Enhancing Problem Solving Skills in Engineering and Graphics Technology Students

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Abstract

The fast pace of product development has caused a need for both managerial and technical graduates who are able to solve problems. In the area of Industrial Education, new methods are needed to enhance problem-solving skills. Industry generated product ideas are turned over to Engineering Technology and Technical Graphics students for design, drawing, and prototyping. 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. Both beneficial and detrimental factors to industrial and educational cooperation are discussed. Various groups of students were tested at different levels of instruction before and after being assigned industry partners in the development of new products. Significant increases in standardized test scores and design skills were noted 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. 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. The use of advanced technology is expensive but there are various ways to defray the cost of this technology to both education and industry. Cooperative ventures of this kind result in more ideas going into production, increase student learning, and help small-scale production facilities increase their profitability.

Introduction

The purpose of this study was to determine effective ways to improve student's problem solving skills. 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:

- *Will drawing an object in 3-D and producing that part with a Rapid Prototyping system improve student problem solving skills?*
- *Do Industry/Education partnerships in design and Rapid Prototyping improve student problem solving skills?*

Additionally several other courses and techniques were also evaluated for problem solving improvement.

Graphics influences many aspects of industry. The ability of a student to accurately visualize the drawing in its' completed physical form is one of the primary purposes of a design and drafting curriculum. Various methods have emerged using prepared models, photographs, and pictorials to illustrate what the drawing is meant to represent. It is common for students to work only from these prepared examples in the classroom in the production of both two-dimensional and three-dimensional drawings. More typically, in working with new products, we were presented with hand drawn sketches from entrepreneurs and industry personnel to translate into working drawings, rendered pictorials, and rapid prototypes.

Rapid Prototyping (RP) and Solid Modeling (SM) give industry, educators, and students the ability to model complex parts in a relatively short time. This allows the student to create objects either virtually or actually instead of copying drawings and parts. It also better matches industrial practice in the common idea, concept, drawings, prototype, and manufacture cycle. 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. 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 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 and others [8].

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].

The second method used was the individual student performance on selected class assignments using normal grading procedures based on accuracy, speed, and quality of work. A comparison between students who participated in the industry work and students who chose not to participate is made as well as trends in individual scores. The results of this comparison were not made available to students but the resulting work done and the pay and problems associated with the project were discussed with the entire class.

The third, and least comparable, method is anecdotal evaluations from the industry people involved. These observations were recorded and posted to both the individuals involved and the class as a whole. Additional media use of these anecdotes was made as well as use in 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 Testing Method One

Students were tested for problem solving 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 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 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 levels three and four above.
- The last comparison involved comparison between students who participated in industry partnerships and those who did not. It therefore involves a subset of the groups with both 3-D 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 (13).

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 Testing Method One

The results of this 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
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 alternate 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 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 51.0	7.0 7.2	1.99, P=6.3E-7 T=-5.51, DF=66	Rejected, significant increase in scores
CAD Rapid Prototyping	51.0 52.0	7.2 7.8	2.00, P=.61 T-.51, DF=58	Accepted, insignificant increase in scores
Above but	55.0	5.1	Insufficient	Indication of improvement

Industry Participant			numbers, n=15	

The data supported the conclusion that the use of Rapid Prototyping in instruction did not significantly improve problem solving visualization skills in students. There is an indication that industry participation resulted in higher scores, but the number (15) involved limited the statistical usefulness of the results. However, later data in the areas of testing and assignments showed dramatic 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 1) shows the relative increases in problem solving scores at various educational levels.

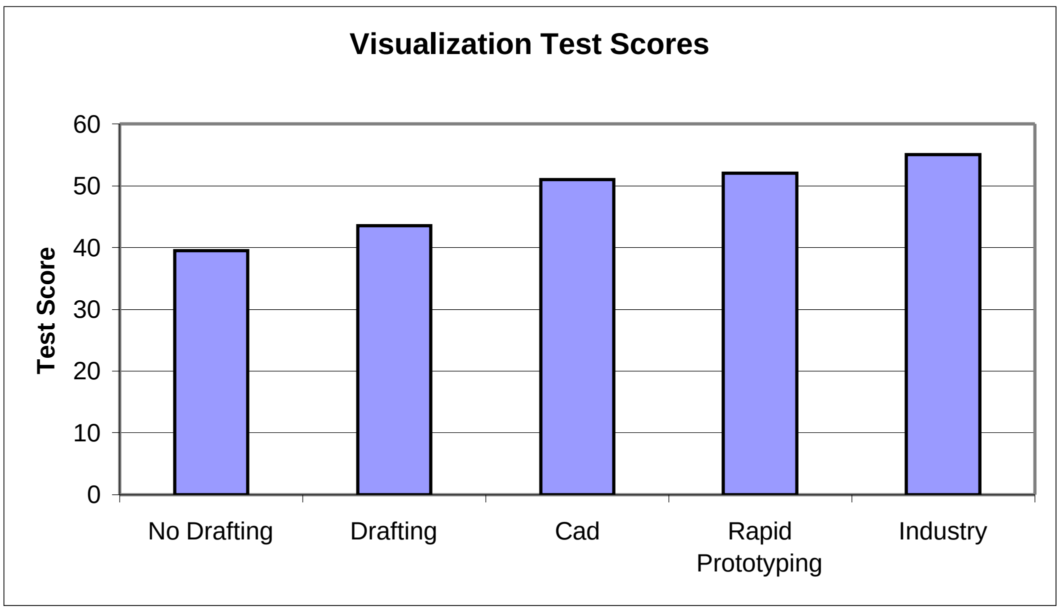

Figure 1. Problem Solving Test Scores Bar Chart.

Procedure for Testing Method Two

The second method involved the use of student performance on selected class assignments. Normal grading procedures based on accuracy, speed, and quality of student work were used. . A comparison between students who participated in the industry partnership and students who chose not to participate is made as well as trends in individual scores. The results of this comparison were not made available to students but the resulting work done and the pay and problems associated with the project were discussed with the entire class. Often the industry person involved would discuss modifications and problems with the whole class. Three normal projects were assigned to the entire class after the industrial design work was done. The students were unaware that this was part of a study as was the instructor at the time. Grading proceeded normally and the data was subdivided after the end of the course. Additionally simple surveys were administered for customer satisfaction and quality control work.

Results of Testing Method Two

Several limitations need to be noted for this procedure before continuing. These include the following:

- Only 15 student volunteers completed the industrial work despite pay scales as high as $20 per hour.
- Only volunteers for industry work were used. Thus randomization did not occur.
- Roughly two groups were observed volunteering. The first group consisted of "A" students and the second group consisted of lower performing students. The "A" students tended to volunteer more often and work more cooperatively.
- Of the "A" group, all except one who started completed the work they volunteered for.
- Of the "C" to "D" group most (~70%) did not complete their industry contracts and were not included in the study from that point on. Since multiple students were assigned to each project this did not affect project completion.
- Industrial personnel exhibited marked preferences over time to work with particular students out of the group assigned to the project. This occurred on all projects and was attributed to higher levels of performance from these individuals. While the other students working on the problem were present they were usually in a secondary role.

Despite these limitations, numerous and successful projects were completed. Of these only two will be discussed in the interests of space requirements.

Project One

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. See Picture 1.

Picture 1. Fluid Evacuator Project

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 2 and 3).

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 2. 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 3. Survey of Students who Completed the Fluid Transfer Product

The next step compared the students' three previously graded projects with the three graded projects after the industrial project. It should be stressed that these were normal class projects and that the instructor had no idea that the data would be used in this study. Only the 3 students who participated in the industrial work were used (see Figure 4). The average increase in points was approximately 3.7 after doing the industrial project.

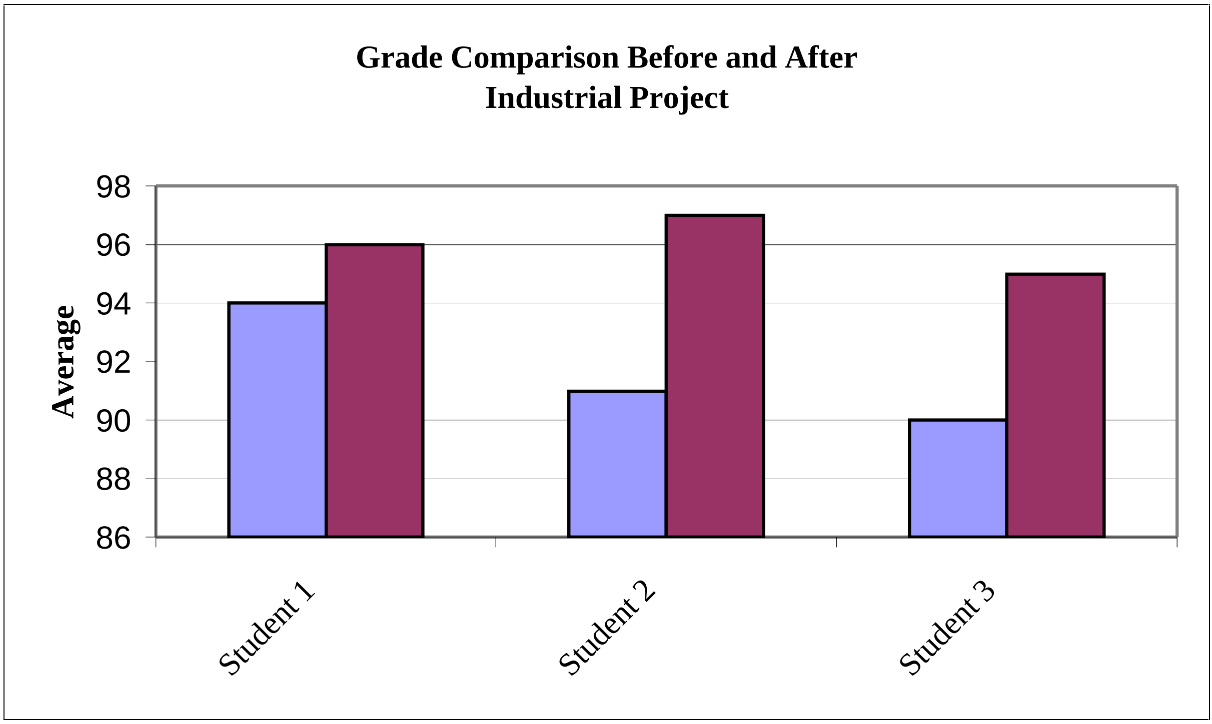

Figure 4. Before and After Comparison of Graded Work

Student 1 before and after

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	94	96
Variance	9	13
Observations	3	3
Pearson Correlation	-0.69338	
Hypothesized Mean Difference	0	
Df	2	
t Stat	-0.56949	
P(T<=t) one-tail	0.313228	
t Critical one-tail	2.919987	
P(T<=t) two-tail	0.626456	
t Critical two-tail	4.302656	

Figure 5. t-Test for Student 1

Student 2

t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	91	97.33333
Variance	4	21.33333
Observations	3	3
Pearson Correlation	0	
Hypothesized Mean Difference	0	
Df	2	
t Stat	-2.17945	
P(T<=t) one-tail	0.080565	
t Critical one-tail	2.919987	
P(T<=t) two-tail	0.16113	
t Critical two-tail	4.302656	

Figure 6. t-Test for Student 2

Student 3

t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	90	97.33333
Variance	100	21.33333
Observations	3	3
Pearson Correlation	0	
Hypothesized Mean Difference	0	
Df	2	
t Stat	-1.15311	
P(T<=t) one-tail	0.184033	
t Critical one-tail	2.919987	
P(T<=t) two-tail	0.368067	
t Critical two-tail	4.302656	

Figure 7. t-Test for Student 3

Since the absolute value of the t statistic is smaller than the critical value in all cases we must accept the null hypothesis that there is no significant difference in before and after scores in this case. Please note that the low number (3) of volunteer students in this case were all “A” students.

Project Two

Project two consisted of a “Jam Lock” device that holds a door to its’ frame during shipping and installation (See Picture 2).


Picture 2. Jam Lock Project

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 speaking.

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 8. 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 9. Survey of Students who Completed the Fluid Transfer Product

The next step compared the students' three previously graded projects with the three projects graded after the industrial work. It should be stressed that these were normal class projects and that the instructor had no idea that the data would be used in this study. Only the 10 students who participated in the industrial work were used (see Figure 10a). The average increase in scores was approximately 10 points, or one letter grade, after doing the industrial project. Unlike the previous project done by students who were already making "A" grades this one included 7 students with less than "A" grades (see Figure 10a and b). Due to space limitations the statistical t-test analysis is omitted and the only overall results are presented in Figure 10b. Please note that the lower performing students showed much greater improvement after working on the industrial project. The non volunteering students acted as a control group and showed no significant change.

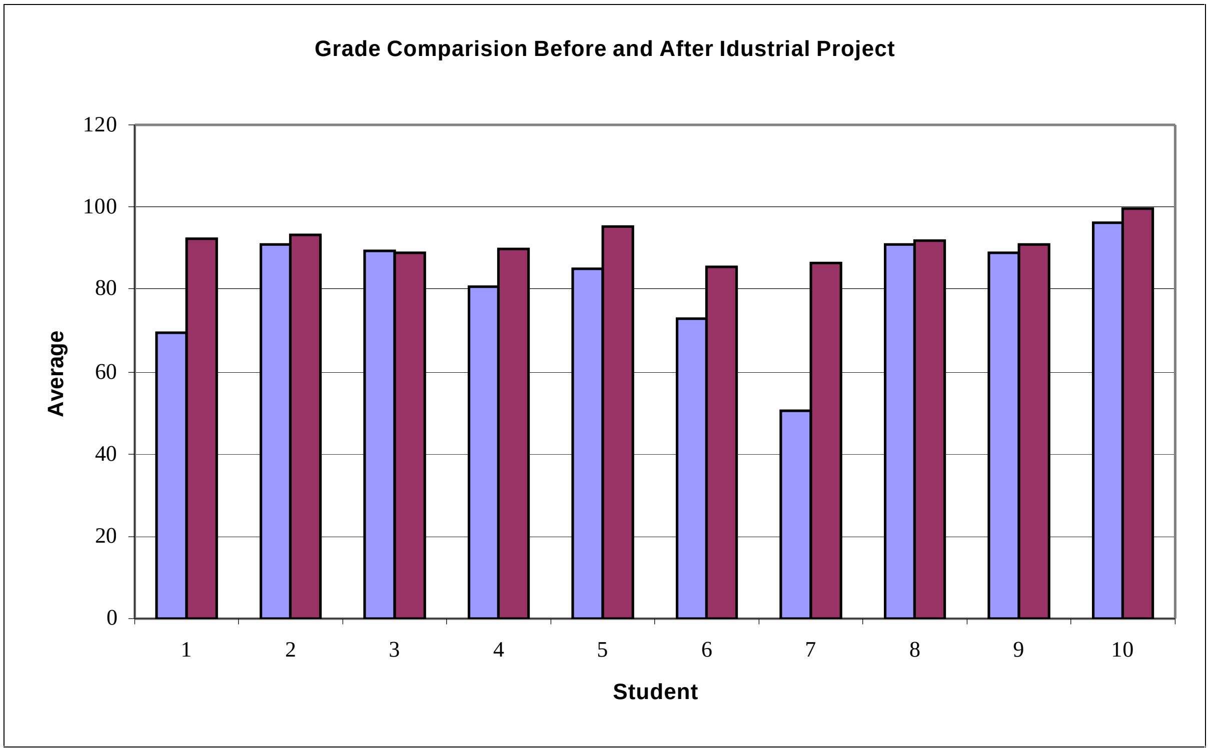

Figure 10a. Before and After Comparison of Graded Work

Student	Initial Grade	Final Grade	Statistically Significant t-test
1	D	A	Yes
2	A	A	No
3	B	B	No
4	B	A	Yes
5	B	A	Yes
6	C	B	Yes
7	F	B	Yes
8	A	A	No
9	B	A	No
10	A	A	No

Figure 10b. Summary

The reasons for the above data are hypothesized as:

- Greater interest was generated in lower performing students due to the industrial job since 6 out of 7 showed a grade increase and 5 out of 7 were statistically significant at the alpha = .05 level.
- Higher performing students are not being challenged in the class or by the industrial projects. Thus they easily complete their work and see no reason to improve.
- The lower performing the student the greater the interest generated.

Further research will be conducted to attempt to answer or further direct these hypotheses.

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 projects 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.

This program has resulted in several newspaper articles and in increased interest in Industrial Technology. The exhibition of both the rapid prototypes and the drawings has resulted in approximately 15 students 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.

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.

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Biography

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