Transfer of Learning Between Solid Modelers: An Investigation of Icon Recognition

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Abstract
Selecting the right solid modeling software is a complex, multi-criteria decision making problem. There are many issues a decision-maker needs to take into account, such as ease of learning, educational materials built into the software, learning curve issues, performance of the software for different solid modeling functions, operations and utilities, and cost. Beyond selecting the right software, the decision-maker should also be concerned about (1) conceptual learning of the solid modeling topics while "the right software" is being used, and (2) transfer of conceptual learning between solid modelers. This is because a sound conceptual learning might increase the probability of learning another solid modeling software in less time.

Accordingly this paper investigates the impact of icon recognition as an aid to transfer conceptual learning between solid modelers. The investigation includes a review of the literature on icon design and usage as it relates to solid modeling, in addition to an experiment in which the icon recognition correctness and duration for over 20 operation icons were compared across two modelers. The results shed light into the impact of icon designs on the transfer of learning between solid modelers using the correct recognition counts as the transfer measure.

1.0 Introduction
Initially solid modeling applications concentrated on replacing engineering drawings with unambiguous computer models to support automated engineering tasks. Nowadays, solid modeling is seen as an integral tool for product development and engineering because of its functionality as a computer-aid in design and documentation[1]. Therefore, due to its importance in engineering design practice, integrating a solid modeling software (solid modeler) to design teaching is necessary[2]. In industry, the trend in adopting solid modeling software is also apparent. A recent review of design software users' survey showed that only 31% of the design practitioners are using 2D CAD systems. The rest are either only using 3D CAD (5%), implementing a hybrid usage of 2D/3D CAD systems (38%), or mainly using 2D CAD, but evaluating 3D CAD (26%)[3].

However, beyond only including a solid modeler, instilling a conceptual understanding of solid modeling basics in students is paramount. This is because it is expected that what students learn in the classroom may not be the solid modeler their future employers use. Therefore, the transfer of learning from one solid modeling software to another has become a concern. This is also highlighted by the fact that there is an increased mobility of professionals among companies, and there are now many cost-effective modeling software packages available[4]. Due to these, studying the transfer of learning is important. The information regarding how conceptual learning in solid modeling transfers from one software to another might provide opportunities for better training designs with potential gains in effectiveness and efficiency.

The remaining sections of the paper includes a review of the related literature, design of an experiment conducted to discern the transfer of learning through icon recognition, results and conclusion along with recommendations for future research.

2.0 Literature Review

For usability testing, focusing on user-based studies has been advocated in place of expert-based ones because of their increased effectiveness in discerning how everyday subjects (such as students) will respond. As such, Hans Van Der Meij[5] emphasizes how information found in text-focused and expert-judgment-focused methods provide no indication as to how an actual reader will respond. For example, in a usability testing experts predicted less than half of the problems users experienced when reading a VCR manual[4]. Although this testing focused on written text rather than a computer interface, it is expected that a similar situation might be true for the usability of a graphical user interface (GUI) and its icons.

Expert-focused studies exist, however. For example, Huang et al.[6] collected a set of 50 icon design criteria from various sources and had two experienced professional graphics designers analyze the guidelines to construct a 19-item questionnaire for their study of "factors affecting the design of computer icons". They then had 43 computer GUI designers complete the questionnaire. Their study proposes that design experience may affect how people judge icons, and therefore it may be undesirable to collect icon design criteria information from subjects with no icon design experience. However, what their study fails to address is the inherent importance of the preferences of these inexperienced subjects. After all, it is for these inexperienced subjects that the icons are ultimately designed, not the computer GUI designers. Wouldn't it then be more desirable to in fact design the icons based on the preferences of the subjects that will actually be using them, rather than that of the GUI designers? This paper intends to illustrate how a user based study sheds light into the impact of icon designs on the transfer of learning between solid modelers.

In general, the implementation of GUI as a means of communicating with the computer takes advantage of the human capability to recognize and process graphical images quickly. Accordingly, most solid modelers use it today. However, the growth of interfaces is a matter of concern for software developers, and might be a barrier in solid modeling education and in engineering practice[7]. This is because it is believed that the layout of GUI elements influences the way users can interpret these elements[8]. While the user's correct mental model of the interface can help with their productivity, a false image of the interface might mislead them and limit their ability to work with the software effectively[9]. For example, a recent experimental study showed that, if an unknown icon A in software 1 looked like a well-known icon B in software 2, the users supposed that the icon A represented the same function as the icon B, even if both pieces of software were quite different[10]. Therefore, it is clear that differences in user mental models of a GUI are expected, and hence icon recognition can be one of the important factors in the transfer of solid modeling learning.

Accordingly, various databases were searched for previous work on icon design and recognition, and its impact on the transfer of learning. Although there is research on visual icon design and usefulness within a GUI, there are no direct studies on the effect of icon designs and transfer of learning issues within the solid modeling domain. However, the research on icon design and icon usefulness can be transferred into the solid modeling area[11].

An extensive search in Compendex resulted in direct hits on keywords in connection with icons that included: design software, 3-D design, 2-D design, and solid modeling. Articles on topics such as interface evaluation based on human eye movement characteristics, usefulness of icons on the computer interface, and visual icon design proved to be related. For example, significant research has been done on the analysis of eye movement characteristics and the impact they have on display design. Using eye movement-based analysis can improve performance evaluations of GUI's[12]. It is common knowledge that the specific grouping of information can lead to enhanced search efficiency. The spatial grouping and mere presence of function icons can greatly increase scanning speed as well as reduce the number of fixations[13]. GUIs with icons that are well organized according to functionality, as opposed to random grouping, resulted in shorter scanning paths and less fixations, ultimately giving way to higher search efficiency[12]. These findings show a direct correlation between user performance and function icon groupings.

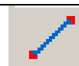
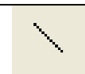
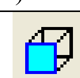
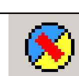
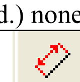
Along with the spatial grouping of icons, the quality of iconic representation can also have an impact on user performance on a GUI. Icons that are visually representative of their respective function are known to be identified considerably faster than icons that are visually arbitrary of their function[14]. User knowledge or experience also plays an important role in determining the ability to correctly identify iconic representations[15].

These findings are important factors to take into consideration when designing icons and are also potentially important when evaluating user performance and transfer of learning. However, earlier studies of transfer of learning between solid modelers did not focus on these issues. For example, Wiebe's[4] experiment related to transfer of learning between Pro/ENGINEER and SolidWorks, and AutoCAD and SolidWorks focused on how successfully users can take higher-level (semantic) task strategies developed using one solid modeler and apply them to a new one. This was considered to be an initial look at the transfer of learning issues between modelers because previous search indicated that many modelers include commands/tools that support the same higher level modeling strategies for modeling simple parts[16]. However, it was also stated that "…all of the packages have different interface elements, which create different syntaxes for achieving these higher level goals."[4]. Accordingly, this study continues the work on understanding issues related to the transfer of learning by focusing on the GUI issues, specifically on the icon design and recognition, and transfer of icon recognition between modelers.

3.0 Experimental Design

The experiment, which was conducted to shed light regarding the effects of icon design and recognition on the transfer of learning between modelers, included subjects from two class sections of the introductory engineering design course at The Pennsylvania State University (Penn State). After having 10 weeks of two-hour weekly in class work on solid modeling learning using SolidWorks, the students were prompted to complete two on-line questionnaires, which were designed to understand their ability to recognize the function icons in SolidWorks, and then in Inventor. Both of these solid modelers, for the most part, include commands/tools for similar higher level modeling strategies for modeling simple parts. However, for the same functions, icon designs might differ. Table 1 provides some examples of the questions asked on the on-line questionnaires both for SolidWorks and Inventor.

Table 1. Partial set of icons used for Inventor and SolidWorks icon recognition test

Inventor	Solidworks
1.  - a.) line - b.) draw - c.) sketch - d.) none of the above	1.  - a.) line - b.) draw - c.) sketch - d.) none of the above
2.  - a.) cube - b.) extrude - c.) extend - d.) box	2.  - a.) cube - b.) extrude - c.) extend - d.) box
3.  - a.) bend - b.) curve - c.) sweep - d.) revolve	3.  - a.) bend - b.) curve - c.) sweep - d.) revolve
4.  - a.) orthographic - b.) isometric - c.) shaded - d.) none of the above	4.  - a.) front view - b.) front shade - c.) front sketch - d.) none of the above
5.  - a.) hole - b.) shell - c.) hollow out - d.) punch	5.  - a.) zoom area - b.) zoom to fit - c.) zoom in/out - d.) none of the above
6.  - a.) clip - b.) mate - c.) help - d.) none of the above	6.  - a.) arrow head - b.) draw - c.) dimension - d.) none of the above

4.0 Results

Table 2 presents the number of participants who participated in the on-line questionnaires and the percentage of correct answers provided by these participants for both SolidWorks and Inventor. It also contains information about their prior CAD experience. As seen in Table 2, the percentage of correct icon recognition for SolidWorks (77%) is higher than that of Inventor (64%). This result indeed was expected because study participants spent about 20 hours in class time working on SolidWorks. What is interesting however is twofold: (1) despite the 20 hours of familiarity with the software the recognition percentage was only 77%, and (2) despite none of the students had prior experience with Inventor, their icon knowledge by and large transferred from SolidWorks learning. Data in Table 2 indicate that none of students was familiar with SolidWorks or Inventor before taking the class.

Tables 3 and 4 present how many participants got a particular question wrong on the SolidWorks and the Inventor on-line questionnaires, respectively. As one can see from these tables, while some icons were recognized by everybody in the participants set, some icons were not recognized as many as 44 participants out of 54 total participants.

Table 5 illustrates a software to software comparison of similar commands and the recognition percentage of their respective icons. When studied closely, one can see that some of these icons' recognition percentage was very close and indeed either icon designs in both software packages were very similar, or the icon design clearly represented the function in each case even though they were different (e.g., offset entities, loft, revolve, and dimension). On the other hand, some icons' recognition transfer and related percentage of correct recognition drastically decreased (from SolidWorks to Inventor) such as for shell, extrude, and sweep. When studied, it is seen that icon designs in Inventor for this set of icons did not match the ones in SolidWorks, and thus related learning did not transfer. What is more interesting is that for an icon (move) the recognition in SolidWorks was lower than in Inventor. This is explained by the fact that perhaps the participants thought that the icon design in Inventor was better in depicting the function (move).

Table 2. The number of participants who participated in the on-line questionnaire and their percentage correct as well as any prior CAD experience they may have had.

Participant	SolidWorks Percent (%)	Inventor Percent (%)	Prior CAD Experience
1	83	77	none
2	88	77	none
3	88	68	none
4	75	64	none
5	83	68	none
6	54	64	Auto CAD
7	71	55	none
8	92	N/A	none
9	92	82	none
10	75	50	none
11	75	45	none
12	83	77	none
13	88	77	Autosketch
14	42	64	none
15	83	55	none
16	79	55	none
17	71	50	Auto CAD
18	92	64	none
19	17	55	none
20	50	59	none
21	79	64	3D Studio Max
22	83	41	none
23	92	73	none
24	88	68	none
25	96	68	none
26	71	86	none
27	88	82	none
28	75	45	Autosketch
29	79	82	none
30	92	68	none
31	100	82	3D Studio Max
32	75	73	none
33	67	45	none
34	79	32	none
35	92	82	none
36	83	77	AutoCAD
37	92	59	none
38	83	64	none
39	79	55	none
40	46	95	none
41	63	59	none
42	79	59	none
43	79	64	none
44	17	77	none
45	92	23	none
46	83	64	none
47	96	73	AutoCAD
48	50	68	none
49	96	68	none
50	83	68	none
51	83	27	none
52	75	77	KeyCad
53	67	55	none
54	75	68	Pspice
Average	77	64	

Table 3. The number of participants that got a particular question wrong for the SolidWorks on-line questionnaire.

	SolidWorks	
Icon	Question	Number wrong
	1	0
	4	0
	6	2
	8	2
	2	3
	9	3
	3	4
	5	8
	11	8
	21	8
	13	9
	22	9
	12	10
	16	10
	10	11
	17	11
	24	11
	19	13
	7	14
	23	21
	15	27
	18	35
	20	36
	14	44

Table 4. The number of participants that got a particular question wrong for the Inventor on-line questionnaire.

	Inventor	
Icon	Question	Number wrong
	6	5
	15	5
	1	6
	2	6
	8	8
	19	8
	22	8
	9	9
	10	9
	11	9
	14	11
	20	11
	16	14
	3	20
	21	19
	7	34
	17	36
	4	36
	18	36
	5	38
	12	39
	13	44

Table 5. Software icon recognition comparison (Percentage Correct)

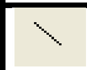
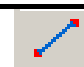
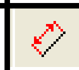
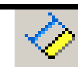
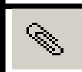
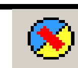
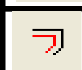
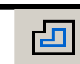
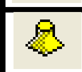
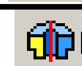
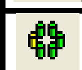
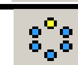
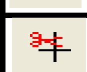
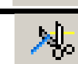
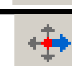
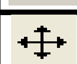
Command	Solid Works	% Correct	Inventor	% Correct
Line		100.00		88.46
Dimension		96.30		90.38
Mate		96.30		90.38
Extrude		94.44		88.46
Sweep		92.59		61.54
Offset Entities		85.19		82.69
Loft		85.19		84.62
Revolve		83.33		82.69
Circular Pattern		83.33		78.85
Rotate		81.48		82.69
Fillet		81.48		78.85
Chamfer		79.63		84.62
Sketch		79.63		84.62
Shell		75.93		30.77
Trim		61.11		63.46
Move		35.19		73.08
Pan		18.52		25.00

Table 6 displays a side by side comparison of function icons that were recognizable in both Solidworks and Inventor. Icons are considered "recognizable" if they have a recognition percentage of 75% or higher. As seen, designs are very similar in both software packages for the set of icons in Table 6.

Table 6. Icons recognized in both software

Recognized in Both Software		
Command	**Solidworks**	**Inventor**
Line		
Dimension		
Mate		
Extrude		
Offset Entities		
Loft		
Revolve		
Circular Pattern		
Rotate		
Fillet		
Chamfer		
Sketch		

Table 7 represents function icons that were not recognized (based on a 75% recognition cut off) in either Solidworks or Inventor.

Table 7: Icons not recognized in either software

Not Recognized in Either Software			
Command	**Solidworks**	**Inventor**	**Comment**
Pan			The Inventor *pan* icon resembles the Solidworks *move* icon which may have resulted in confusion.
Move			The Inventor *move* icon resembles the Solidworks *pan* icon which may have resulted in confusion.
Trim			Both of these icons seem to resemble the *cut* icon in many commercial word processing software.

Table 8 shows function icons that were recognized (based on a 75% recognition cut off) in Solidworks only. In order to perform a comparison, it also illustrates the respective icon that was not recognized in Inventor.

Table 8: Icons recognized in Solidworks only

Recognized in Solidworks Only			
Command	**Solidworks**	**Inventor**	**Comment**
Shell			The Inventor *shell* icon strongly resembles the Solidworks *extrude cut* icon, which may have resulted in confusion.
Sweep			The Inventor *sweep* icon seems to be <u>less</u> visually representative of the function than the Solidworks icon.

5. 0 Discussion and Conclusion

Based on these results, it is speculated that icon recognition is most likely determined by a user's software experience and also whether an icon is visually representative or visually arbitrary of its respective function. As one can see in Table 6, the 12 icons are indeed visually representative of their function. Similarly, each icon from Solidworks strongly resembles the icon for the same command in Inventor. This corroborates Szewczyk's[10] theory that, if an unknown icon A in software 1 resembled a well-known icon B in software 2, the users will most likely suppose that the icon A represents the same function as the icon B.

The icons illustrated in Table 7 are somewhat visually arbitrary of their respective function. However, similar to Szewczyk's theory, the Inventor *pan* icon resembles the Solidworks *move* icon, which may have resulted in the mislead assumption that it was in fact a *move* icon. Similarly, the Inventor *move* icon resembles the Solidworks *pan* icon. On a different note, the *trim* icon from both software resembles the *cut* icon from a word processing software and may have been falsely identified even though the students consciously knew they were working with solid modeling software icons.

Overall, results indicate that the participants were more likely to select the correct explanation of the icons on the software that they have worked with. This situation was expected. However, surprisingly, even after about 20 hours in class time they had difficulty in identifying certain icons. Related to this, we predict issues related to icon design, or usage of text based menu bars while learning the modeler, as inhibitors for learning the icons, and not being able to exploit the potential speed the GUI provides. In addition, it is clear that even without having worked on Inventor, participants were able to predict the function definition of certain icons in Inventor. We assert that this has to do with the similarity of the related icons in SolidWorks and Inventor, and thus we conclude that we find icon design to be an important aspect of learning transfer in solid modeling.

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