The Role of Design and Prototyping in Industry/Education Partnerships

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Introduction

The purpose of this continuing study was to determine if industry and educational partnerships are effective ways to improve student learning and provide services that industry could otherwise not afford. It was thought that Solid Modeling and Rapid Prototyping would be valuable in increasing the translation between abstract 2-D drawings and actual 3-D parts. In order to accomplish this, the following research questions were proposed:

- Will drawing an object in 3-D and producing that part with a Rapid Prototyping system as part of an Industry initiated project improve student visualization skills?
- Does industry and education see benefits in this type of partnership?

To do this several courses and industrial projects were used and evaluated for visualization skill improvement and perceived benefits to provide a more complete picture.

Need

The need is seen as twofold in nature. Industry needs both trained personnel and access to special services. Education needs to provide trained personnel and access to the latest technology possible. Graphics is one of the core areas and permeates most aspects of industry and education. The ability of a student to visualize the material depicted on a drawing in its' completed form is one of the primary purposes of a graphical design curriculum. Various methods have emerged using prepared models, photographs, and pictorials to illustrate what the drawing is meant to represent. Students typically work from these prepared examples in the production of both two-dimensional and three-dimensional drawings with little opportunity to create something new. The question arises if students really see what the drawings represent. Larger companies, such as Chrysler, are now sending design engineers out for real world design experience on the shop floor before actually having them design cars. The ability to see (visualize) is considered very important by these companies as these engineers solve small-scale design problems in production. Many of these larger companies have in-house rapid prototyping and design departments to help solve production problems beforehand.

However, smaller companies cannot afford this kind of training or equipment and need to have personnel coming in with "real" design experience. Often these same companies need solid models and rapid prototypes also. While solid modeling software is available at relatively low prices even low accuracy desktop prototyping machines start at $50,000. Typical prices for industrial models start around $200,000 and can exceed $500,000. The sharing of such equipment among a variety of businesses and educational institutions seems to be a logical answer to the high cost dilemma. The added benefit of a better-trained student is equally attractive.

The advent of Rapid Prototyping (RP) gives industry and education the ability to model complex parts, after the production of a three-dimensional CAD file, in a relatively short time. Additionally, the advent of Rapid Tooling (RT), where the RP model is used to produce molds or mold inserts, lends additional timesaving support to the legitimacy of these processes [15]. Both processes can aid in the production of the actual part by the typically paper oriented drafting classes. In this study we will focus on Solid Modeling and Rapid Prototyping while neglecting the Rapid Tooling aspect. These processes allow the student to create objects, rather than merely copying drawings and parts in a reasonable amount of time. Since much skill is required to produce parts by traditional means the time factor prohibits use inside a drafting class. It also parallels industrial practice in the common idea, concept, drawings, prototype, manufacture cycle. Any technology that could increase visualization skills and service industry projects needs to be examined and tested to determine its' usefulness.

Methodology

Three methods of testing the usefulness of this partnership were used. These methods were as follows:

- Standardized testing of students
- Survey of students
- Survey of industry personnel involved

Of these the most significant is the standardized testing since it has years of comparison data with large numbers of students. The survey of students is the next most significant data due to the large number of students used. The survey of the industry persons is the least statistically significant since typically only one person was involved in the procedure. Due to this low number statistical analysis of industry data was not done.

The Revised Minnesota Paper Form Board Test was used as the instrument for evaluating student performance in visualization. This aptitude test is a well-documented instrument with equivalent forms available for repetitive testing of the same sample group. Various reliabilities ranging from .85 to .91 have been reported [3, 7, 11].

The validity of the test has been shown to have high multiple correlations with successful school to work performance in areas requiring visualization skills [4]. This was particularly true in the drafting, printing, engineering, and inspection areas [2, 4, 13]. These areas all exhibited correlation relationships greater than 0.40. In addition, extensive normative data exists for comparison purposes with both school and industrial groups [6].

While the study was originally designed only to evaluate whether Rapid Prototyping would increase visualization skills, it was necessary to eliminate or reduce the effect of as many variables as possible. The extended time period in this study allowed repetition with various groups for verification of the results [14]. In addition, accuracy is improved if the researcher knows both the control and experimental group differences and this helps to correctly evaluate the results [1]. For this reason, only classes taught by the same instructor were used throughout the study. The extended time allowed for this study helped in both of these regards as well as increasing sample sizes. The "before and after" nature of this study indicated that Paired Difference Testing would best describe the data statistically.

All of the students were informed that the testing was for comparison purposes with other groups and for determining teaching effectiveness within the class itself. It was emphasized that it had no effect on their grade. The results of the testing were made available to all students under a coded identification procedure within a week after each test was given. The students were also informed of average test scores in national testing of similar and dissimilar groups [6]. Alternate forms of the Minnesota Paper Forms Board Test were used throughout the study. These forms are available from The Psychological Corporation in San Antonio, Texas.

The surveys of industry and student personnel were done as part of the process with multiple inputs sought from both groups. These surveys were very simple and short as they were used for initial directions the new program should take.

Procedure for Standardized Testing

Students were tested for visualization skills, using the Minnesota Paper Forms Board tests, at each of the following instructional levels:

1. No drafting instruction
2. Drafting instruction
3. Computer Aided Drafting instruction in 2-D and 3-D
4. Rapid Prototyping Simulation of 3-D part

Due to certain limitations it was necessary to use different students at different levels of the study. Some students would complete instruction at step two while others would continue through step four. In any case the difference in performance between steps is representative of one student's score, regardless of whether that particular student completed all the levels.

- The first comparison involved students in two sections of TG 120, Engineering Graphics. These students were all tested at the beginning and the end of the class. This corresponds to levels one and two above.
- The second comparison involved all students continuing their education in TG 126, Computer Aided Drafting. This group was tested at levels two and three above.
- The last comparison involved students in two sections of TG 126, Computer Aided Drafting. All students, in both sections, were given the same instruction until the last three weeks of the course when one randomly selected group worked with an exercise in 3-D CAD and in a simulation of Rapid Prototyping the CAD part. The other group completed the 3-D CAD drawings used in the simulation, but did not run the simulation. This corresponds to levels three and four above.

While this portion of the study was originally designed only to evaluate whether Rapid Prototyping would increase visualization skills, it was necessary to eliminate or reduce the effect of as many variables as possible. The extended time period in this study allowed repetition with various groups for verification of results [14]. In addition, accuracy is improved if the researcher knows both the control and experimental group differences and this helps to correctly evaluate the results [1]. The extended time allowed for this study helped in both of these regards as well as increasing sample sizes.

Results of the Standardized Testing Portion of the Study

The results of this continuing study are summarized below. Several levels of testing are presented that are outside the original proposal, but are useful to understanding the results. These are divided according to the testing levels presented in the Introduction. These are:

1. No drafting instruction
2. Drafting instruction
3. Computer Aided Drafting instruction in 2-D and 3-D
4. Rapid Prototyping Simulation of 3-D part

Since paired difference testing was employed, the null hypothesis was that there was no difference in visualization scores between the students who had one level of instruction and those who did not. The research hypothesis was that the students who had rapid prototyping experience would score higher than those who did not. Since the students were randomly divided into two groups it is reasonable to say the two sampling distributions are independent. Small sample size in certain groups and limited time constraints dictated the use of the Student's *t* distribution instead of the *z* distribution.

Standard methods of measuring Rapid Prototyping's benefits are currently undergoing development at the National Institute of Standards and Technology (NIST) [5]. Until these standards are promulgated comparisons and reproducibility in experimental design are, at best, poor. Additionally, the wide variety of Rapid Prototyping methods, software, and documentation available will make comparisons among differing systems open to varying interpretation. For these reasons the data collected in this study is applicable only to the population group and Rapid Prototyping methods examined.

Levels	**Mean**	**Std. Dev.**	**T(a/2), P, T, DF A=.05**	**Null Hypothesis**
No Drafting Drafting	39.5 43.5	8.7 7.0	1.98, P=.0091 T=-2.658, DF=108	Rejected, significant increase in scores
Drafting CAD	43.5 53.0	7.0 7.2	1.99, P=6.3E-7 T=-5.51, DF=66	Rejected, significant increase in scores
CAD Rapid Prototyping	53.0 54.0	7.2 7.8	2.00, P=.61 T-.51, DF=58	Accepted, insignificant increase in scores

Figure 1. t-Test Data

The data supported the conclusion that the use of Rapid Prototyping, in and of itself, in instruction did not significantly improve visualization skills in students. The visualization tests did show a dramatic rise in scores as learning occurred at the other levels tested. These occurred at levels two and three (Drafting 2-D and CAD 3-D). The further use of the Rapid Prototyping system (level four) to simulate production of the drawn object did not show an increase in visualization scores. The following graph (Figure 2) shows the relative increases in visualization scores at various educational levels.

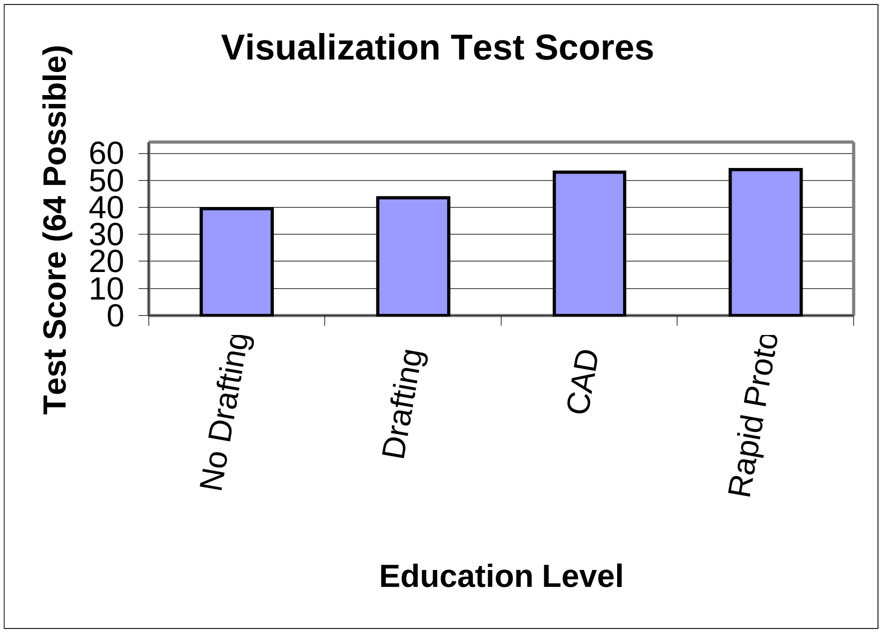

Figure 2. Visualization Test Scores Bar Chart.

Procedure for Survey of Students and Industry Portion of Study

The process of designing a solid model and then prototyping it met with great initial interest on the part of both industry and the students. Industry was chiefly interested in the prototypes, of which the solid modeling was a necessary precursor. The students showed great interest in both procedures. After an initial article appeared in the local paper, more than 30 projects were initiated by local entrepreneurs and industrial personnel. The projects mostly consisted of mechanical projects but some architectural projects surfaced also. The following is a partial list of these projects. Several projects either had no name or were not yet patented with the consequence that confidentiality agreements still apply.

1. Fluid Transfer Project
2. Safety Receptacle Cover
3. Magnetic Levitation Generator
4. Light Construction Housing
5. Audio Device Cover
6. Speaker Cover
7. Jam Lock Device
8. Detailing Device
9. Fruit Juice Cover
10. Knife Handle
11. Motorcycle Drink Holder

12. Insulated Water Bottle
13. Erosion Control Block
14. Plastic Bag Carrier
15. Vent Screen
16. Harley Davidson Tank Logo
17. Sheltered Workshop Floor Plans
18. Power Building Plan

While a detailed description of each project is beyond the scope of this paper the overall success of each venture will be indicated.

The usual procedure was that the project initiator would bring in a sketched idea to the author. The author would then determine the suitability of the project based on the following factors.

- Technical difficulty
- Available student numbers and expertise
- Time available
- Suitability to RP machine size or Solid Modeling software
- Price

It should be noted that most of the work was done without cost where the initiating persons appeared to be private individuals or where a charitable or start-up business was concerned. Even where the industrial people involved were charged for the use of the RP machine, it was below the standard rate of $150 per hour of RP service businesses. This was to encourage business and to compensate for the lack of speed and expertise that our students had in comparison to professionals. Basically a rate of $50 per hour seemed to work best.

After the initial acceptance the industry initiator would come in to speak to the students during class to explain what was wanted. Most often student volunteers would be solicited working for pay, or without, to complete the project. Each student worked independently on the project with occasional group meetings with the initiator to discuss progress and changes. The number of students working on each project was variable. Rates of pay for the students ranged from $10/hr. to $20/hr. when applicable.

At the conclusion of the projects various surveys were done to determine satisfaction of both the industrial customer and the students. The scale used was 1 = strongly disagree, 2 = disagree, 3 = average, 4 = agree, 5 = strongly agree. Again due to low numbers rigorous statistical analysis is was not appropriate. A sample industrial and student survey follows.

Industry Survey **N = 1**	**Points on a five point scale**	**Representative Comments**
Did the design meet your expectations?	5	Exceeded all expectations, very fast
Did the drawings meet your expectations?	5	The students were very willing to make requested modifications.
Was the prototype to your specifications?	4	Prototype needed finishing operation and would be better in color
Overall satisfaction	4.7	Very fast and cheap

Figure 3. Survey of the Industry Personnel most Involved with the Project.

Student Survey N = 3	Average value on a five point scale	Comments
Do you feel that your technical skills improved as a result of this project?	5	Very interesting Good money Software made it easy
Do you feel this project will improve your job chances?	5	Have already talked to one employer who was very impressed
Overall satisfaction	5	

Figure 4. Survey of Students who Completed the Fluid Transfer Product

Results of the Industrial Survey Portion of the Study

The results are presented in Figure 5 below. The high scores need little explanation so the reasons behind the lower scores will be discussed first. On Project 1, the fluid transfer product, the prototype was rated lower because it would not hold water. The fused deposition modeler RP machine used in this study inherently makes porous models. Painting the model solved the problem but required an extra step. On Project 3, the generator, only one student worked on it and he eventually dropped out without explanation. The main cause appeared to be little or no communication. The project was abandoned after an acrimonious exchange between the inventor and the author. On project 4, the housing project, a very long delay in making the individual parts fit together in both the solid modeling and RP phases decreased customer satisfaction. This was somewhat understandable since neither the customer nor the students knew exactly how the housing panels would really assemble. Project 12, the water bottle, had leaking problems in the prototype, which accounts for the somewhat lower score. The Harley Davidson tank logo was rated lower due to a lack of surface quality in the prototype. The filling and painting of the surface solved this problem but again an extra step was required. The floor plans were not prototyped and were thus rated not applicable. It should be noted that the overall average satisfaction was 4.52 on a 5.0 scale for industry personnel. It is evident that the industry personnel were highly pleased overall.

Project	Design Met Expectations?	Drawing Met Expectations	Prototype Met Specifications	Overall
1. Fluid Transfer Project	5	5	4	4.67
2. Safety Receptacle Cover	5	5	5	5.00
3. Magnetic Levitation Generator	1	1	1	1.00
4. Light Construction Housing	4	4	1	3.00
5. Audio Device Cover	5	5	5	5.00
6. Speaker Cover	5	5	5	5.00
7. Jam Lock Device	5	5	5	5.00
8. Detailing Device	5	5	5	5.00
9. Fruit Juice Cover	5	5	5	5.00

10. Knife Handle	5	5	5	5.00
11. Motorcycle Drink Holder	5	5	5	5.00
12. Insulated Water Bottle	5	5	4	4.67
13. Erosion Control Block	5	5	5	5.00
14. Plastic Bag Carrier	5	5	5	5.00
15. Vent Screen	5	5	4	4.67
16. Harley Davidson Tank Logo	5	5	3	4.33
17. Sheltered Workshop Floor Plans	5	5	N. A.	N. A.
18. Power Building Plan	5	5	N. A.	N. A.

Figure 5. Industry Survey Responses

Results of the Student Survey of the Study

Figure 6 details the results of the student survey. It is notable that all the students involved (except for the student who dropped out entirely) thought that their skills increased as a result of doing these industrial projects. Similarly the students thought that this resume builder would most definitely improve their chances of getting a job when they graduated. Again it is evident that the students are very enthusiastic about this program.

Project	**Skill Improvement**	**Improve Job Search**	**Overall Satisfaction**
1. Fluid Transfer Project	5	5	5.00
2. Safety Receptacle Cover	5	5	5.00
3. Magnetic Levitation Generator	N. A.	N. A.	N. A.
4. Light Construction Housing	5	5	5.00
5. Audio Device Cover	5	5	5.00
6. Speaker Cover	5	5	5.00
7. Jam Lock Device	5	5	5.00
8. Detailing Device	5	5	5.00
9. Fruit Juice Cover	5	5	5.00
10. Knife Handle	5	5	5.00
11. Motorcycle Drink Holder	5	5	5.00
12. Insulated Water Bottle	5	5	5.00
13. Erosion Control Block	5	5	5.00
14. Plastic Bag Carrier	5	5	5.00
15. Vent Screen	5	5	5.00
16. Harley Davidson Tank Logo	5	5	5.00
17. Sheltered Workshop Floor Plans	5	5	5.00
18. Power Building Plan	5	5	5.00

Figure 6. Student Survey Responses

Results of Marketing the Products

As is usual with projects of this nature not every product succeeds in the market place. The only product, out of the 30 plus we have worked with, that was outstandingly successful in the "real world" was the Jam Lock. This device holds a door and doorframe together during shipping and installation. This replaces the former method of using casing nails, which have to be removed and the resultant holes filled. This device leaves no holes and reduces installation time by 25%. Ten patented products with approximately ten actually being produced, even in limited numbers, must be considered successful. The fact that five were at least somewhat successful in the marketplace is encouraging.

Project	Patented?	Produced?	Successful?
1. Fluid Transfer Project	Yes	Yes	Yes, Somewhat, 10,000 sold
2. Safety Receptacle Cover	?	No	No
3. Magnetic Levitation Generator	No	No	No
4. Light Construction Housing	Yes	No	No
5. Audio Device Cover	Yes	Yes	Yes, Limited worldwide sales
6. Speaker Cover	Yes	In Process	No
7. Jam Lock Device	Yes	Yes	Yes, 2.5 million per year
8. Detailing Device	No	Yes	Yes
9. Fruit Juice Cover	Yes	In Process	No
10. Knife Handle	No	Yes	Yes, somewhat
11. Motorcycle Drink Holder	No	Yes	No
12. Insulated Water Bottle	Yes	Yes	Yes, nationwide distribution
13. Erosion Control Block	Yes	Yes	No
14. Plastic Bag Carrier	Yes?	Yes	?
15. Vent Screen	Yes	Yes	No
16. Harley Davidson Tank Logo	No	No	No
17. Sheltered Workshop Floor Plans	N.A.	N.A.	N.A.
18. Power Building Plan	N.A.	N.A.	N.A.

Figure 7. Product Marketing Success

Conclusions

While some low numbers restricted the statistical significance of the study it seems clear that industry/education partnerships are beneficial to both parties. The entrepreneurs and industry personnel were nearly unanimous in their high approval of the services offered and continuing requests for these services are being made. Both problem-solving and technical skills appear to increase, especially in lower performing students. Since the industrial sector is frequently paying both the students and the university for their projects, both groups are helped in their financial situation. Because the costs are less than in the private sector, inventors who may not have brought their ideas forward before are now doing so. The students and the instructor, as a public service, also donate much work. Strictly speaking, much of the cost of operating a program like this is charged to education. In rapid prototyping it is best to run the machines fairly continuously to recoup the initial cost of the machine before obsolescence.

The exhibition of both the rapid prototypes and the drawings from these projects has resulted in 15 students, that we know of, declaring their intention to major in our department. Presently Technical Graphics is the largest area in our department and has the greatest growth. Several newspaper, radio, and technical sessions have occurred with increased interest in our services as a result.

The negative aspects of these projects are headed by severe increases in time usage by the instructor and students involved. Often 20 or more additional hours per week were attributed to this activity. Sometimes 40 additional hours were accrued in a weeks' time. Traditional breaks, such as Christmas and Spring Break, were severely curtailed on numerous occasions. Other negative aspects are:

- Delays compared to professional service providers who often provide overnight service
- More meetings needed between industry personnel and students
- Some miscommunication due to student inexperience
- Poor designs in the early stages
- Designs not optimized for manufacturing
- Increased record keeping

Overall the benefits exceed the problems incurred. Many of the projects we have worked on either would not have been put into production or would have been delayed for years. Chiefly the low cost and local availability of the service caused many to come forward who had been hesitating before.

It appears that Rapid Prototyping does not of itself improve problem-solving visualization skills. It is also fairly clear that Industry/Education partnerships both improve student problem solving skills and have substantial benefits in other areas. The near unanimous high survey ratings from both groups are good indicators of support. This result is supported by less specific design and prototype work done in France (Michaud, 1999). That study was an open design project making robots to help autistic children. A somewhat similar successful student generating design project, in the area of electronics, at the University of Idaho is now providing power at a remote site (Peterson, 2000).

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Biography

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