open question. For future work, the first study produced a set of user-created symbols that can be used in future research involving education of students in CAD programs. The second study tested the effectiveness of user-created symbols against traditional CAD icons but yielded inconclusive results. Several limitations of this study could have affected our results. For example, the sample size of our study was not large enough to nullify individual differences in understanding among the participants. Furthermore, sampling a greater number of participants with and without CAD experience could answer if our inconclusive results were specific to inexperienced CAD users. Lastly, the difficulty of the test was lower than originally anticipated. More challenging questions or including a longer time period between halves could increase the stratification between groups and yield a more conclusive result.

In addition, with an increased sample size and test difficulty, the future study could have a wider scope. Incorporating traditional icons from popular CAD software other than Autodesk Inventor (such as PTC Creo, Ansys Workbench, Solidworks, NX, etc.) or using alternative symbols in the short-term recall study could lead to different results. A future study could test which of these symbol sets are most intuitive for each operation individually, not the five operation sets as a whole. Another future research direction is to create a CAD system that will allow each user to choose the symbol that they want to use to represent each CAD operation, instead of adopting a standard user-created symbol set. Such a study could show the impact of symbol choice on individual learning. Additionally, a study could test could test the effect of showing a quick pop-up animation and its effects on the recall time of user’s learning CAD operations. The behavior of users while interacting with a CAD package, for example how they select the icons, could be studied as well.

Another possible direction involves integrating machine learning into existing CAD programs, which could collect the behind-the-scenes information to make a more user-focused product, such as testing which symbols should be used for each operation. Such a feature would be useful if the researchers have the right symbols to use as a starting set, and the work from the Symbol Study could provide that. Finally, future work could focus more on the correlation between clicking and drawing icons on the recall rates of learning CAD operations. By potentially adding a fourth group that draws the traditional icons, comparisons could be drawn between these interaction methods.

CAD software is often difficult to learn, and there is currently a lack of research on which symbols should be used to represent which CAD operations. Our work was designed to identify a set of symbols for extrude, revolve, trim, chamfer, and fillet which reduced short-term recall time of those five operations. The results of the first study are several series of symbols that can be used in future research involving education of students without CAD experience and have also identified differences in symbols drawn by experienced versus inexperienced users. The second study sought to determine the effectiveness of those symbols compared to Autodesk Inventor icons, although the results were inconclusive.

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