Selecting a Solid Modeling Software for Integration to Engineering Design Teaching: A Proposed Methodology & Its Application Results

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Abstract

This study proposes a methodology that would enable design educators and practitioners to optimally select a design software for varying objectives. Specifically, tasks accomplished to propose the methodology include: (1) reviewing past literature on methodologies and criteria used for selecting design software, (2) comparing a number of design software packages based on established criteria, (3) running designed experiments for testing differences among various software, and (4) compiling the experience gained as a generic methodology. The application was completed over two years while a systematic selection process was undertaken at The Pennsylvania State University. This paper documents the entire selection process including the user performance data collected. The set of outcomes of the study is expected to aid companies and design educators in making design software selection decisions.

1. Introduction

One of the necessities for a company to succeed in today's global competition is its ability to identify customer needs and to quickly create products that meet these needs. This necessity, which involves a set of activities beginning with the recognition of an opportunity and ending in the delivery of a product to the customer, is the rapid product development process. Rapid product development has been especially important since the late 80s. There have been vast improvements in the area, mostly focused on searching ways to shorten the development process duration. Among these, the advancement in design software is very significant, particularly for solid modeling. Accordingly, when preparing engineering students for similar responsibilities, integrating a solid modeling software to design experience is a must.

Integrating a solid modeling software to design teaching, however, is not a trivial task. Associated with the integration, several questions will need to be answered. For example, (1) Does the software have educational materials? (2) Are the educational materials adequate? (3) Is it easy and quick to learn, (4) Can the faculty gain the necessary knowledge and expertise to teach the course in a short time? (5) Does learning the software help students learn another solid

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modeling software easier, etc. These questions are important to answer when the goal is to prepare students for design responsibilities in an effective and efficient way.

This study proposes a methodology that would enable a design educator or a design practitioner to optimally select a design software for varying objectives. The methodology presented is a result of a systematic selection process undertaken at The Pennsylvania State University. Following sections of the paper document the selection process and the resulting methodology.

2. Literature Review on Solid Modeling Software Selection

Selecting solid modeling software is not a trivial task. One needs to consider several issues when making such a decision. In addition, one set of criteria that is good for one setting may not be for another. For example, criteria used to select a solid modeling software for a design company will differ when compared to the criteria used at an educational setting. In order to establish the criteria for use during solid modeling software selection a comprehensive literature search was completed in databases, which included (1) Compendex, (2) Ingenta, (3) NTIS, (4) Aerospace and High Technology, (4) AIAA online publications, (5) ASCE online journals, (6) ASME online journals, and (7) Mechanical Engineering Abstracts. Each database was given a script of keywords that included: CAD, Computer Aided Design, Solid Models, Solid Modeling, Solid Modeling Software, Design Software, Design Software Criteria, Software Selection Criteria. Below is a summary of the findings.

Majority of the previous work on solid modeling software comparisons include: 1) one CAD expert offering his review comments for various products without providing an established set of criteria, 2) rating a software using a predetermined set of criteria, and 3) comparing several similar software using predetermined criteria. For example, one can find solid modeling software review and ratings in Professional Engineering and CADENCE (now CADALYST) magazines. To give examples: January 1993 issue of the Professional Engineering magazine includes a review on four different low cost CAD offerings by a CAD expert, where no particular review criterion is provided (Claypole, 1993). October 2003 issue of CADANCE contains a review of CATIA V5 R11. After its review, a set of ratings is provided for the criteria including: 1) installation and setup, 2) interface/ease of use, 3) features/functionality, 4) expandability/customization, 5) interoperability/web awareness, 6) support/help, 7) speed, 8) operating systems, and 9) innovation (Greco, 2003). In this sort of rating, there are several problems. For example, it is not possible to compare ratings of two different software completed by different people because the way reviewers have interpreted the criteria might be different. Even when the same person evaluates a number of different software, the potential bias the evaluator may have toward one application is very hard to eliminate. Accordingly, this problem was brought up by Martin and Martin (1994) and studied using published reviews and tracing the reviewer and his expertise.

It is possible to eliminate the potential bias one can have towards one software by introducing expert users to the comparison. For example, Martin and Martin (1994), and Kurland (1996) invited various vendors to supply operators to take part in separate comparison studies. This way potential biases due to partiality towards one software over the other, or differences between software operators in terms of their skill levels were eliminated. However, in this situation it is

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still not clear if the solid modeler can be used by any user as effectively as the expert user after an adequate learning period. In other words, experimenting with an expert user cannot yield broader conclusions because graphical user interface (GUI) of the modeler determines the overall usability of the modeler and the productivity of the user (Rossignac and Requicha, 1999), which might be perceived differently by novices and experts.

GUI implementations take advantage of the human capability to recognize and process graphical images quickly, and has become a universal human/computer interaction standard. Accordingly, all 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 (Jakimowics and Szewczyk, 2001). Because it is believed that the layout of GUI elements influences the way the user can interpret them (Ambler, 2000). While the user's correct mental model of the interface can help with his productivity, a false image of the interface might mislead them and limit their ability to work with the software effectively (Genther and Nielsen, 1996). 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 students supposed that the icon A represented the same function as the icon B, even if both pieces of software were quite different (Szewczyk, 2003). Therefore, it is clear that differences in user mental models of GUI is expected, and thus productivity differences may arise. This point makes it clear that any comparative study of solid modelers should involve several users being tested under similar circumstances. The methodology proposed in this paper overcomes these limitations of early comparison studies.

In addition to implementing the correct methodology (that will yield objective, generalizable results), selection of the comparison criteria is very important. Determining the criteria for solid modeler comparison should be context specific because what is needed from the solid modeler depends on the specific applications of the unit that is looking into acquiring the modeler. Overall, comparison criteria used or proposed so far can be groped into three categories: 1) functions, 2) performance, and 3) collaborative tools. Function category refers to the various solid modeling functions such as extrusion, shelling, sweeps, patterns, revolves, assemblies etc. Solid modeling software have been evaluated or compared using various functional criteria (Mackrell, 1992; Kurland, 1996; and Greco, 2003). Performance category refers to the user friendliness of the software excluding the functional performance, and may include installation and setup, ease of use, speed, reliability, support and help functions, and training manuals. To give an example, Martin and Martin (1994) used performance criteria when comparing six software packages. Finally, due to the increasing importance of design collaboration because of globalization, outsourcing, and customization, a new set of proposed criteria is focused on collaborative tools effectiveness of solid modelers. However, published empirical comparison results for collaborative tools were not found during the literature survey completed for this research.

3. Solid Modeler Comparison Application at Penn State

As Rossignac (2003) acknowledged there is a gap between traditional research in any specific field (such as CAD), which is not concerned with educational objectives, and research in education, which is focused on fundamental teaching and learning principles; and he proposed

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Education-Driven Research (EDR) as to simplify the formulation of the underlying theoretical foundation and of specific tools and solutions, so as to make them easy to understand and internalize. A similar point view was taken at Penn State while trying to develop a methodology to select a solid modeler that will enable effective and efficient learning without limiting the time to teach design knowledge. With this in mind, a comprehensive solid modeler comparison was initiated during Spring 2002, which was completed in two years. This section summarizes the steps of this two-year effort.

- **Step 1) Develop a short list of solid modelers for comparison.**

For this purpose, using the list of the top 30 engineering schools of 2002 provided by US News, a web search was completed to document the solid modeler (i.e. *Solid Works, Inventor, ProEngineer,* etc.) usage at each school. Search on specific school's website included solid modeler usage in any of its engineering design courses, focusing primarily on mechanical engineering. To do this, first Mechanical Engineering Department's home page was targeted and then curriculum listings as well as any available course descriptions or syllabi were reviewed. Course descriptions proved to be of little help since they are somewhat broad and do not go into very much detail about the course. However, if a course syllabus was accessible, it usually listed what software was used for the geometric or solid modeling portion of the course. If neither a course description nor a syllabus was available, the school's website search engine was turned to as the next resource. The website was searched for direct hits on keywords such as *Solid Works* or *ProEngineer*. This resulted in a listing of any web page (on the school website) containing those keywords. From this list, a course web page containing the information needed could usually be found. As the last resort, individual course instructors were emailed.

After gathering, all data were compiled using a spreadsheet. The spreadsheet is composed of each school in order of ranking, the engineering design course number and name, software used in the course, as well as the respective website from which the information was collected. Table 1 includes the updated information for 2003. Of the 21 schools from which data were collected, 11 use *ProEngineer*, 10 use *Solid Works*, 2 use *Solid Edge*, 2 use *Inventor*, 1, uses Alibre, 1 uses *Mechanical Desktop*, 1 uses *CATIA*, and 1 uses *MATLab*. These data show what the top engineering schools are using for solid modeling while teaching design.

Based on this information, a short list of solid modelers was selected using cost as the primary criterion. This yielded 3 solid modelers: Inventor, Solid Works, and Solid Edge. To the list IronCAD was added because it was the software used at Penn State at the time. Then, all four companies were contacted at the same time informing them of our intention -- to compare and select the software that satisfies our needs in the best way. During this initial contact all companies were asked to provide a sample of educational materials for review.

- **Step 2) Determine The Solid Modeling Topics To Be Covered In The Design Course.**

Deciding on the topics to be covered led to the list of functions to be compared in the solid modelers. Selected functions for comparison include extrusion, shelling/ skinning, filleting, chamfering/ blending, feature patterns (linear, circular), sweeping profiles along curves, lofting, revolve, associativity of the solid model (one way, two way), cross sections, offset sections, isometric views and assembling parts.

- **Step 3) Compile A Customized Manual For Solid Modeling Learning.**

This compilation required reviewing the educational material provided by the companies and sequencing and enhancing the material to supplement the design teaching for the Introductory Engineering Design course at Penn State. This process eliminated two of the solid modelers originally selected to be in the short list for comparison. Because their educational materials were not found to be adequate for implementation or integration to the course.

- **Step 4) Conduct Experimentation With The Customized Curriculum.**

For the remaining two solid modelers, a classroom experimentation was planned to compare their effectiveness on student learning and student design performance. The experimentation involved the same instructor teaching two sections of the same Introductory Engineering Design course -- teaching solid modeling with one software in one section, and using the other in the second section during the same semester. When students completed the pre-prepared manuals, for which they needed about 20 hours in class-work, two CAD quizzes were given to both sections at the same time using same questions. Questions were designed to understand the student learning on the predetermined curriculum subjects, which include the software comparison functions. Table 2 shows the results of this experimentation.

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Table 1. Solid Modeler Used in Design Courses in Top 30 Engineering Schools In the U.S.

Rank	Name	Course	Software	Website
1	MIT	2.971 - Intro to Design	Solid Works or Pro/Engineer	http://ocw.mit.edu/OcwWeb/Mechanical-Engineering/2-9712nd-Summer-Introduction-to-DesignJanuary--IAP-2003/CourseHome/ Site visited: 9/18/03
2	Stanford University (CA)	ME 118 - Intro to Mechatronics	Solid Works	http://me118.stanford.edu/pictures/Win00Projects/mrroboto/drivesaround.html Site Visited: 9/25/03
3	University of California–Berkeley	ME128 - Com. Aided Mechanical Design	MATLab	http://www.me.berkeley.edu/Design/courses.html Site visited: 9/18/03
4	Georgia Institute of Technology	ME 4041 - Interactive Computer Graphics & CAD	ProEngineer Solid Edge	http://www.me.gatech.edu/me/semester_conversion/ME4041.html http://www.cad.gatech.edu/software/
		AE 4351 - Aerospace Engineering Design Project II	CATIA	http://www.cad.gatech.edu/courses/index.html Sites Visited: 9/25/03
5	University of Illinois–Urbana-Champaign	GE103 - Engineering Graphics and Design	Mechanical Desktop	http://www.ge.uiuc.edu/crsinfo/crsdesc/ge103.html Site visited: 9/18/03
		ME170 Computer Aided Design	ProEngineer	http://www.mie.uiuc.edu/content/asp/programs/course_offerings/100_level_mechanical_engineering_courses.asp Site visited: 9/18/03
6	University of Michigan–Ann Arbor	ME250 - Design and Manufacturing I	Solid Edge	http://www.engin.umich.edu/class/me250/currentcourse/solid-edge.htm Site visited: 9/18/03
7	Caltech	ME73 - Machine Component Design	Solid Works	http://idesign.caltech.edu/%7Eme73/index.html Site Visited: 9/21/03
8	Cornell University (NY)			
9	University of Southern California			
10	Carnegie Mellon University (PA)	48-745 Geometric Modeling	Solid Works ProEngineer	http://weld.arc.cmu.edu/48-745/Lectures-handouts/new0.pdf Site Visited: 9/25/03
11	University of Texas–Austin	ME 302 - Intro to Engineering Graphics and Design	Solid Works	http://www.me.utexas.edu/~me302/210-302Syllabus.htm Site visited: 9/18/03
12	Purdue University–West Lafayette (IN)	CGT226 - Constraint Based Modeling	ProEngineer	http://www.tech.purdue.edu/cgt/Courses/cgt226/CGT226-F03.pdf Site Visited: 9/25/03

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Table 1. continued

13	Texas A&M University–College Station	MEEN 402 - Mechanical Engr. Design	Solid Works	http://www.mengr.tamu.edu/Academics/Syllabi/ABET%20MEEN%20402.pdf Site Visited: 9/25/03
14	University of California–San Diego	MAE3 - Intro to Engineering Graphics & Design	Inventor	http://maelabs.ucsd.edu/mae3/index.htm Site visited: 9/18/03
15	Penn State University–University Park	ED&G – Introduction to Engr. Design	Alibre Inventor Solid Works	http://www.cede.psu.edu/~pmb168/design2/index.htm Site Visited: 9/25/03
16	University of Wisconsin–Madison	ME232 - Geometric Modeling for Engineering Applications	Pro/Engineer	http://www.cae.wisc.edu/~me232/ Site visited: 9/18/03
17	Harvard University (MA)	ES51 - Computer Aided Design	Solid Works	http://www.courses.fas.harvard.edu/~es51/Syllabus/ES51-syllabus-03.htm Site visited: 9/18/03
18	Princeton Univ. (NJ)			
19	University of Maryland–Col. Park			
20	Northwestern University (IL)	ME240 - Introduction to Mechanical Design and Manufacturing	Solid Works	http://aquavite.northwestern.edu/cdesc/course-desc.cgi?school_id=700&dept_id=740&course_id=2650&quarter=SP03 Site visited: 9/18/03
21	University of California–Los Angeles	MAE94 - Intro to Computer Aided Design and Drafting	Pro/Engineer	http://mae.ucla.edu/academics/courses/ (click on undergrad course outlines and then MAE94) Site visited: 9/18/03
22	Univ. of Minnesota–Twin Cities			
23	Virginia Tech			
24	Johns Hopkins University (MD)	ME530.114 - Intro to Computer Aided Design	Pro/Engineer	http://urology.jhu.edu/cad/ Site visited: 9/18/03
25	University of California–Santa Barbara	ME 10 – Engr. Graphics: Sketching, CAD, & Conceptual Design	Solid Works ProEngineer	http://www.me.ucsb.edu/dept_site/student_info/undergrad/undergrad%20courses.html Site Visited: 9/25/03
26	Columbia University			
27	Ohio State Univ.			
28	University of Pennsylvania	MEAM 100 - Introduction to Design and Manufacturing	ProEngineer	http://www.seas.upenn.edu/~meam100/ Site Visited: 10/2/03
29	North Carolina State University	MAE 416 - Mechanical Engineering Design	ProEngineer	http://courses.ncsu.edu/mae416/lec/003/syllabus.html# Site Visited: 10/2/03
30	University of Florida			

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Table 2. Classroom Experimentation Results

Performance for Quiz1, Software1 **PerQ1S1 (out of 1.00)**	Time Spent for Quiz1, Software 1 **TimeQ1S1 (in min.)**	Performance for Quiz2, Software1 **PerQ2S1 (out of 1.00)**	Time Spent for Quiz2, Software 1 **TimeQ2S1 (in min.)**	Performance for Quiz1, Software2 **PerQ1S2 (out of 1.00)**	Time Spent for Quiz1, Software 2 **TimeQ1S2 (in min.)**	Performance for Quiz2, Software2 **PerQ2S2 (out of 1.00)**	**Time Spent for Quiz2, Software 1 TimeQ2S2 (in min.)**
1.00	30	1.00	65	1.00	30	1.00	35
1.00	25	0.75	60	1.00	15	0.75	40
1.00	60	0.80	30	0.90	20	0.90	90
1.00	30	1.00	60	1.00	30	1.00	50
1.00	60	1.00	60	1.00	25	1.00	55
1.00	30	1.00	25	0.75	30	1.00	30
0.75	45	1.00	50	1.00	35	1.00	45
1.00	24	1.00	54	1.00	20	1.00	20
0.50	30	1.00	20	1.00	20	0.75	55
1.00	15	1.00	30	1.00	30	1.00	40
1.00	15	1.00	25	1.00	30	1.00	25
1.00	15	1.00	30	1.00	10	1.00	20
1.00	15	1.00	45	1.00	23	1.00	33
1.00	35	1.00	30	1.00	30	1.00	40
1.00	12	1.00	45	1.00	30	1.00	40
1.00	25	1.00	48	1.00	40	1.00	25
1.00	50	1.00	55	1.00	20	1.00	76
1.00	50	1.00	70	1.00	20	1.00	30
1.00	20	1.00	60	1.00	45	1.00	45
1.00	40	1.00	60	1.00	20	1.00	50
1.00	15	1.00	45	1.00	45	1.00	65
1.00	15	1.00	30	1.00	41	1.00	56
1.00	9	1.00	45	0.75	15	1.00	25

- **Step 5. Analyze The Performance Data Statistically and Conclude.**

Using Minitab™ Release 13.1, differences of sample averages for student design performance and completion time for both quizzes were tested for their significance. Table 3 shows these data. As can be seen with the p values for all four t tests, differences in averages were not found to be statistically significant. This means that for the functions that are the subject of comparison, both software deliver similar results and hence either of them can be used for effective solid modeling teaching.

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Table 3. Statistical Analysis of Results

T-Test	N	Mean	Standard Deviation	Result
Two sample T test for PerQ1S1 vs PerQ1S2	23	0.967	0.114	Estimate for difference: -0.0065 95% CI for difference: (-0.0637, 0.0507) T-Test of difference = 0 (vs not =): T-Value = -0.23 P-Value = 0.819 DF = 44 Both use Pooled StDev = 0.0962
	23	0.9739	0.0737	
Two sample T test for TimeQ1S1 vs TimeQ1S2	23	28.9	15.4	Estimate for difference: 1.78 95% CI for difference: (-5.85, 9.41) T-Test of difference = 0 (vs not =): T-Value = 0.47 P-Value = 0.640 DF = 44 Both use Pooled StDev = 12.8
	23	27.13	9.61	
Two sample T test for PerQ2S1 vs PerQ2S2	23	0.9804	0.0653	Estimate for difference: 0.0065 95% CI for difference: (-0.0348, 0.0479) T-Test of difference = 0 (vs not =): T-Value = 0.32 P-Value = 0.752 DF = 44 Both use Pooled StDev = 0.0696
	23	0.9739	0.0737	
Two sample T test for TimeQ2S1 vs TimeQ2S2	23	45.3	14.9	Estimate for difference: 2.26 95% CI for difference: (-7.48, 12.00) T-Test of difference = 0 (vs not =): T-Value = 0.47 P-Value = 0.642 DF = 44 Both use Pooled StDev = 16.4
	23	43.0	17.7	

4. Conclusion

Overall, the solid modeling software selection procedure articulated above, which was designed to yield an optimum solid modeler, has eliminated several limitations of similar studies in the literature. Therefore, it is proposed as a solid modeler selection methodology for use by design practitioners and educators as a decision-making tool. Tasks accomplished to propose the methodology include: (1) reviewing past literature on methodologies and criteria used for selecting design software, (2) comparing a number of design software packages based on established criteria, (3) running designed experiments for testing differences among various software, and (4) compiling the experience gained as a generic methodology. The proposed methodology can be given in steps as the following:

Step 1) Develop a short list of solid modelers for comparison.
Step 2) Determine the solid modeling topics to be covered in the design course/practice.
Step 3) Compile a customized manual for solid modeling learning.
Step 4) Conduct experimentation with the customized curriculum.
Step 5) Analyze the performance data statistically and conclude.
Step 6) Repeat steps 1-5 in regular intervals (for example in every two years).

The application was completed over two years while a systematic selection process was undertaken at The Pennsylvania State University. This paper documented the entire selection process including the user performance. The set of outcomes of the study is expected to aid companies and design educators in making design software selection decisions.

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