An Empirical Evaluation of Puzzle-Based Learning as an Interest Approach for Teaching Introductory Computer Science

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Abstract—This paper describes an adaptation of puzzle-based learning to teaching an introductory computer programming course. Students from two offerings of the course – with and without the puzzle-based learning – were surveyed over a two year period. Empirical results show that the synthesis of puzzle-based learning concepts with existing course content improves students’ learning experience by increasing their interest and participation in the course, and developing their critical thinking skills.

Index Terms—Computer science education, puzzle-based learning, problem-solving, interest approaches.
I. INTRODUCTION

Puzzles have been used as teaching tools for thousands of years. Recently, problem-based [1], project-based [2] and puzzle-based [3, 4] learning courses are being introduced as a component of engineering courses and degrees. These paradigms aim to teach engineering students critical thinking and problem-solving techniques, in addition to the content of a specific course or degree.

This paper describes the incorporation and empirical evaluation of puzzle-based learning in an introductory computer programming course, Computer Tools for Engineers (CTE). Section II motivates the need for incorporating puzzle-based learning into CTE by describing the student demographic. Section III describes how aspects of puzzle-based learning were adapted and incorporated into CTE. Finally, Section IV describes an empirical evaluation of CTE over two years, 2009 and 2008, with and without puzzle-based learning, respectively. Results show that using puzzle-based learning significantly changes the student learning experience, by increasing students' interest and participation in the course and developing their critical thinking skills.

II. THE NEED FOR INTEREST APPROACHES WHEN TEACHING COMPUTER SCIENCE

CTE is a first year subject at the University of New South Wales, Australian Defence Force Academy (UNSW@ADFA). UNSW@ADFA is a military academy attended by officer cadets in the Australian armed forces. A small number of cadets from outside Australia also attend the academy, as shown in Fig. 1(a). The course had 106 students in 2008 and 97 students in 2009. Fig. 1(b). shows that these students are predominantly male. The course is compulsory for students enrolled in Bachelor of Engineering
degrees in Aeronautical, Civil and Mechanical engineering, and Bachelor of Technology degrees in Aviation and Aeronautics. A small number of students took the course as an elective in 2009. These students were enrolled in a range of degrees including the Bachelor of Science and Bachelor of Business, as shown in Fig. 1(c).

As suggested by their range of degrees, students also have a range of competence levels in computer programming when entering CTE. Although most students have basic computer literacy, some students have no previous experience with programming. Others have high school level experience. Because the course is compulsory for most of the students enrolled, their attitude to course also varies. Some students have a genuine interest in learning to program, while others feel that the course is an unnecessary evil in their engineering degree.

One of the challenges of this course is keeping the interest of students with such a range of attitudes to, and previous experience with, computer programming. In 2008, a student experience survey showed that students found the content presented in the course was neither interesting nor relevant to their engineering degrees. In addition, students felt that the course did not develop their critical thinking or problem-solving
skills and thus did not meet its stated aims. There was thus an urgent need to revise the course and improve its perceived relevance to engineering students.

III. USING PUZZLE-BASED LEARNING TO TEACH INTRODUCTORY COMPUTER SCIENCE

The aim of CTE is to prepare first-year engineering students to use computer programming as a tool in their engineering course and future employment. Students gain an awareness of the components of a computing system and how a computer works; an introductory knowledge of some computing packages that will be useful for their engineering studies; an introductory knowledge of the structured approach to problem-solving using a computer; and a working familiarity with the MATLAB programming language and development environment. These aims are met through presentation of content covering the history of computer systems; components of a computer system; types of programming languages; program design and problem-solving using MATLAB; Boolean algebra and selection; loops; code clichés; vectors and matrices; input and output; plotting; functions; and testing, tracing and debugging.

The course is structured over thirteen weeks. Each week students attend two one-hour lectures and one two-hour laboratory. A student’s final grade in the course is determined by their attendance and participation in laboratories (10%); two programming assignments (40%); and a two-hour, open-book exam (50%).

In both 2008 and 2009 the aims, content and structure of CTE remained the same. The 2008 offering relied predominantly on Power Point slides for presentation, with some additional exercises written on the white board. Programming lectures generally started with a discussion of motivating examples for a particular code construct, such as a loop or selection statement. Code templates were then presented. Lectures would
conclude with one or more worked examples and exercises for students to work through themselves. These exercises provided a time for students to try out concepts learned and ask questions to clarify their understanding.

The key difference between the two offerings was the incorporation of puzzles in the 2009 offering as an ‘interest approach’ [5]. In 2009, puzzles were used as the motivating examples in lectures and as the basis for the laboratories and assessment items. The number of Power Point slides was also reduced, with worked examples replaced by live demonstrations using MATLAB.

A. Lectures

Puzzles were introduced into the lectures for two purposes. First, they were used to shift the focus of the course towards the idea of the computer as a practical tool that can be used by engineers for problem-solving, and away from a ‘science of computing’ approach. Each lecture was structured around one or two puzzles. Each puzzle was introduced with a short Youtube video (www.youtube.com) or another interactive demonstration. For example, the puzzle used to teach program design, was to write a program to compute whether different bikes can stoppie (rise up on their front wheel). A simple physics model for solving the puzzle was then presented, often from a source such as Wikipedia (www.wikipedia.com). The focus on new media such as Youtube and Wikipedia was deliberate, to tie into activities that students may already engage in and enjoy. One or more solutions to the puzzle were then discussed. These solutions were demonstrated live in the lecture so students could ask ‘what-if’ style questions and the lecturer could modify the demonstration program on the fly. Other examples of engineering-oriented puzzles used during the course included whether or not a meteor
with certain properties will hit Earth; and the difference in braking distance between Formula 1 racing cars and road cars.

Secondly, puzzles were used in lectures as a tool to address the difference in ability of students in the course. Each week a secondary puzzle, was displayed on a second projector, next to the primary set of lecture slides. The secondary puzzles were based around programming concepts, but also aimed to entertain and stimulate thought, often by having a counter-intuitive solution. Students were told that there was a small prize for the first correct, written solution to the puzzle. No other introduction to the puzzle was given. The purpose of the secondary puzzle was to challenge strong students who already felt comfortable with the content of the primary lecture slides.

B. Laboratories

In 2009, laboratories had two parts: (1) Quick exercises with each week’s concepts; and (2) Puzzles requiring each week’s concepts to solve. The purpose of the quick exercises was to ensure all students attain a basic level of competence with the material. The puzzles then provide a way for students to apply that competence in a complete program, and combine the week’s concepts with other concepts taught previously.

C. Assessment

In the 2008 offering of CTE, the two assessment items posed design briefs for which there was a single correct solution. In contrast, in the 2009 offering a detailed marking scheme was provided and students were instructed to find their own puzzle to solve, such that their resulting code fulfilled the marking scheme. For example, some of the pass criteria in the marking scheme stipulated that students’ code should contain at
least one correctly used function, a selection statement, appropriately named variables, constants and so on. Students also needed to submit a written test report detailing the tests they did to convince themselves their code worked and give a five minute demonstration of their working code.

Using this approach, students could not only choose a puzzle that was interesting to them, but they could also choose which grade they wished to aim for in the assessments. This encourages both originality and creativity [6]. In addition, stronger students could choose more difficult puzzles to challenge themselves, while weaker students could choose simpler puzzles and still fulfill the marking scheme and obtain high grades.

IV. EVALUATING STUDENT EXPERIENCE

A. Course and Teaching Evaluation and Improvement (CATEI) Survey

One way to measure the effectiveness or quality of a course is through student feedback. There is general agreement that students can provide valid observations and judgments on a range of aspects of teaching [7]. These include the overall effectiveness of teaching, how effectively a teacher communicates, the degree to which the teacher stimulates interest in the subject and the appropriateness of assessment material [8]. The UNSW Course and Teaching Evaluation and Improvement (CATEI) [8] survey is one means of gathering such feedback. The CATEI survey is a voluntary, anonymous questionnaire completed by students near the end of a teaching session. It evaluates a course from the perspective of the student experience in twelve dimensions corresponding to ten closed-questions and two open-questions, shown in Table 1. The closed-questions are in the form of statements. Students must rate each statement by
selecting one of six options, Strongly Agree (SA), Agree (A), Mildly Agree (MA), Mildly Disagree (MD), Disagree (D) or Strongly Disagree (SD). The two open questions are in the form of open-ended statements with a half a page of space allocated for students to complete each sentence.

Table 1. Components of the Course and Teaching Evaluation and Improvement (CATEI) survey: Ten open questions Q1–Q10 and two closed questions Q11–Q12.

<table>
<thead>
<tr>
<th>Question</th>
<th>Statement</th>
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<tbody>
<tr>
<td>Q1</td>
<td>The aims of this course were clear to me</td>
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<tr>
<td>Q2</td>
<td>I was given helpful feedback on how I was going in the course</td>
</tr>
<tr>
<td>Q3</td>
<td>The course was challenging and interesting</td>
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<td>Q4</td>
<td>The course provided effective opportunities for active student participation in learning activities</td>
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<tr>
<td>Q5</td>
<td>The course was effective for developing my thinking skills (e.g. critical analysis, problem solving)</td>
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<tr>
<td>Q6</td>
<td>I was provided with clear information about the assessment requirements for this course</td>
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<tr>
<td>Q7</td>
<td>The assessment methods and tasks in this course were appropriate given the course aims</td>
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<tr>
<td>Q8</td>
<td>The information/materials provided for this course helped me to learn independently</td>
</tr>
<tr>
<td>Q9</td>
<td>The aims of this course were met</td>
</tr>
<tr>
<td>Q10</td>
<td>Overall, I was satisfied with the quality of this course</td>
</tr>
<tr>
<td>Q11</td>
<td>The best features of this course were…</td>
</tr>
<tr>
<td>Q12</td>
<td>This course could be improved by…</td>
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</table>

**Response Scale and Mean Rating**

To permit a detailed graphical and numerical summary of student responses to the ten closed-questions, a numeric value is assigned to each response category as follows: SA(6), A(5), MA(4), MD(3), D(2), SD(1). These values can then be used to compute a mean rating for each statement, standard deviation and confidence intervals. The 95% confidence interval is used on charts in this paper.

**Positive Versus Negative Responses**

A broader summary of results can also be made by analyzing positive and negative responses to the closed-questions. Using this interpretation, SA, A and MA are counted as positive responses while MD, D and SD are counted as negative responses.
B. Results and Discussion

In 2008, 96 students (91% of those enrolled) responded to the CATEI survey. In 2009, 94 students responded (97% of those enrolled). Students did not know in advance when the survey would be conducted, so these figures can be thought of as roughly reflecting the attendance rate in each year. Because UNSW@ADFA is a defense academy, attendance rates tend to be very high; as students caught skipping classes can be disciplined. However, the increase in attendance rate from 2008 to 2009 is a first indicator that students were more willing participants in the 2009 offering than the 2008.

Mean Rating

Fig. 2 compares the mean rating given by students for each statement in the CATEI survey in 2008 and 2009. It shows an improvement in the student experience in all measured dimensions in 2009. This improvement is statistically significant in the 95% confidence interval for all but Q2.

The largest improvement is apparent for Q1, Q6 and Q7. Students felt that the aims of the course were better met in 2009, and were particularly positive about the assessment.
strategy used. The mean ratings for Q3 and Q5 are also pleasing because they suggest students’ found the course more interesting and challenging in 2009 and felt that it better developed their critical thinking and problem-solving skills. These are key aims of puzzle-based learning. Inspection of student responses to the open question Q11 revealed that students enjoyed the puzzles used in lectures and particularly appreciated the live demonstrations and access to working code examples for each lecture. Students also commented that they enjoyed being able to select their own puzzles for assessment items as they could select something that was interesting to them. In the first assignment students chose puzzles as diverse as simulating gravity induced loss of consciousness; the penetrative ability of various weapons; the motion of a cricket ball; and the cooking time of potatoes.

The secondary puzzles and prizes in lectures were also well received, with students commenting that they enjoyed competing for the ‘bragging rights’ associated with winning a prize.

The lowest change in mean rating is apparent for Q8 and Q2. The low (although statistically significant) change in mean rating for Q8 is disappointing as it was hoped that by making the course more interesting, students would be more intrinsically motivated to engage in independent study. Inspection of students’ responses to the open question Q12 suggests that the reason students were not motivated to engage in independent study is that they did not find the subsidized textbook helpful. In addition they wanted greater access to MATLAB. While they were provided 24/7 access to the computer laboratories only a short walk from their dormitories, they would have preferred a subsidized copy of MATLAB to run in their rooms.

The low (and statistically ambiguous) change in mean rating for Q2 is understandable
as none of the changes to the course directly address provision of feedback to students.

**Comparison to Positive Responses for Other Courses**

Fig. 3. shows that in 2008 the percentage of positive responses to CTE was below average in all categories compared to other courses offered by the School of Information Technology (ITEE) at UNSW@ADFA. This was accepted to some extent because the course was compulsory and viewed by many students as a ‘non-core’ component of the engineering curriculum. This attitude is reflected by the below average positive response to Q3 (whether the course is interesting) in both 2008 and 2009.

![Graph showing comparison of positive responses to CTE with average positive response rate to other courses offered by the School of Information Technology and Electrical Engineering at UNSW@ADFA.](image)

Fig. 3. Comparison of positive responses to CTE with average positive response rate to other courses offered by the School of Information Technology and Electrical Engineering at UNSW@ADFA. Refer to Fig. 5. for statements Q1-Q10.

Results do, however, show that the positive perception of the course in 2009 was at least as high as other courses offered by ITEE in five of the ten dimensions measured. Large improvements for Q4, Q5 and Q6 mean that the course now provides opportunities for student participation, development of critical thinking skills and clear assessment strategies on par with other courses offered by the school. In addition, students felt that the course was more successful in meeting its aims, and had more appropriate assessment items than other courses. The main areas for further improvement are the provision of feedback to student regarding their progress in the
course and provision of resources for independent study.

V. CONCLUSION

This paper has described how aspects of puzzle-based learning were incorporated into an introductory computer programming course as an ‘interest approach’. Puzzles were used as the motivating examples in lectures, and as the basis for laboratory exercises and creative assessment items. Results of an empirical study of nearly 200 students over a two year period indicate that using puzzle-based learning as an interest approach can significantly change the student experience. This includes increasing students’ interest and scope for active participation in the course, and developing their critical thinking and problem-solving skills.

REFERENCES


[8] University of New South Wales, “Course and teaching evaluation and improvement: the CATEI process”, University of New South Wales, Sydney, NSW, Australia, 2007