Manipulating Mindset to Positively Influence Introductory Programming Performance

Quintin Cutts
Dept. of Computing Science
University of Glasgow
Scotland.
quintin@dcs.gla.ac.uk

Emily Cutts
Centre for Confidence & Well-being
Glasgow
Scotland.
emily@centreforconfidence.co.uk

Stephen Draper
Dept. of Psychology
University of Glasgow
Scotland.
s.draper@psy.gla.ac.uk

Patrick O'Donnell
Dept. of Psychology
University of Glasgow
Scotland.
p.odonnell@psy.gla.ac.uk

Peter Saffrey
Dept. of Computing Science
University of Glasgow
Scotland.
pzs@dcs.gla.ac.uk

ABSTRACT

Introductory programming classes are renowned for their high dropout rates. The authors propose that this is because students learn to adopt a *fixed mindset* towards programming. This paper reports on a study carried out with an introductory programming class, based on Dweck's mindset research. Combinations of three interventions were carried out: tutors taught mindset to students; growth mindset feedback messages were given to students on their work; and, when stuck, students were encouraged to use a crib sheet with pathways to solve problems. The study found that the mixture of teaching mindset and giving mindset messages on returned work resulted in a significant change in mindset and a corresponding significant change in test scores – improvements in test scores were found in a class test given immediately after the six-week intervention and at the end-of-year exam. The authors discuss the results and the strengths and weaknesses of the study.

Categories and Subject Descriptors

K.3.2 [Computers & Education]: Computer & Information Science Education—*Computer Science Education*

General Terms

Experimentation, Human Factors

Keywords

Self-theories, growth mindset, CS0, CS1, debugging, programming, Dweck, attitudinal, novice programmers.

1. INTRODUCTION

Some learners behave as though they believe that ability is a fixed commodity and once it has been shown that they cannot do something then they should give up. Dweck has shown that a learner's mindset towards ability levels has a crucial effect on their learning [5]. She identifies two categories of learners, one consisting of those with a *fixed* mindset (the students described above) and the other, those with a *growth* mindset, who act as if persistent effort and attention to data gleaned from failures will lead to the desired learning.

Dweck's work on mindsets highlights a number of ramifications for learning. Each mindset is supported by a motivational framework guiding future thinking and behaviour [3]. Those with a fixed mindset tend to be interested only in *performance* goals – they feel a need to be seen to be achieving well at all times, since this broadcasts their ability to the world. Those with a growth mindset adopt *learning* goals. They are classical deep learners who sacrifice looking good in the eyes of others in order to learn and understand a topic. Those endorsing a growth mindset continue to enjoy learning even after failures and setbacks, compared to those holding a fixed view of their ability [4]. Those with a fixed mindset tend to disregard formative feedback, since the very idea goes against their belief of ability being essentially fixed; someone with a growth mindset will use all the data available in order to help them learn [9]. Negative feedback of any kind is likely to lead the fixed mindset learner to give up, to display a helpless response, or to avoid, because it represents an insurmountable barrier to further progress. Beliefs about effort differ too (e.g, [11]). Those with a fixed mindset believe that if someone has to put effort in then this demonstrates that they do not have what it takes; they lack the ability. Those with a growth mindset view effort as a necessary part of the learning process, and essential for future understanding and success.

Learning to program at university can easily induce a fixed mindset. There are many ways in which a student can get stuck: they do not understand a programming task they have been given, or they understand the task but cannot think of a way of solving it; they do not know the right programming constructs to use; the computer rejects the program because of syntax errors; the program runs but gives the wrong answer; computer science content at university is different from school content which is more about training in computer use; and there are widely differing levels of ability in the class. These are all potential points where a student may get stuck and be susceptible to attributing this to a lack of intellect. Such an attribution

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strengthens a fixed mindset, reducing learning potential and thereby increasing the likelihood of poor performance in tests.

The study presented in this paper addresses whether small changes to an introductory programming course can foster a growth mindset and influence performance. Given that previous studies reveal a relationship between mindset interventions and test scores, this study examines tests scores at three points across the academic year. We describe three interventions, along with the findings from applying these interventions experimentally, and discuss what implications, if any, these have for first year programming students. We conclude with thoughts about the strengths and weaknesses of the design, as well as future research.

2. RELATED WORK

Specific interventions can change mindset and directly influence motivation and performance [1], and have been carried out in subjects similar to computer science such as math [3] and engineering [7].

Computer science seems like the perfect candidate for a mindset intervention. [12] and [14] link the problems faced by new programmers to a fixed mindset detailing the characteristics of the course that may lead to helpless responses in students.

The authors know of only one study that has carried out a mindset intervention with programming students. The intervention did not move the students' beliefs about their ability [14]. The study looked at students' beliefs only and did not measure any changes in student performance. No study, as far as the authors are aware, has examined the impact of a mindset intervention on performance in introductory programming or indeed in any CS course. Though [14] found no change in students' beliefs after their mindset intervention, this does not necessarily mean it doesn't work with this discipline. Dweck uses computer science as an example of a subject that requires a growth mindset [6]. Simon et al. [14] note some flaws in their design, such as less intensive training than other published research, a less personal approach, and not much follow-up.

3. CONTEXT

The course used for this study was a two-semester, 26-week, introductory programming course in Python with around 170 students enrolled. The previous programming experience in the student cohort typically ranges from none at all right up to commercial programming. Students attend two lectures and one 2-hour practical session per week and submit exercises for review by tutors every fortnight. The student cohort for this study was divided into 12 small groups for their practical work, each under the supervision of a tutor. The typical group size is 14 students; in the year of the study, it varied from 9 to 17. The same tutor assists with a student's practical work and marks their work.

The design of the course aims to maximise the frequency and quality of feedback to *all* students in two ways. First, one of the weekly lecture sessions is given over to classwide discussion of issues arising directly from the practical session. Second, the students receive a feedback sheet when their fortnightly submissions are returned that contains extensive feedback on a number of issues arising in the submissions of a representative sample of the class. This level of feedback is far more than can typically be written by hand on each student's printed submission. The tutors can provide high quality feedback cheaply as they simply cross-reference issues in the student's work with the corresponding feedback points on the sheet. Although use of the sheet is not a variable in this study, the design is itself inspired by mindset-related principles: the student's score is at the bottom of the second side, reducing the focus on the summative feedback; the feedback items to which they should particularly pay attention are numbered and noted at the head of the document, accentuating the formative feedback; and there is encouragement to read all points, even if not specifically identified for this student, encouraging learning goals generally.

4. THE THREE INTERVENTIONS

In this study, three different mindset-related teaching interventions were designed in order to gain insight into whether small changes in the course design could effect significant changes in performance. The interventions are described in this section; their experimental application is described in Section 5.

4.1 *Mindset training* intervention (MT)

A series of four 10-15 minute teaching sessions were developed for delivery by tutors at the start of their small-group 2-hr tutorial/lab sessions – to be used over four consecutive weeks early in the semester. The tutors were taught about the material for each of these sessions in the week prior to its delivery. Each session involved the tutor talking about a particular aspect of mindsets and then taking the students through a reflective exercise focusing on their own learning experience and relating it to the mindsets work. Tutors were then encouraged to refer back to this material when working with students encountering problems in the lab environment. The four sessions introduced: fixed and growth mindsets; performance and learning goals; responses to feedback; role models and the neuroscience underpinning mindsets. In addition, a short overview document was created that introduced the fundamental aspects of mindset research.

A survey of the tutors after the third teaching session showed that they had delivered the material in very different ways, with some hardly touching on it at all. It was clear that some tutors were *not* fully on board with the mindsets research, and were themselves displaying a strongly-fixed mindset. Such attitudes in tutors are likely to affect their behaviour towards students to a large extent, according to [6]. These tutors were given access to a range of further research papers and in particular the neuroscience studies that relate to Dweck's work, which they found more engaging than our earlier teaching. Additionally, we developed the overview document covering the main Dweck findings, and asked all tutors to get their students to read this in the final teaching session. In this way, we were sure that all students in the mindset training intervention definitely had knowledge of Dweck's work.

4.2 *Crib-sheet* intervention (C)

Students with a growth mindset tend to have a range of strategies for resolving problems and setbacks in their learning, whereas those with a fixed mindset will keep on trying to fix their problem with a single inappropriate strategy [5]. The collection of 35 ways in which successful computing students get unstuck, reported in [10], is in line with this finding.

In order to assist students to develop these strategies, the course design was extended with a crib sheet containing a list of questions/hints/pointers for what to do when a student gets stuck. Each item on the sheet linked to a wiki entry explaining the item in much more detail and with examples. The aim here was to increase self-efficacy by encouraging the student to see that they could help themselves, any time, whether the tutor was present or not, just by following the questions/steps on the crib sheet. *All* students received a copy of the crib sheet, and half a lecture was spent explaining its purpose.

The crib-sheet intervention (C) required tutors to help students via the crib sheet *only*. The tutor followed the diagnostic questions on the crib sheet during *every* interaction with the student to find their problem. Hence, students in the intervention group were repeatedly (a) reminded by their tutors that they had at their disposal a range of strategies to solve their problems, and (b) taken through the process of picking the appropriate strategy for the current problem.

4.3 *Rubric* intervention (R)

[11] shows that a simple exhortation, based on mindsets research, to make use of the feedback given on assessment tasks improved motivation and performance. For our intervention, the following related script or rubric was added into the text of the feedback sheet attached to the students' fortnightly exercise submissions:

Remember, learning to program can take a surprising amount of time & effort – students may get there at different rates, but almost all students who put in the time & effort get there eventually. Making good use of the feedback on this sheet is an essential part of this process.

The key to this intervention is that students are reminded of their capacity to overcome learning hurdles *precisely at the delivery point* of feedback that can help them do so.

The three interventions were used in a semi-controlled experiment, described in detail in the next section.

5. THE EXPERIMENT

There were 8 different treatment conditions (a 2x2x2 design), giving all possible combinations of the interventions, from none of them to all three. However, it was tutor group, not students, who were assigned to the interventions because the interventions were delivered by tutor.

Tutors were randomly assigned to groups and were told only about the intervention(s) where necessary – tutors in the rubric intervention were not even aware their feedback sheets were different to those of the non-intervention tutors. Students were allocated to tutorial groups by an automated system taking account of their timetable in other subjects, but with no control over their general ability or previous programming experience.

The disadvantages of this assignment by tutorial group not individual student are: a. some doubt about random assignment of students to tutorial group; b. the experiment cannot distinguish between different tutors' skill and different treatment conditions as the causal factor; c. the size of each treatment condition cannot be the same because the number of tutor groups was not a multiple of eight. As will be seen, only interventions MT and R turned out to be of interest, and after further attrition because not all students completed all aspects of the study, the number of students in the two main conditions of interest were:

Total=101	In TM	Not in TM
In R	11	28
Not in R	29	33

The experiment was designed to run for the first six weeks of the first semester, at which point there is a class test in the course. These test scores were used to determine whether the interventions were having any effect. If there were any positive results at the six-week point, those interventions producing it were to be applied to the rest of the class at once, to maintain fairness.

The reason for running the experiment so soon in the academic year was a preventative measure. Students can very quickly get behind in programming classes and this may act to cultivate a fixed mindset. Starting the interventions early provides students with the tools and expectations to get them through the course – in other words, we aimed to foster a mastery approach to learning from the beginning.

As Section 6 shows, there was an effect at the week six checkpoint involving the mindset training and the rubric. All students were then told about the mindset research in lectures and the feedback sheets were standardized for all students to include the rubric. Two further performance measures were used to assess the effect of the experiment on students: a second class test in week 13 and the final examination for the course in week 27.

The students completed two questionnaires, in weeks 1 and 7, to ascertain measures of mindset, self-efficacy and positive and negative affect. The questionnaire in week 7 was completed just after students had received marks and feedback on their class test.

Obvious confounding factors were allowed for. The previous programming experience of the students was measured through a self-report, and gave a hugely significant and sizeable effect when correlated against the students' performance scores. The time of day of the tutorials and their position in the week (and hence in the learning cycle design of the course) were also considered in the allocation of interventions to groups. The existence of statistically significant differences between the treatment groups remained after an attempt to correct for these factors.

A summary of the experimental timeline is as follows:

Wk	Activity
1	1st Questionnaire
2	Crib-sheet distributed to all students
3	MT Session 1 (MT 1), Crib-sheet intervention starts, First Feedback Sheet (FS 1) returned to students
4	MT 2, Crib-sheet continues
5	MT 3, Crib-sheet continues, FS 2 returned to students
6	MT 4, Crib-sheet continues, Class Test 1 (CT1)
7	FS 3 and Class Test 1 returned to students, 2nd questionnaire
9	FS4 – all students now receive the growth mindset rubric
11	FS5 – again, all students receive growth mindset rubric
13	Class Test 2 (CT2)
26	Final Exam (FE)

6. RESULTS

89 students completed questionnaires both in weeks 1 and 7 and so our analysis of the effect on mindset attitude is based on this subset. From the mindset measure taken in the first week, and based on the thresholds set for Dweck's general mindset measure, 19 (21%) of the students displayed a fixed mindset and 38 (43%) a growth mindset. The remainder were between fixed and growth.

Multiple Analysis of Variance (MANOVA) was used to compare the effects of the interventions on mindset and test scores. The results showed no effect due to the crib-sheet intervention.

The students' mindset showed a two-way interaction between the time interval from weeks 1 and 7 and the mindset training intervention ($F(1,75)=4.18$; $p<.044$). Figure 1 shows that, on average, people who were taught about mindsets displayed a shift in their theory of intelligence towards a growth mindset – this is the upper line in the graph. Figure 1 additionally shows that generally those who were not taught about mindset developed a more fixed mindset over time – this is the lower line.

Despite this shift in mindset attitude, the training by itself did not have an impact on any of the test scores.

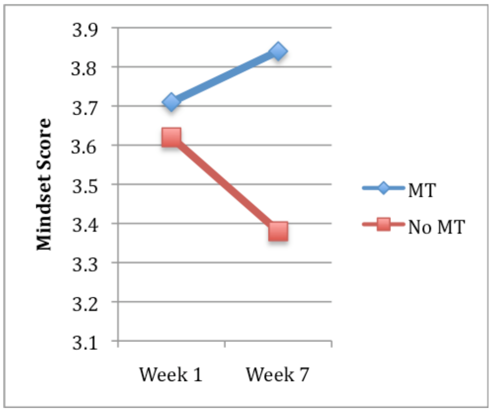

Figure 1. Plot of Means showing shift in mindset between wks 1 & 7 according to mindset training intervention

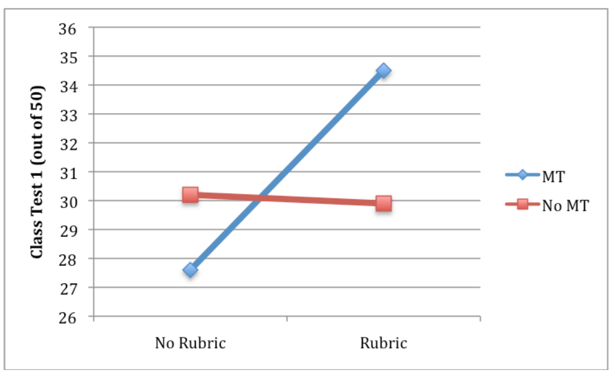

Figure 2. Plot of Means showing first class test performance shift by mindset training and rubric interventions

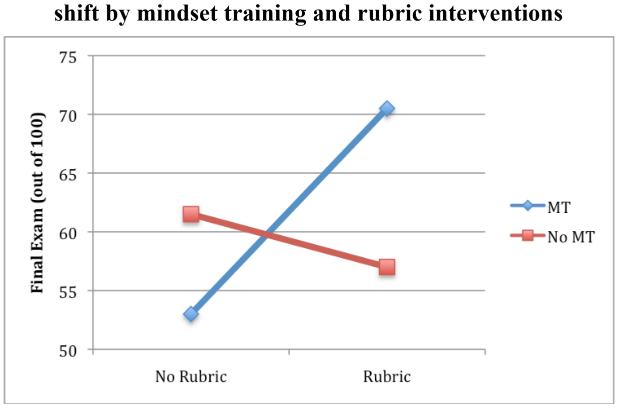

Figure 3. Plot of Means showing final exam performance shift by mindset training and rubric intervention

Of the three test scores, the second (CT2) showed a simple effect for the rubric intervention ($p<.034$).

Figures 2 and 3 show two-way interactions with mindset training and rubric interventions on both the first class test and final exam, respectively ($F(1,91)=4.82$; $p<.031$) and ($F(1,92)=5.43$; $p<.022$).

7. DISCUSSION

In discussing this significant improvement in performance, we first note that the whole course is designed in such a way as to promote a growth mindset approach to learning. Since students can so easily and quickly get stuck when learning to program, it is essential that detailed feedback on progress be provided as early as possible on any student work. We believe the feedback-oriented lecture session and the design of the feedback sheets are a step towards this requirement, given the inevitable constraints of large classes and limited funding. Additionally, students need to develop a range of strategies for getting unstuck if they are to foster a growth mindset, and the crib sheet should help with this.

The interventions described here, to encourage students to focus on the issues raised by mindset research, simply make it more likely that they will make use of the resources that are provided.

Dweck shows repeatedly that teaching mindsets changes a person's belief about their own ability towards the growth mindset (e.g. [5]). Our study supports these findings: students in the mindset training condition became more growth mindset. Other studies (e.g. [2]) have shown that particular scenarios can change a mindset towards fixed. Our study also found that students in the control group became more fixed over time. This fits with our proposition that learning to program may foster a fixed mindset due to the very high number of potential error points. As outlined earlier, students may get stuck at many different stages and could interpret this to mean that they do not have the ability.

Our study found that teaching growth mindset did change mindset but it did not find that this alone transferred to an improvement in test scores. One possible reason for this is that the computer science atmosphere is one where a growth mindset may be challenged repeatedly. Students come up against failure regularly, more than in most other subjects. Hence the mindset message may need to be reinforced regularly. As mentioned earlier, students in the control group became more fixed mindset over time suggesting that the system reinforces a fixed view of ability, despite the course design.

Though a person's mindset may change, the atmosphere within their course may not be conducive to the growth mindset message and may even undermine it. A previous study [8] found than over the course of a 4-year university degree, students moved from endorsing learning goals in 1st year to performance goals in 4th year; linked respectively to a growth, and then a fixed, mindset.

Students in *both* the mindset training and rubric intervention did gain improved scores. The mindset training explicitly taught students about the growth mindset and the consequences that this has on brain and behaviour, providing them with a general schema for approaching their studies. We speculate that the feedback sheet rubric then reinforced this schema, and, as stated earlier, did so at exactly the point where students have received high quality feedback on their learning, enhancing the likelihood of their putting it to good use.

All students received feedback sheets, but only those with both the rubric and mindset training benefitted. This fits with [9] where those with a growth mindset paid attention to formative feedback after failure and did better on future tests.

Educational interventions sometimes do not make themselves apparent until a later date, even years after (e.g. [13]), while others have an immediate impact (e.g. [11]). We found both immediate and long-term gains through mindset interventions.

The crib-sheet intervention did not show any significance on mindset or test scores. This may be because *all* students had the sheet, and if a student has developed a growth-mindset from one of the other interventions, then they would use the sheet whether their tutor encouraged it or not, thereby nullifying the individual effect of this intervention. We could have given the sheet only to those in the intervention; this was not done to avoid students outside the intervention querying why they did not have a sheet.

There are some flaws in the research design. The application of treatment conditions to students could not be truly randomised. It is not clear whether the teaching of mindset, or the reading of the summary sheet, changed mindset. It is also unclear whether we were influencing more significantly the students' or the tutors' minds with both mindset training and the rubric on the feedback sheets – which tutors may have subliminally drawn from as they returned students' work. The effect of previous programming experience was both statistically significant and larger than that due to the interventions, and while the analyses corrected for this in calculating significance, they did not give us a good way of estimating the size of the group effect after subtracting the effect of previous experience because the latter was unevenly distributed between groups. It also remains uncertain whether the effect of the groups was entirely due to the mindset-related interventions or partly to individual tutor skill. We will be re-designing and re-running the experiment with these concerns in mind.

Our difficulty with tutors' adopting the mindset research, noted earlier, is backed up by [14] in which 77% of teaching staff polled disagreed with the statement "Nearly everyone is capable of succeeding in the computer science curriculum if they work at it." It is at least as important that teaching staff have a growth mindset as it is for their students. To effect a really sizeable shift in students with respect to their attitudes towards learning, we may have to instigate a major project to do the same for staff members.

8. CONCLUSIONS

We have designed three interventions for introductory programming based on mindset principles, and applied them in all combinations: tutors taught mindset to students; growth mindset feedback messages were given to students on their work; and, when stuck, students were encouraged to solve problems using a crib sheet with pathways. Performance in a class test and the final exam of the course was better for those students who were taught mindset and who received the mindset message on their feedback sheet.

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