

Rapid Prototyping and Design: Partnerships between Business and Education

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Abstract

This presentation examines the value of industry/Education cooperation in regard to improving product development and sales as well as examining it's effect on student scores, skills, and self esteem. Additionally, the success of the resulting products in the marketplace is examined. The cost of product development has caused a need for accessible and economical design and prototyping of parts and assemblies. Both small business and privately generated product ideas are turned over to Engineering Technology and Technical Graphics students for design, drawing, and prototyping.

Beneficial and detrimental factors to industrial and educational cooperation are discussed. Significant increases in standardized test scores and design skills were noted in some cases after the cooperative development of these designs and prototypes. Various uses for product design and prototyping partnerships in education and industry are examined and their benefits to students, educators, administrators, and industry are examined. Individual case studies are examined with the following general results:

- Successful economic products are rare.
- Problem solving and technical skill increases in students result from these ventures.
- That the Engineering Technology and Technical Graphics student's ability to solve design problems and enthusiasm improve as student's progress through their class work with further increases after the cooperative ventures.
- An educational and industrial consortium improves student chances for employment and interaction with industry.
- Recruitment and retention benefits may result from the publicizing of these efforts.
- Educational / Industrial cooperation benefits both groups and help defray the costs of acquisition of advanced technology and getting products to market.

While the time constraints placed on both the students and the instructors is a problem, the benefits are great enough to make this cooperation worthwhile. Cooperative ventures of this kind result in more ideas going into production, increase student learning, and help small-scale production facilities and private individuals increase their profitability.

Introduction

The purpose of this study was to determine the usefulness of business/education partnerships in the areas of design and rapid prototyping. It was thought that the Rapid Prototyping and design of industrial projects would be valuable in increasing the translation between 2-D drawings and actual 3-D parts. In order to accomplish this, the following research questions were proposed:

- *Does offering a lower cost design and prototyping service provide a useful service?*
- *Do Industry/Education partnerships in design and Rapid Prototyping result in viable products?*
- *Do these partnerships increase student scores on standardized tests?*

Following the initiation of a new low cost or *pro bono* cooperative program for design and prototyping at Southeast Missouri State University a steady influx of inventors and companies showed interest in pursuing development of products that had been tabled due to prohibitive cost or distance factors. Typically, in working with new products, we were presented with hand drawn rough sketches from entrepreneurs and industry personnel to translate into working drawings, rendered pictorials, and rapid prototypes.

Rapid Prototyping (RP) and Solid Modeling give industry, educators, and students the ability to model complex parts in a relatively short time. Often the custom prototyping of the product by conventional means is so expensive that it is not attempted. This is especially true because the initial prototype often reveals flaws in the looks, operation, or strength of the part. Since each part is a one of a kind project, economies of scale are not realized and the cost remains the same for each succeeding trial. While this is also true of Rapid Prototyping the initial cost is usually much lower and thus succeeding iterations are also lower in cost. While the advent of High Speed Machining has lessened the need for Rapid Prototyping due to the fact that machined models take less time than previously, RP still is a faster way to obtain a prototype in general. Some parts, of particularly complex geometry, can only be produced by the RP process.

Methodology

It should be emphasized at this point that all student work was done individually with meetings as needed where ideas, but not work, were shared. The use of cooperative team learning, while apparently of benefit does not work well in the authors' opinion ⁴. There are typically "hitchhikers" who do little work but are still rated satisfactory in peer reviews. The self-evaluations conducted seemed to be well done and their validity as a technique is discussed by Lowman ⁸. Two basic techniques were used in this study:

1. Standardized and normed testing
2. Surveys of both industry and students

In order to determine if Industry/Education partnerships improve product development and sales the resulting sales, time, and financial data (if available) from industry was used as a basis for testing. To determine if these partnerships resulted in increased student learning several techniques were used.

The first, the Revised Minnesota Paper Form Board Test was used as the instrument for evaluating student performance in problem solving in the visualization area. 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, 8, 10}. The validity of the test has been shown to have high multiple correlations with successful school to work performance in areas requiring problem-solving skills ⁵. This was particularly true in the drafting, printing, engineering, and inspection areas ^{2, 5, 12}. 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 ⁷.

Another method is anecdotal and survey evaluations from the industrial personnel and students involved in various design projects. These observations were recorded and mostly kept confidential. Additional media use of these data was made as well as being used in department advertising.

While the study was originally designed to evaluate whether just Rapid Prototyping would increase problem-solving skills, it somewhat naturally expanded into different areas. The extended time period in this study allowed repetition with various groups for verification of the results ¹³. 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 in the testing and grading areas only.

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
5. Industry partnership

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 five. In any case the difference in performance between steps is representative of one student's score (paired difference), 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 third 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 level three above.
- The fourth comparison involved students in two sections of TG 220, Solid Modeling and Rapid Prototyping. Much more extensive use was made of the 3D CAD and prototyping programs and actual prototypes were produced.
 - The last comparison involved a comparison between students who participated in industry partnerships and those who did not. It therefore involves a subset of the groups with both 3D Cad and Rapid Prototyping experience. Since most students do not volunteer for extra work, even if paid, the industry partnership group is small in size (<20).

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 as such. 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 ⁷. Alternate forms of the Minnesota Paper Forms Board Test, forms AA and BB, were used throughout the study. These forms are available from The Psychological Corporation in San Antonio, Texas.

Results of Standardized Testing

The results of this study are summarized below in Figure 1. 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
5. Industry/Education partnership participation.

Since paired difference testing was employed, the null hypothesis was that there was no difference in problem solving 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) ⁶. 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 method, Fused Deposition Modeling, examined.

Levels	Mean	Std.	T(a/2), P, T, DF	Null Hypothesis
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		Dev.	A=.05	
No Drafting	39.5	8.7	1.98, P=.0091	Rejected, significant increase in scores
Drafting	43.5	7.0	T= -2.658, DF=108	
Drafting	43.5	7.0	1.99, P=6.3E-7	Rejected, significant increase in scores
CAD	51.0	7.2	T= -5.51, DF=66	
CAD	51.0	7.2	2.00, P=.61	Accepted, insignificant increase in scores
Rapid Prototyping	49.6	3.9	T= -.51, DF=58	
Above but Industry Participant	51.6	3.4	1.729, P=.0009, T= -3.619,19	Rejected, significant increase in scores

Figure 1. Scores and t-Test Results

t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	49.6	51.6
Variance	15.30526	11.62105
Observations	20	20
Pearson Correlation	0.780602	
Hypothesized Mean Difference	0	
Df	19	
t Stat	-3.61987	
P(T<=t) one-tail	0.000912	
t Critical one-tail	1.729131	
P(T<=t) two-tail	0.001824	
t Critical two-tail	2.093025	

Figure 2. t-Test Results

The data In Figure 1 and Figure 2 supported the conclusion that the use of Rapid Prototyping in instruction did not significantly improve problem solving visualization skills in students. There is a significant indication that industry participation resulted in higher scores however. However, later data in the areas of testing and assignments showed some improvements as will be shown later. The visualization problem solving tests did show a dramatic rise in scores as learning occurred at the other levels tested. These occurred at levels two (drafting) and three (CAD). The further use of the Rapid Prototyping system (level four) to simulate production of the drawn object did not show an increase in problem solving scores. The following graph (Figure 3) shows the relative increases in problem solving scores at various educational levels.

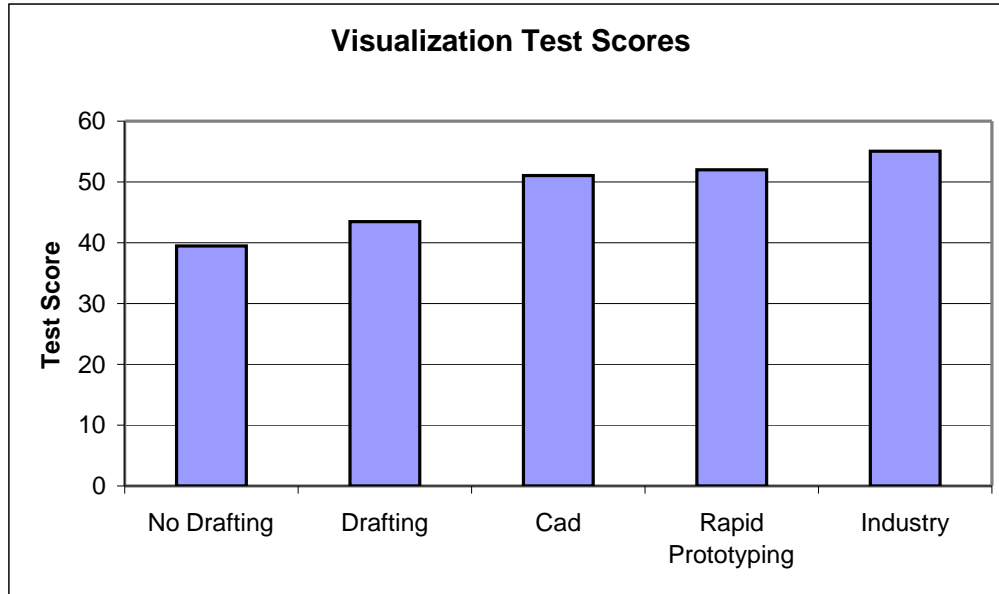


Figure 3. Visualization Test Scores Bar Chart.

Various Uses for Rapid Prototyping

Rapid Prototyping can be used for many things outside of just the look and feel of the prototype itself. Testing for fit with other parts is one example. Another example is strength testing. While the prototype itself is made of layers of plastic in the Fused Deposition Modeler process used in this study, some comparisons to actual metal or plastic production parts can be made. The layers are often weak points if incorrect temperature settings are used, but if the correct process is followed then the model seems to respond to stress much the same way as a production part. The model and part tends to break in the same location, at a lower load for the model than the part of course. The use of the Sintered Laser Prototyping process can actually produce sintered metal parts with higher strength values than the original parts in some cases. This process is often used for molds for limited production. Since the sintering process leaves a porous surface some lubricant storage is possible for bearings also. Another use for a prototype is as a replacement part in and of itself. A prototype can often substitute for broken parts that are under low stresses in use. Particularly helpful in this regard is the use of a CMM to reverse engineer the broken part back to a 3-D CAD file. The CAD file is then used to prototype the part. If the Rapid Prototyping process used permits the use of wax as a build material then lost wax casting is possible. Very intricate designs such as turbine blades, jewelry, and honeycomb filters can be cast with much less trouble than previously.

The RP work we have done consists mostly of mechanical projects. The following is a partial list of these projects:

1. Fluid Transfer Project – Transfers transmission fluid from the top of an engine
2. Safety Receptacle Cover – Child safety device
3. Magnetic Levitation Generator – Generates electricity with magnetic bearings
4. Light Construction Housing – Emergency plastic housing
5. Audio Device Cover – Improved cover for digital patch box

6. Speaker Cover – Stronger, lighter, cheaper, emergency alarm cover
7. Jam Lock Device – Holds door and frame together during shipping and installation
8. Detailing Device – Helps in cleaning narrow access areas of windshields
9. Fruit Juice Cover – Plastic cover for fruit juice
10. Knife Handle – Ergonomic handle for fillet knife
11. Motorcycle Drink Holder – Holds cup on motorcycle
12. Insulated Water Bottle – Keeps drinks cold for about 4 hours on hot days
13. Erosion Control Block – Prevents stream bank erosion and uses recyclable materials
14. Plastic Bag Carrier – Permits arthritic persons to carry more than one plastic grocery bag
15. Vent Screen - Filters HVAC air at vent
16. Harley Davidson Tank Logo – Logo for motorcycle

While a detailed description of each project is beyond the scope of this paper the overall success of each venture will be indicated. Some of the more extreme uses of RP that we have done are:

- House Models
- Trophies or Plaques
- 6" Working Band saw
- Jewelry
- Prosthetics

These projects were often initiated with the industry person coming in to discuss the project with the instructor. Then a meeting would be set up where the industry person would meet with a design and prototyping class. Student volunteers would then apply for either free or paid jobs doing the project. When the predetermined due dates came up a follow up meeting would be arraigned to critique both the design and prototype. Then the final drawings and prototypes would be made.

Description and Results of the Fluid Transfer Device Project

Project one consisted of a fluid transfer device that uses automobile engine vacuum to pull automatic transmission fluid out of the filler tube. This negates the having to get under the car. The device can also push clean fluid in using shop air. Initial parameters were:

- That it would hold 2 quarts of fluid
- That it would hold 150 psi shop air
- That it would be able to hang from the inside hood of a car
- That it have a pressure release valve
- That the fluid level be visible through the sides of the container
- That the container resist a four foot drop on a concrete floor multiple times

The inventor of the device is a transmission repair specialist and had made a device with less stringent parameters out of plastic pipe and used it for many years. He had often tried to interest manufacturers in the device with little result. It was felt that a more presentable model, rendering, and drawings would attract attention. Three students bid on this job and were accepted. In less than one week acceptable drawings were produced and a rapid prototype was started in the second week. Due to the porous nature of the fused deposition RP procedure the container would leak under pressure as designed. Since it was felt that the model would look better in contrasting colors it was painted. This solved the leaking problem and made the Rapid Prototype more attractive. The client being satisfied, the prototype was taken to a new products

show in Dallas, Texas where a manufacturer for production and marketing picked it up. Subsequent manufacturing decisions were taken over by industry personnel. The product is essentially the same as designed. The actual material selection resulted in a lowering of the 150 psi requirement to 70 psi. Since the pressure relief valve operates at 20 psi, a high safety factor is present. Initial production was set at 10,000 units. Subsequent sales have been slow and a new manufacturer and marketer are being sought. All three students completed the project and shared ideas in the final product with the inventor.

Initial estimates for a machined one-off prototype were approximately \$5,000. The estimate for a molded version had a \$10,000 price tag just for the mold. The design and prototyping came to under \$1,000 in our classroom. The inventor rated the student work very favorably on a 5-point scale, with 5 being most favorable, in the design, drawing, and prototyping phase. The students expressed their satisfaction as very high in obtaining and doing the work (see Figures 4 and 5).

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

Description and Results of the Jam Lock Project

Project two consisted of a device that holds a door to its' frame during shipping and installation. This replaces the common practice of using two or more casing nails with their subsequent holes. The initial parameters were:

- That it would be made of injection molded plastic in two parts
- That it would screw together and securely hold the door to its' frame during shipping and installation
- That it would easily unscrew after leveling and securing the door in the house framing.

- That minimal material would be used to make the parts while still being functional

The inventor of this project was a successful door manufacturer who could not stand retirement. He contacted us with a hand drawn sketch on letter size paper with primitive dimensioning. Eventually 10 students were involved with this project. In two weeks acceptable drawings were produced after several modifications. Several rapid prototypes were made. Assembly and disassembly was tested and further modifications to the design were made. Several more rapid prototypes were made overnight and were used for both assembly/disassembly tests and for a 3,000-mile road-shipping test. No further modifications were needed as all tests were passed. Subsequent production matters were handled by industry personnel. In the first year of production up to 7% market share was achieved. Present production is approximately 2.5 million per year after 3 years with substantial increases each year. Actual use over this time showed a need for an increase in fillet size at the thread root to reduce breakage in use. This was an extremely successful project economically. Figures 6 and 7 show the results of the industrial and student responses.

Industry Survey N = 1	Points on a five point scale	Representative Comments
Did the design meet your expectations?	5	Exceeded all expectations
Did the drawings meet your expectations?	5	Exceeded
Was the prototype to your specifications?	5	Exceeded
Overall satisfaction	5	Very satisfied

Figure 6. Survey of the Industry Personnel most Involved with the Project.

Student Survey N = 10	Average value on a five point scale	Comments
Do you feel that your technical skills improved as a result of this project?	5	Easy job Good money Software made it easy
Do you feel this project will improve your job chances?	5	Only if they use this software Will recommend to my boss Definitely
Overall satisfaction	5	We should have more of these projects Definitely

Figure 7. Survey of Students who Completed the Fluid Transfer Product

Conclusions

While 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 unanimous in their 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 paying both the students

and the university for their design and prototyping work both groups are helped in the financial aspects of education. 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.

The exhibition of both the rapid prototypes and the drawings has resulted in approximately 15 students declaring their intention to major in our department over 3 years. 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.

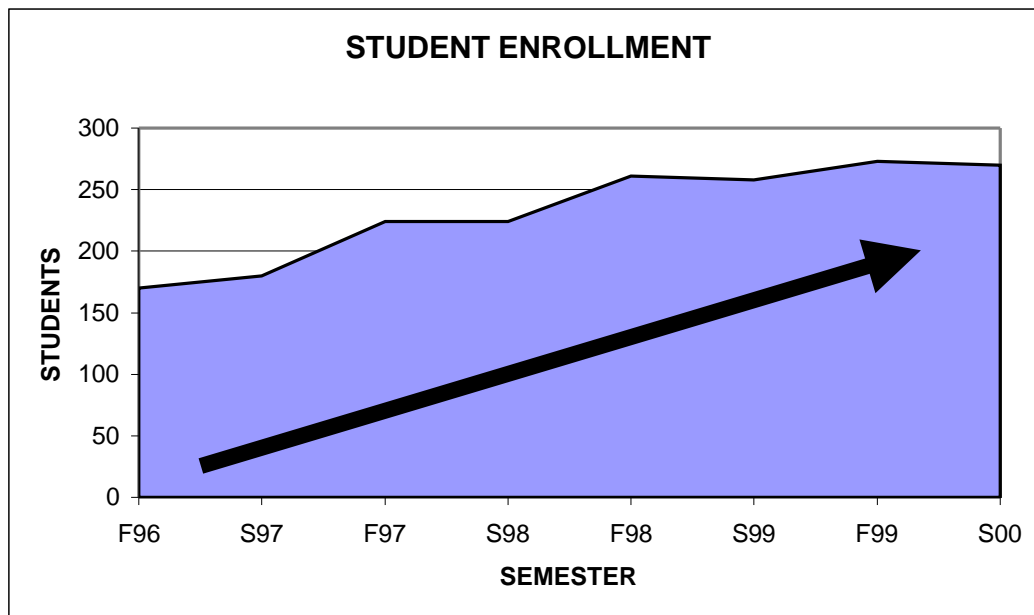


Figure 8. Student Enrollment

The negative aspects 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, 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.

It appears that Rapid Prototyping does not of itself improve visualization skills. It is also fairly clear that Industry/Education partnerships both improve student problem solving skills and have substantial benefits in other areas.

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Biography

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