

# USING 3-D MODELS TO TRAIN ENGINEERING DESIGNERS

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## ABSTRACT

During a preliminary investigation of the learning capabilities of injection machine operators, it was found that many possessed limited spatial skills. Previous studies with naïve engineering designers had found that those with low visual skills had difficulties in reading and manipulating data from engineering drawings, and since the advanced training material for machine operators principally comprised technical cross sections, some learning difficulties were anticipated. Some success was gained by using a 3-D wooden model in the operators' training, so the approach was adapted to train engineering designers for the work reported in this paper. The spatial skill of forty-two trainee designers was measured, and a model of an injection molding machine was made. Half the trainees were instructed on aspects of injection molding design using the model, and half by using conventional 2-D teaching materials. It was found through a post-test that trainees with high visual skills learned equally well from both approaches, but those with low visual skill learned much more effectively when their training involved the use of the 3-D model. In view of the difficulty in developing advanced spatial skills, it would appear that more effective engineering design education across a wider range of abilities might be achieved by a greater use of 3-D teaching tools.

*Keywords: Artifacts, visual skill, learning preferences, injection molding design*

## 1 INTRODUCTION

From a survey of the Australian plastics industry in 2004, the authors found there was a need to enhance the training of die designers and injection molding machinery operators. A questionnaire was prepared and distributed to the majority of significant plastic companies in the state of Victoria, Australia – 53 companies in total [1]. Eighteen companies responded to the questionnaire. The average number of employees in the respondent companies was 53, with a median of 50. Larger Victorian companies did not respond, so the largest number of employees in the respondent companies was 170. The responding companies were active in numerous industry sectors, with automotive and building industries identified as significant clients. Other industry sectors included materials handling, electronics, horticulture and marine. Companies were asked to provide a quantitative measure of importance to a series of proposed strategies that may improve the overall performance of the Australian polymer industry sector. There were eight strategies with the highest perceived importance, heavily weighted towards a series of training strategies. An overall weighted score for each of the 8 strategies was calculated by summing the product of each normalized percentage importance and an importance weighting in the range 8 (most important) to 1 (least important)(Figure1). Improved training of die designers had, by far, the largest score (7.28). A secondary, but more immediately accessible goal was the training of machine operators (a score of 3.5). This latter issue was explored in a study using timber model die components and flawed moldings for training machine operators, and the outcomes were reported in 2005 [2]: in particular we identified a direct connection between the trainees' visual skill and their training outcomes. The present paper reports on the results of an extended study with trainee engineering designers, using more sophisticated models of an injection molding machine and a die.

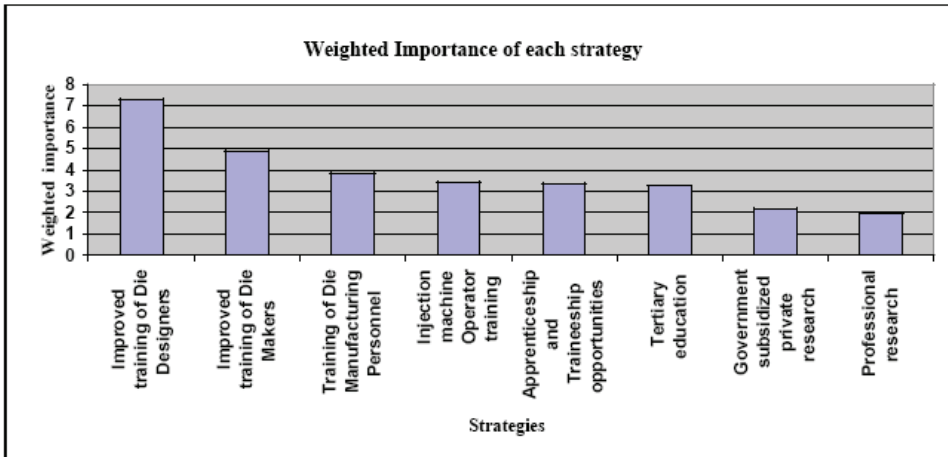


Figure. 1 Outcome from an industry survey that identified the need for training die designers.

## 2 TRAINING DIE DESIGNERS

A typical training program for die designers will follow conventional engineering professional education protocols, but there are particular aspects that demand special attributes. Plastic artifacts and die components can have complex 3-D forms, and the dies are, after all, ‘negative’ representations of the molded components. Consequently, there is a demand for learners to exercise advanced visual capabilities.

Training materials for most engineering programs, and for molding usually contain two dimensional (2-D) representations (in text books, for example), and often include cross sections of those complex three dimensional (3-D) components commonly encountered in die design. Figure 2 is an example of this type of image.

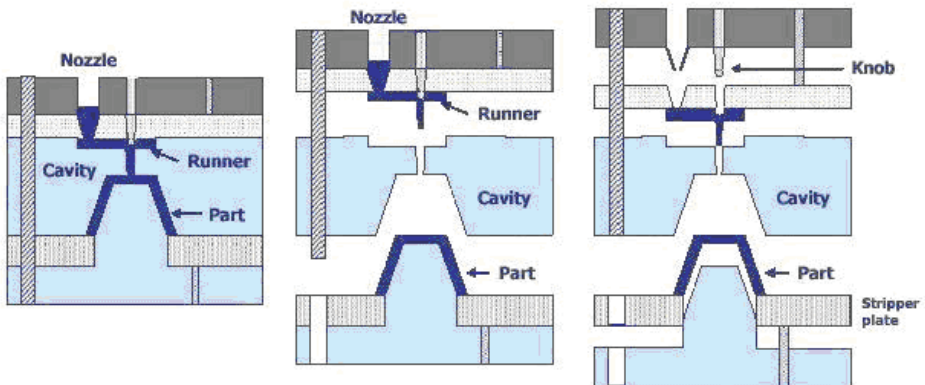


Figure. 2 Typical image from die and molding training material (tooling for a plastic cup) [3]

During a study of trainee molding machine operators in 2005, it was reported that many of those operators had difficulty in comprehending the three-dimensionality of the artifacts and injection machine components when those parts were represented by cross sections of the type shown in Figure 2. It appeared that their learning was impeded by their visual skills. While it appeared more likely that, as a group, trainee engineering designers would have a higher level of visual skill, there was

some evidence that this may not have been the case, or at least, that many of the trainee designers may not possess high visualization skills [4, 5, 6].

### 3 SPATIAL SKILL IN DESIGN

The skills associated with the successful solution of holistic spatial problems (e.g., 3-D machines) with incomplete and contradictory data where the form of the solution is not obvious are part of the subset of human skills called the 'right brain skills' [7]. The use of systematic logic (such as mathematical tools) within a narrowly bounded domain draws predominantly on 'left brain skills'.

It is apparent that most of the systematic learning that occurs when the engineering sciences are taught in the traditional manner engages left brain skills, and that students with a highly developed left brain intellect will excel in these courses. It seems as though excellence in design requires a balanced application of skill from both the left and right hemispheres.

During 2004, the authors found that visual capability of trainee engineering designers was correlated with their performance in their design examination [8], so this right-brain skill was included in a study to uncover further related skills. The undergraduate students selected as subjects for the study were drawn from the introductory engineering design course at Monash University (Australia) during the first half of 2006. Most of the 280 design students had completed a 'common' first year in 2005, where they had passed in studies of mathematics, computer programming (both compulsory studies), dynamics, and other fundamental engineering sciences. There were no design studies in that preparatory year.

Grades for four first and second year courses in mathematics and computing were obtained, along with those of the second year design course.

The design grade combined students' separate scores gained from a formal examination comprising an open-ended design and drawing task (40%), individual 2-hour class assignments covering a dozen component skills in design methodology (20%), an individual drafting component within group project work (7%), and the remainder from group scores in two projects (33%).

The students enrolled in design course were tested on two occasions during breaks in the normal lectures. On the first occasion, during the eighth week of the 13-week course, a ten-question version of the Mental Cutting Test (MCT) of spatial visualization skill [9,10], was undertaken (Figure 3). On the second occasion, during the fifth week of the following semester, a management questionnaire [11] with the imbedded question: "When solving a problem (a) I use all of the data available, and get concerned when data seems to be inadequate, or (b) I feel comfortable making assumptions from my own viewpoint" was completed by most of the students.

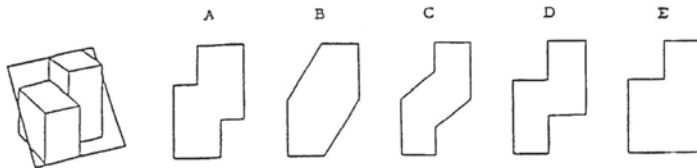


Figure 3. Sample question from the MCT. Respondents are required to select the cross section A-E that would result from the cutting plane shown in the pictorial representation

Results for studies in four mathematics and computing courses with enrolments from 100 to 238 students at two levels were extracted from university records and correlated in pairs. The correlation coefficients for those pairs ranged from 0.59 for level 1 mathematics and computing (238 sets) to 0.67 for a level 2 mathematics course and level 1 computing (151 sets) (all were significant, with  $p < 0.01$ ). This confirmed that there was a reasonably common basis for performance in the science-based studies, and showed the spread that existed between courses with similar structures. The correlations between the science-based courses were taken to indicate that an underlying academic skill accounted for about 0.6 of a student's grade, and the remaining proportion reflected individual differences in motivation, teaching compatibility, timetabling influences, access to tutors etc.

The correlation for the 97 pairs of results from the engineering design grade and the grade in second level mathematics was 0.32 ( $p < 0.01$ ). This correlation with mathematics was noticeably lower than correlations between the mathematical sciences, and supported anecdotal evidence that many of the academically strong students did not perform as well in design.

The correlation coefficient for the 179 students who completed the 10-question MCT for their visualization score, and their design outcome was 0.32. This is significant ( $p < 0.01$ ), and showed either that visualization skill is very useful in design education, or that there was some other common component that underpinned visual and design skills.

The correlation coefficient between response (b) (i.e., comfort in making assumptions) to the management question and the design grade was 0.28 for the 72 students who undertook the test. This is significant ( $p < 0.01$ ), so it may be concluded that the better performing design students are more comfortable in making assumptions during problem solving.

A multiple regression of design grade with the 50 complete sets of student results from (a) mathematics, (b) the MCT and (c) the question on comfort with assumptions yielded the regression coefficient of 0.62 and an equation of:

$$\text{Design grade} = 26 + 0.42 \times \text{Mathematics} + 0.14 \times \text{MCT score} + 0.056 \times \text{Assumption score},$$

with all components measured as percentages. The ANOVA is significant ( $p < 0.005$ ) (Figure 4).

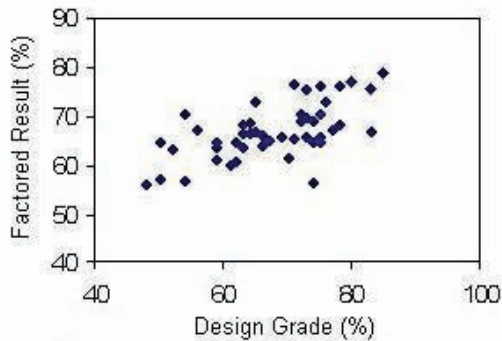


Figure 4. Scatter plot for 50 students' design grade and composite result from mathematics, visualization and management tests

The study set out to identify possible causes for the spread of design performance in an undergraduate engineering program. It was noted that the average correlation coefficient between mathematics-based courses was about 0.6, providing a baseline target for design course correlation. The design course in the study correlated at only 0.32 with the averaged mathematics courses, showing that there were factors in design performance that were not present in mathematics assessment tasks.

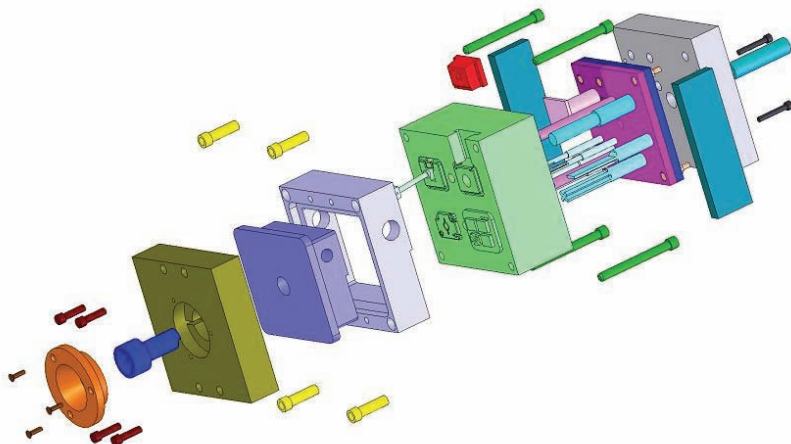
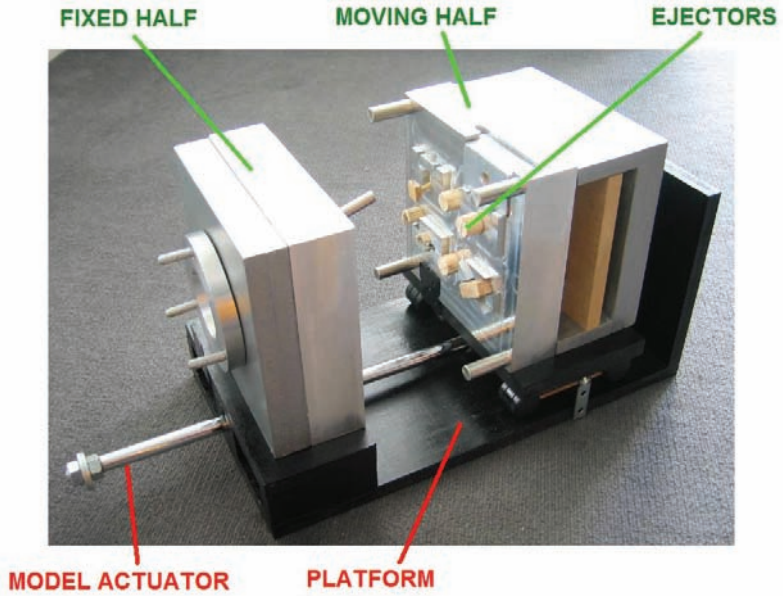
The multiple regression correlation was 0.62 when grades for the mathematics courses, the MCT and the students' willingness to make assumptions were factored together. It was concluded that while a student's academic capability, as demonstrated with left-hemispheric mathematics techniques, was a major correlated factor in their undergraduate design performance at Monash, there were significant design grade advantages if they were also strongly visual, and were comfortable when making approximations during problem-solving.

This finding suggested that some engineering design students would probably find it especially difficult to become proficient in the design where advanced visual skill would appear to be advantageous. Consequently, we set out to apply the findings from our study with injection machine operators, where the use of 3-D artifacts proved to be useful teaching aids, to a more extensive study with potential die designers.

#### 4 EXPERIMENTAL PROTOCOL

We had hypothesized that trainee designers with weak visual skills would find it relatively difficult to cope with spatial concepts when engaged with conventional 2-D learning materials, such as illustrations and sections like those in Figure 2. However, we expected that those weak visualizers would be more comfortable with actual artifacts that could be physically manipulated.

To test this hypothesis, a simplified model of an injection molding machine and die set was designed and built (Figure 5), and a set of conventional 2-D learning material was developed to cover the same concepts (Figure 6).



bolts for backplate and retaining plate	angled-moving ejector pins	cavity plate - bolster	slider finger pin	angled-moving ejector plate	moving half platen	fastening ejector pins (sleeve ejector)
locating ring	core plate	cavity - insert	slider	pushback pins	rail screw	sinksharp ejector pins (blade ejector)
screw for locating ring	guide pillar	sprue bush	slider finger pin lock	retaining plate 1	nuts for backplate and retaining plate	snapfit ejector pins (pin ejector)
		backplate - base	screw for fixed half platen + cavity plate	retaining plate 2	guide bush	ejector rod
				retaining plate 3	fixed half platen	rail

Figure. 5 Model injection molding machine and die set, and features included in the model

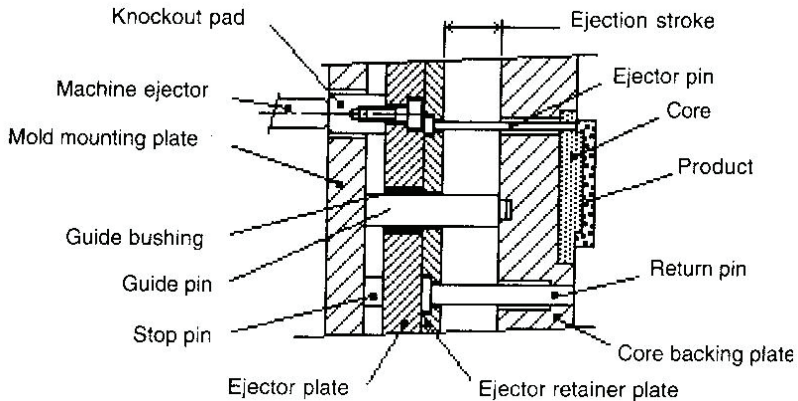
### C. Ejection method:

The purpose of ejection system is to remove the solidified product from the mould and provide the empty space in cavity for next cycle.

It consists of ejection plate assembly (ejector plate and retaining plate), and ejector rods (surface). [Figure 27]

The ejector rod in injection machine actuates the ejection system.

There are different kinds of ejector pins available. The choice of each design selection depends on the product configurations. [Figure 28]



**Figure 27: Typical mould with ejector pins**

*Figure 6. Sample of 2-D training material*

Forty two volunteer students from the University of Melbourne were recruited and tested with a 15-question version of the MCT to determine their visual capabilities. Their scores ranged from zero to 15 out of 15, with an average of 8. Test subjects of similar visual capability were paired (forming 21 pairs) and scored on a pre-test of their residual knowledge on injection molding: all showed a similar, but very limited basic knowledge. The third author then trained one subject from every pair for a period of 45-60 minutes, using only the model die set. The other subject from every pair was trained for a similar period by the same author, using only the 2-D materials. Two weeks after they were trained, all subjects undertook a post-test on aspects of injection molding that comprised ten questions to be attempted in ten minutes.

A sample post-test question is illustrated in Figure 7. Most questions contained 2-D images, including cross sections, rendered pictorial drawings from a CAD model and photographs of a die set and molded artifacts, so were expected to favor those subjects who had been trained with 2-D materials.

The outcomes of the post-test are plotted in Figure 8.

The linear graphs in Figure 8 show a clear trend. When subjects had high visual capabilities (the subjects toward the right hand end of Figure 8), their post-test scores in injection molding terminology and characteristics were not significantly different whether they had trained with 2-D or 3-D materials. However, for the subjects with lower visual skills, it appears as though those who were trained with the physical artifact scored somewhat better than those who were trained solely with the 2-D printed material. When the post-test scores of the ten subjects with strongest visual skills trained on the 3-D artifact are averaged, and compared with the similar average of the strong visualizers trained with the 2-D material there is no significant difference ( $p > 0.2$ ). However, the post-test scores of the ten subjects with the weakest visual skills trained on the 2-D artifact were some 20% better on average than their counterparts trained with 2-D materials. This difference is very significant ( $t = 1.9, p < 0.05$ ).

8. Which of the identified parts 1, 2 or 3 is the **sliding core** in Figure 4?

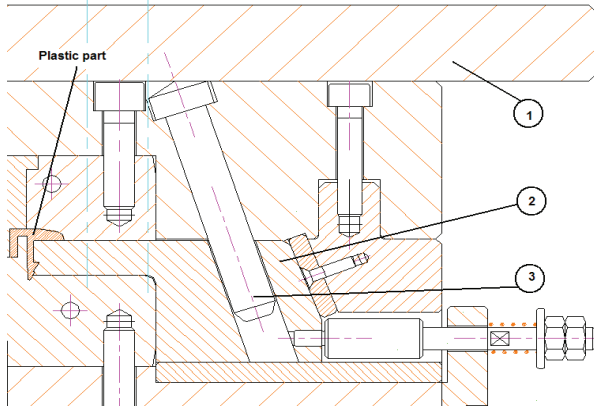


Figure 4

Figure 7. Sample question from the post-test on injection molding

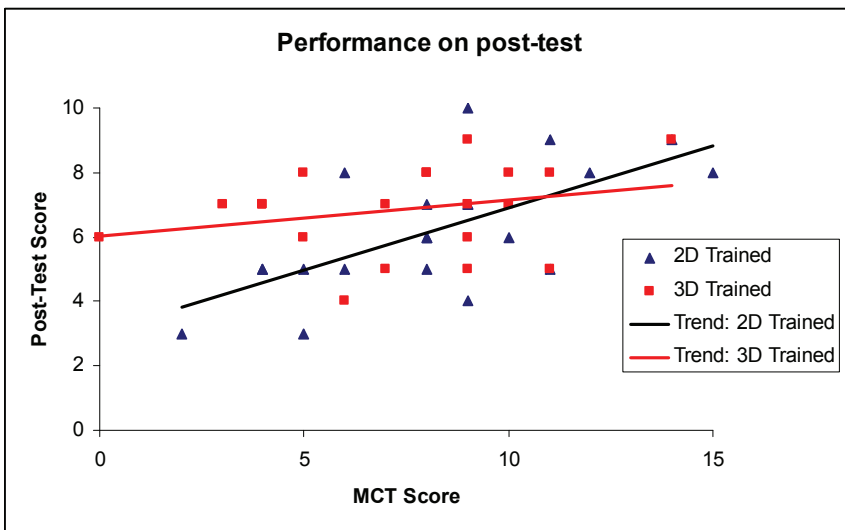


Figure 8. Results from the post-test on injection molding for the two groups of subjects

## 5 RESULTS AND DISCUSSION

The principal finding from the research was that trainee die designers with weaker than average visual skills as measured by the MCT benefited from being trained with a model of a die set, whereas there was little, if any disadvantage suffered by strongly visual trainee designers when they were forced to use a model die set. When trained with the model die set, the subjects with low visual skill may have learned less than those with high visual skill, although in the experiment this trend was not significant. The results are consistent with the parallel experiment where it was found that a trainee designer's grade from their formal study in an engineering design course was significantly correlated with their visual skill as measured by the MCT: this correlation was about the same as that between their university grade in mathematics and their design grade.

While it is apparent that naïve engineering designers with low visualization scores would benefit from specific training to develop their spatial abilities, research has shown that the rate of change in visual skill for mature people is slow, even when undertaking a focused course of one to four hours per week for up to thirteen weeks [5, 12]. It would appear, however, that a more rapid development of design skill in those weak visualizers may be forthcoming if the educational programs in engineering design could by-pass the limitations of 2-D teaching materials by using, where appropriate, physical artifacts. It is also possible that the concentrated manipulation of 3-D artifacts is one path by which visualization skill is increased [5].

Furthermore, the findings add support to the development of, or retention of undergraduate courses where engineering students handle and become engaged with engineering components and machinery. These courses include machine shop work, laboratory tasks involving the dismantling of machinery, and design-and-build competitions [13, 14].

It is as yet not known whether the valuable engagement with 3-D artifacts can be partly replaced with more portable and economic, but realistic representations of those artifacts, such as through current solid modeling software (with or without full rendering) or various forms of virtual reality. This question provides a basis for useful future research.

## 6 CONCLUSION

Trainee die designers with low spatial skill achieved greater learning outcomes when their training program was built around the use of a physical model compared with a similarly skilled sub-group who were trained using conventional 2-D printed material.

A control group comprising two separate sub-groups of trainee designers with high spatial skill but trained with the same artifacts or 2-D printed material respectively, achieved learning outcomes that were not significantly different.

It was concluded that training with the use of 3-D artifacts improved the outcomes of designers with low visual skill and did not disadvantage the designers with high visual skill.

The finding has implications for the educational programs for other types of engineering designers, especially since it has been shown elsewhere that trainee designers with low visual skills tend to achieve inferior performance in university design assessments compared to design students of a similar academic capability.

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