Abstract thinking: a predictor of modelling ability?

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ABSTRACT
In this paper, we describe a study of the abstract thinking skills of a group of students studying object-oriented modelling as part of a Masters course. Abstract thinking has long been considered a core skill for computer scientists. This study is part of attempts to gather evidence about the link between abstract thinking skills and success in the Computer Science discipline. The results of this study show a positive correlation between the scores of the students in the abstract thinking test with the marks achieved in the module. However, the small numbers in the study mean that wider research is needed.

Categories and Subject Descriptors
D.2.2 [**Design tools and techniques**]: Object-oriented design methods K.3.2 [**Computer and Information Science Education**]: Computer Science Education

General Terms
Design, Abstraction

Keywords
Abstraction, modelling, computer science education

1. INTRODUCTION
The ability to think abstractly has long been considered a core skill for computer scientists. As an educator of students at Higher Education level in Computer Science I have been aware of divergence in groups of students into those that 'get' abstract thinking and those that do not. This study is part of attempts to gather evidence about the link (if one exists) between abstraction skills and success in the Computer Science (CS) discipline. This evidence may be used to improve the quality of CS education.

Definitions of abstraction focus on two aspects: removing unnecessary details and the process of generalizing concepts and finding patterns. The ability to think in these abstract ways was identified by Piaget [7] as one of the four stages of children's cognitive development. Piaget's work, based on observational studies, covered the development of children from birth to age 14 years. The fourth (and final) stage of development observed was described by Piaget as the "Formal Operation Stage". His observation was that only around 35% of the 14-year-olds reached that stage. Huitt and Hummel [5] claim that a *"special environment"* is needed for most adults to attain this stage of development, but it is not certain whether reaching this stage is governed by an innate ability that people are born with or developed through the environment or learning to which children are exposed. Piaget [7] describes the Formal Operation Stage as *"the logical use of symbols related to abstract concepts"*. This description could also be used to describe a key ability in computer science: the ability to produce models of a system.

There has been recent research interest in gathering evidence of a link between abstract thinking and computing ability. Kramer [6] has called abstraction the "*key skill*" in computing. Other research [1,2] has sought to find a link between success in programming courses and abstraction skills, with varying success. This research focuses not on programming but on another key aspect of CS education: object-oriented analysis and design and, in particular, the ability to produce object-oriented graphical models. Conceptually there appears to be a more direct link between Piaget's "*logical use of symbols related to abstract concepts*" and this aspect of Computer Science.

In the CS discipline modelling skills are gaining in importance. One reason for this is the emergence of model-driven development of software. Model-Driven Engineering (MDE) is the process of developing software through automatic generation from models of a system. At the heart of MDE are the models used to describe complex systems at different levels of abstraction and from different perspectives [4]. If a model is to be used for the automatic generation of software then the skill of creating good quality models becomes increasingly important.

The study presented here was carried out on a group of students on a Masters programme at the University of Westminster [8] in the spring of 2009. The study gathered evidence about the link between the abstraction skills of the students and their success in a module on object-oriented analysis and design.

2. RESEARCH QUESTIONS
The main focus of this study is to determine whether there is a link between the abstraction skills of students and their success in object-oriented modelling. This leads us to the first hypothesis:

Hypothesis 1: Students with high scores in an abstraction test will achieve better results in an object-oriented analysis and design module than those with lower scores.

A tangential use of the data gathered was in finding whether there is any gender difference in the abstraction abilities of the students. Recent studies show that girls consistently outperform boys in virtually all of the school subjects in England [3]. However, there has been a decline in numbers of female students on CS courses observed in recent years [10]. It is useful to determine whether there are any barriers to success for female students on CS courses because of differences in abstraction skills. This leads us to our second hypothesis:

Hypothesis 2: Male students have no advantage over female students by ability in abstract thinking or in object-oriented modelling.

Another aspect of interest here is to determine whether abstract thinking is simply a descriptor of general intelligence or whether it is separate from other cognitive skills such as verbal reasoning. This leads to the third hypothesis:

Hypothesis 3: Abstract thinking is an ability that is not necessarily linked to verbal skills.

3. RESEARCH EXPERIMENT

3.1 Developing and trialling the test instrument

There were certain challenges in developing a test for our first hypothesis. Firstly, we needed a test of abstraction skills in adults that does not also rely on their language skills. Secondly, we needed a test that was quick and easy to conduct on a group of students. Thirdly, we needed to ensure that the test would give as wide as possible a range of scores.

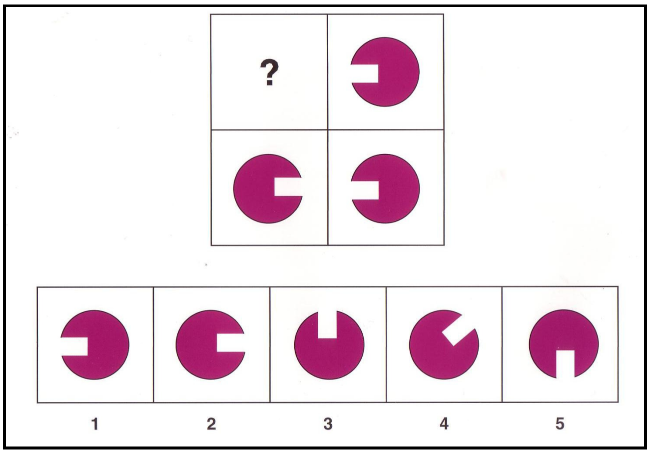

Figure 1. An example of a test from the Wechsler Adult Intelligence Scale Matrix Reasoning [9]

The Wechsler Adult Intelligence Tests [9] are a well reputed set of general intelligence tests that seem to be suitable for our purposes. These test instruments are normally used by an examiner in a one-to-one interview with a subject, in which the subject's abilities in a range of cognitive areas are assessed. One of the Wechsler tests, the Matrix Reasoning Test (MRT), requires that the examiner presents sets of pictures to the subject and asks them to "complete the picture". Figure 1 shows an example of a set of images that is presented in this test. The answer to this question is number 2: it is the missing form, from those numbered 1 to 5, to complete the picture above.

This particular test does not require any verbal skills of the subject and only requires that they can distinguish the digits 1 to 5. The test concerns the recognition of patterns in abstract shapes and in making generalizations about positions, orientations etc. This correlates well with the definitions of abstract thinking, so the test satisfies our first requirement.

The next requirement is that the test is quick and easy to apply to a group of students. In the original form the test was conducted on a one-to-one basis so, to satisfy this condition, some customization was required. First a selection of 26 picture sets was chosen from the Wechsler test. These were ordered from the very simple puzzles at the start, as shown in figure 1, to more complex and difficult puzzles at the end. The next challenge was how to present this test to a group of students, rather than individually. The solution was to present the pictures to students, in a lecture environment, by use of a slide show, which presented each picture on a large display screen and moved on to the next picture after a fixed length of time. The students would be given an answer sheet where they marked the answer (1 to 5) for each slide. This allowed the test to be conducted in a short time in a controlled environment and in a setting that could be used for larger groups of subjects.

The third requirement was that the tests produce a wide range of test scores. The nature of these picture sets means that, if the subject is given unlimited time, most adults will find the correct solution. If subjects are given a very short time, most people will not have time to analyze the problem and will not find the correct solution. So, too long a time for each picture will result in all the subjects gaining a high score and too short a time would result in the subjects scoring in a very low range. To gauge the correct time a pilot study was carried out, using four volunteers. They were given the selected set of slides but allowed to spend as long as they wished on each slide. When they had arrived at an answer they moved on to the next slide. The time taken for each slide was recorded. The answers were then marked and the average time to arrive at a correct answer was calculated. The four participants in the pilot averaged 9, 9.7, 15.6 and 36.7 seconds to arrive at a correct answer. A time of 10 seconds was therefore fixed for each slide in the slide show. This timing was calculated to give as wide as possible a range of scores, as indicated by the pilot timings.

3.2 The experimental subjects

The students who were the subject of the test were all studying on the MSc course in Business Computing at the University of Westminster [8] in the academic year 2008/9. There were 15 students in all (6 female, 9 male) and their ages ranged from 23 to 37. The test was carried out in the first week of the second semester, in January 2009. This was the first session of a module called Object-oriented Analysis and Design (module code 2CMM7H8) in which the students were introduced to object-oriented modelling techniques for the first time. The key learning outcome for the module is that students "use analytical techniques to develop a range of design diagrams, using particular object-oriented design notations". In practice they learn to use a range of

UML models (principally class, sequence, statechart and activity diagrams) to analyse and design Business Information Systems from case studies. It might be expected that the students abstract thinking skills would be developed during the module, although this study has not focused on this aspect. Further studies could examine how the abstract thinking skills are developed during a course. This aspect is one of the extensions considered in the final section of this paper.

3.3 The second test on similarities

One of the aims of this study was to isolate the skill in abstract modelling from general intelligence. It could be argued that high scores in the Matrix Reasoning Test would just indicate high intelligence, rather than a specific ability in abstraction, so a second test was devised to act as a control study. In the Similarities test (also from the Wechsler Adult Intelligence Tests [9]) the subjects are shown two items and are asked to give one way in which those items are similar. For example, they may be given "fork" and "spoon" and an answer might be "they are both used to eat food" or "they both have handles". This test was carried out on the same group of students, but only 12 students chose to participate in this test.

4. RESEARCH OUTCOMES

4.1 Outcomes of the Matrix Reasoning Test

In the Matrix Reasoning Test (MRT) the students scored between 11 and 21 correct answers out of the 26 slides shown. The full list of scores for the test is shown in Table 1. The mean and median of the scores were both the same at 17. This gave a reasonable range of scores and confirmed the decision to use a 10 second timing for each slide.

Table 1. Scores for the MRT

12	17	15	11	17	16	17	19	18	18	15	21	15	19	18

4.2 Outcomes of the module

The students' marks for the module (Object-oriented Analysis and Design) ranged between 50 and 82 out of 100. The full list of marks for the module is shown in Table 2. The mean of the marks was 63 and the median 65. No student failed the module.

Table 2. Marks for the OOA&D module

50	69	56	51	65	65	57	77	63	65	54	82	71	67	60

4.3 Outcomes of the Similarities Test

In the Similarities test the students scored between 4 and 12 correct answers out of 14. The full list of scores for the test is shown in Table 3. Only 12 students participated in this test.

Table 3. Scores for the Similarities Test

8	10	6	4	14	9	11	8	10	7	12	12	12

4.4 Statistical analysis

Having carried out these tests we were interested to find whether there was any correlation between the test scores and the module results. We used a Pearson correlation coefficient test to find if there is a significant correlation between the MRT scores and the module results, as shown in Table 4. The coefficient, R, is 0.7845 which indicates a correlation between the MRT scores and the module results. However, it is unwise to infer too much from the data because of the small number of participants in this study. We can say that there appears to be a positive correlation between the test results and the module marks. The correlation is also shown in the scatter chart in figure 2.

Table 4. Correlation coefficients between the MRT and module results

Pearson correlation test	
R	0.7845
R^2	0.6155
Observations	15

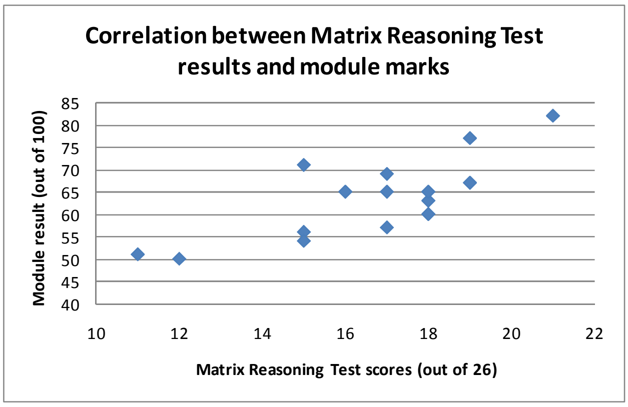

Figure 2. Correlation between Matrix Reasoning Test results and module marks.

We also used a Pearson correlation coefficient test to find if there is a significant correlation between the Similarities test scores and the module results, as shown in Table 5. The coefficient, R, is 0.2464 which indicates no significant correlation was found, confirmed by the scatter chart in figure 3.

Table 5. Correlation coefficients between Similarities test and module results

Pearson correlation test	
R	0.2464
R^2	0.0607
Observations	12

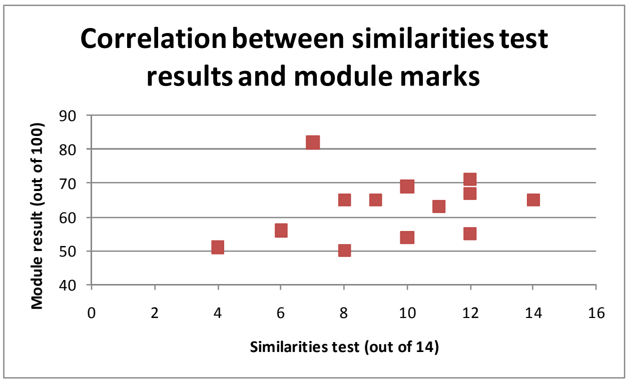

Figure 3. Correlation between Similarities Test results and module marks.

Finally, we analysed the data gathered from the two tests and the module results to examine the gender differences. Mean and median calculations were made by gender, as shown in Table 6. Although the differences are very small, there were higher scores for females in the MRT and module results and higher scores for males in the Similarities test.

Table 6. Scores by gender

Gender	Matrix test score (mean)	Matrix test score (median)	Similarities test score (mean)	Similarities test score (median)	Module mark (mean)	Module mark (median)
Male	16	17	9.6	10.5	61	60
Female	17	18	9.2	8	67	65
Both	17	17	9.5	10	63	65

5. MAIN FINDINGS

The main findings are related to the hypotheses posed at the start of the study:

Hypothesis 1: Students with high scores in an abstraction test will achieve better results in an object-oriented analysis and design module than those with lower scores.

Finding: The results of these tests confirm this hypothesis, using this test instrument on a small number of students.

Hypothesis 2: Male students have no advantage over female students by ability in abstract thinking or in object-oriented modelling.

Findings: This hypothesis is confirmed by the test results. In module marks and MRT the females in the group outperformed the males, on average. In the Similarities test males have performed better than females, on average, but this test does not show a correlation with the modeling results

Hypothesis 3: Abstract thinking is an ability that is not linked to verbal skills.

Finding: This hypothesis is confirmed by the result and no correlation was found between the Similarities test and both the MRT and module results.

6. CONCLUSIONS AND FUTURE WORK

The results of this study are interesting, in gathering more evidence of a link between abstract thinking skills and modelling ability, but are inconclusive because of the small numbers involved. A positive correlation was found between the Matrix Reasoning Test and the marks achieved in an object-oriented analysis and design module. However, the small numbers in the study mean that little statistical confidence can be placed on the findings. A wider study is needed to confirm the findings. A further study is planned in the next academic year, when the MRT will be used to test the first year intake of an undergraduate Computer Science course at the University of Westminster. This will use the same test slides but will have around 200 test subjects and so will be a more useful study. One possible use for the test results would be to identify students who may find difficulty with the abstract thinking requirements of the course, allowing additional support to be offered.

Another extension of the study would be to use the MRT at the start and end of a course, to examine the effectiveness of the course in developing the abstract thinking skills of students. This would require careful analysis of the background of students (whether they have a background in modelling or programming) and monitoring of the teaching and learning provision of the course. We are not planning to carry out this type of study in the next academic year, but it is possible in the future.

A very useful outcome of the study has been the development of an instrument for assessing abstraction skills. The Matrix Reasoning Test, adapted as a slide presentation has proved to be a quick and easy test to conduct with a large group of students, which shows promise in discriminating between the abstraction skills of students. Kramer [6] argues that these kinds of tests are needed for "*checking student progress, checking out teaching techniques, and potentially as an aid for student admissions selection*". There is, however, no intention to use the tests as part of the admissions process for our courses.

The issue of a gender imbalance in the CS discipline is given interesting new evidence in this study of the positive achievement of female students compared to their male colleagues. Although not statistically significant, the findings would be heartening to those encouraging more women to participate in CS. More evidence is also needed in this area, some of which may be gathered in the planned tests in the next academic year.

This study is part of attempts to gather evidence about the link between abstraction skills and success in the Computer Science discipline. We hope that this will improve the quality of Computer Science education.

7. ACKNOWLEDGMENTS

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