Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
An affect-sensitive intelligent tutoring system
with an animated pedagogical agent that
adapts to student emotion like a human tutor

A thesis presented in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy
in Computer Science

at Massey University, Albany,
New Zealand.

Samuel Thomas Vaughan Alexander

2007
Abstract

One of the established strengths of human tutors is their ability to recognise and adapt to the emotions of students. This is a skill that has traditionally been lacking from Intelligent Tutoring Systems (ITSs); despite their ability to intelligently model and adapt to aspects of the student’s cognitive state, ITSs are generally completely unable to detect or adapt to aspects of the student’s affective state.

In response to this shortcoming, this thesis explores the pioneering development of an emotion-sensitive ITS. With the empathy of effective human tutors as our blueprint, we investigate how an artificial tutor should adapt to the affective state of students, and develop an original affective tutoring strategies method. As a validation of the feasibility of an emotion-sensitive tutoring system, we implement and test our method in a functional Affective Tutoring System (ATS) for counting and addition, Easy with Eve, featuring an empathetic animated pedagogical agent, Eve. Eve is able to detect student affect using an in-house real time facial expression analysis system.

To inform the system’s adaptation to student affect, the novel method for student modelling and emotion-sensitive tutoring strategies has been developed using a fuzzy, case-based reasoning approach. This approach is used to mine data about human tutor adaptations to student affect that was generated by an observational study of human tutors that was carried out in a local primary school.

To test the impact of emotion detection and the presence of the animated agent, four different versions of the ATS were tested in local primary schools with a total of 59 participants. The findings from the study indicate that adding the detection of facial expressions to the student model did not improve student short-term performance, but there was mixed evidence that the presence of the animated agent Eve may cause students to perceive the system slightly more positively (a persona effect). This effect was marginally greater when the animated agent was enabled to detect and adapt to the affective state of students, which tentatively shows that emotion detection in an ATS may have a positive effect on student motivation.
Acknowledgements

Primarily, I am indebted to Abdolhossein Sarrafzadeh, my main supervisor, who has been an unceasing source of advice, feedback, guidance and kind support over the time that I have worked with him; without his assistance, preparing this thesis would have been many, many times more difficult. Secondly, I am also very grateful to Stephen Hill, my co-supervisor, who has also been a rich source of insight and good judgement, and who has provided a much valued psychological perspective on my research.

The development of Easy with Eve was greatly assisted by Chao Fan, who implemented the real-time facial expression recognition system that was used to detect student emotion. I am also thankful for the help that I received from Charlotte Bostin, who recorded the voice tracks for Eve and who also helped with the inter-rater reliability study in Chapter 3.

Thank you to Gail and Micah Williams, and Tabitha and Luke Beaumont, who helped with the pilot tests of Easy with Eve. Thank you also to the teachers, students and parents who assisted with the observational study of human tutors and the study of the effectiveness of Easy with Eve. I am especially grateful to Karen Spicer of Murrays Bay School and Sheila Brown of Torbay School, who helped with the organisation of the study of the effectiveness of Easy with Eve.

Thank you also to Antonija Mitrovic and Stellan Ohlsson, for their timely advice near the beginning of this research. I am also grateful for the financial assistance that I received from Massey University, the Institute of Information and Mathematical Sciences, the New Zealand Vice-Chancellors’ Committee and Education New Zealand.

On a personal note, the other PhD students in the Computer Science and Information Systems departments have helped to make my time in Albany bright and enjoyable, and I will miss our little chats. Finally, thank you to all of my family, and especially my parents, for their consistent support and encouragement that has helped to make this all possible.
List of publications

Refereed journal articles


Refereed international conferences


### Other publications


# Table of contents

1 Introduction ............................................................................................................. 1  
1.1 Statement of the problem .................................................................................. 1  
1.2 A definition of affect ......................................................................................... 3  
1.3 Research goals................................................................................................... 4  
1.4 Contributions of the thesis ................................................................................ 6  
1.5 Structure of the thesis ........................................................................................ 7  

2 Literature review ..................................................................................................... 9  
2.1 Affect and learning............................................................................................ 9  
  2.1.1 How student emotions affect learning .................................................... 10  
  2.1.2 How student emotions affect human tutoring ......................................... 13  
  2.1.3 Summary ................................................................................................. 15  
2.2 Affective computing ....................................................................................... 15  
  2.2.1 Recognising emotion............................................................................... 16  
  2.2.2 Showing emotion .................................................................................... 18  
  2.2.3 Having emotion, and being emotionally intelligent................................ 20  
  2.2.4 Summary ................................................................................................. 21  
2.3 Affective Tutoring Systems (ATSs)................................................................ 21  
  2.3.1 Related work ........................................................................................... 22  
  2.3.2 Summary ................................................................................................. 25  

3 Video study of human tutors ................................................................................ 27  
3.1 Aims of the study ............................................................................................ 28  
3.2 Human tutors................................................................................................... 29  
  3.3.1 Participants .............................................................................................. 31  
  3.3.2 Procedure ................................................................................................ 32  
  3.2.3 Tutoring exercise ..................................................................................... 32  
  3.2.4 Coding the videos .................................................................................... 33
4 Case-based reasoning tutoring strategies module ............................................. 45
  4.1 Background ..................................................................................................... 45
  4.2 A case-based approach .................................................................................... 47
    4.2.1 An overview of case-based reasoning ..................................................... 47
    4.2.2 A novel application of case-based reasoning .......................................... 49
  4.3 The basic case-based module .......................................................................... 50
    4.3.1 Scenarios as sequences of interactions ................................................... 50
    4.3.2 Using case-based reasoning to adapt to tutoring scenarios ..................... 53
  4.4 The fuzzy case-based tutoring strategies module ........................................... 55
    4.4.1 Why incorporate a fuzzy approach? ......................................................... 55
    4.4.2 Generating similar sequences ................................................................. 56
    4.4.3 Weighting similar sequences .................................................................. 58
    4.4.4 Searching for the generated sequences .................................................... 60
    4.4.5 Efficiency ................................................................................................ 61
  4.5 Summary ......................................................................................................... 61

5 Design and implementation of Easy with Eve .................................................... 63
  5.1 Architecture ..................................................................................................... 64
  5.2 Domain ............................................................................................................ 65
    5.2.1 Levels in Easy with Eve .......................................................................... 66
    5.2.2 Moving between levels ........................................................................... 66
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>Facial expression analysis</td>
<td>67</td>
</tr>
<tr>
<td>5.4</td>
<td>Animation</td>
<td>68</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Agent animation</td>
<td>68</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Tens frame and counters animation</td>
<td>71</td>
</tr>
<tr>
<td>5.5</td>
<td>Student model</td>
<td>72</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Concept scores</td>
<td>72</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Maintaining a history of interactions</td>
<td>73</td>
</tr>
<tr>
<td>5.6</td>
<td>Tutoring strategies module</td>
<td>73</td>
</tr>
<tr>
<td>5.6.1</td>
<td>Choosing a tutoring action using the tutoring strategies module</td>
<td>74</td>
</tr>
<tr>
<td>5.6.2</td>
<td>Carrying out the tutoring action</td>
<td>75</td>
</tr>
<tr>
<td>5.7</td>
<td>An order of events</td>
<td>76</td>
</tr>
<tr>
<td>5.8</td>
<td>Pilot tests</td>
<td>78</td>
</tr>
<tr>
<td>5.9</td>
<td>Summary</td>
<td>78</td>
</tr>
<tr>
<td>6</td>
<td>Study of the effectiveness of Easy with Eve</td>
<td>81</td>
</tr>
<tr>
<td>6.1</td>
<td>Methodology</td>
<td>81</td>
</tr>
<tr>
<td>6.1.1</td>
<td>Goals</td>
<td>81</td>
</tr>
<tr>
<td>6.1.2</td>
<td>Participants</td>
<td>83</td>
</tr>
<tr>
<td>6.1.3</td>
<td>Measures</td>
<td>84</td>
</tr>
<tr>
<td>6.1.4</td>
<td>Procedure</td>
<td>87</td>
</tr>
<tr>
<td>6.2</td>
<td>Results from the study</td>
<td>89</td>
</tr>
<tr>
<td>6.2.1</td>
<td>Overall effectiveness of Easy with Eve</td>
<td>89</td>
</tr>
<tr>
<td>6.2.3</td>
<td>Questionnaire responses</td>
<td>91</td>
</tr>
<tr>
<td>6.3</td>
<td>Summary</td>
<td>94</td>
</tr>
<tr>
<td>7</td>
<td>Discussion</td>
<td>95</td>
</tr>
<tr>
<td>7.1</td>
<td>The video study of human tutors</td>
<td>95</td>
</tr>
<tr>
<td>7.1.1</td>
<td>Can the results of the study be applied to different domains?</td>
<td>95</td>
</tr>
<tr>
<td>7.1.2</td>
<td>What can we assume about the expertise of the tutors?</td>
<td>96</td>
</tr>
<tr>
<td>7.1.3</td>
<td>Are there enough data?</td>
<td>96</td>
</tr>
<tr>
<td>7.1.4</td>
<td>Should the data from different tutors be grouped together?</td>
<td>98</td>
</tr>
<tr>
<td>7.1.5</td>
<td>Improvements to the coding scheme</td>
<td>99</td>
</tr>
<tr>
<td>7.2</td>
<td>The case-based tutoring strategies module</td>
<td>102</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Amount of data from the video study</td>
<td>102</td>
</tr>
</tbody>
</table>
List of figures

Figure 1.1  Model of the ATS, adapted from Conati (2002) ..........................................5
Figure 2.1  The four quadrant model of student affect and learning
(Kort et al., 2001) ................................................................................................... 12
Figure 3.1  Tens frames and counters in the mathematics exercise. ............................33
Figure 3.2  Frequencies of the most common tutor responses following correct
student answers ..................................................................................................37
Figure 3.3  Frequencies of the most common tutor responses following incorrect
student answers. The codes for the tutor turns are given in brackets..............37
Figure 3.4  Frequencies of facial expressions for tutors and students.......................38
Figure 3.5  Frequencies of tutor expressions following student expressions.............39
Figure 3.6  Frequency of particular tutor expressions following neutral, all, smile
(low) or smile (high) student expressions.........................................................40
Figure 4.1  Flow chart of the algorithm for the basic version of the tutoring
strategies module ..........................................................................................52
Figure 4.2  Interaction with the basic tutoring strategies module. ..............................54
Figure 4.3  Generated interactions that are similar to the initial interaction.................57
Figure 4.4  Interaction with the fuzzy tutoring strategies module..............................57
Figure 5.1  Architecture of Easy with Eve. ..........................................................64
Figure 5.2  Screenshot of the interface of Easy with Eve at Level 1 .........................65
Figure 5.3  Screenshot of the interface of Easy with Eve at Level 2, showing the
screen as it covers the counters ....................................................................65
Figure 5.4  Screenshot from the facial expression recognition system......................67
Figure 5.5  Order of events in Easy with Eve .......................................................77
Figure 6.1  Example of the Likert scale used in the questionnaire...........................85
Figure 6.2  Experimental set up used in the study at the first school........................87
Figure 6.3  Experimental set up used in the study at the second school....................87
Figure 6.4  Graph showing the increase from pre-test mean to post-test mean ........90
Figure 6.5  Graph showing the mean increase in score (post-test score minus pre-test score) for the agent present groups vs. the mean increase for the text-based feedback groups. ................................................................. 91

Figure 6.6  Graph showing the mean increase in score for the facial expressions detected groups vs. the mean increase for the facial expressions not detected groups. ................................................................. 91

Figure E.1  Extensible structure of Easy with Eve, showing how new emotion detection methods, content domain and data sets for the tutoring strategies module can be added to the ATS. ........................................... 153
## List of tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1</td>
<td>Frequency of student turns used in the coding scheme</td>
<td>34</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Frequency of tutor turns used in the coding scheme</td>
<td>34</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Frequencies of student and tutor expressions</td>
<td>35</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>The four different groups in the 2x2 experimental design</td>
<td>83</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Main effect and interaction results from the first four questions showing means, $F$ scores and $p$ values for the three possible effects: agent present, facial expressions detected, and agent present and facial expressions detected. Significant and marginally significant $p$ values are in bold.</td>
<td>92</td>
</tr>
<tr>
<td>Table A.1</td>
<td>Definitions of composite tutor turns, and frequencies of tutor turns.</td>
<td>137</td>
</tr>
<tr>
<td>Table A.2</td>
<td>Definitions of composite student turns, and frequencies of student turns.</td>
<td>140</td>
</tr>
<tr>
<td>Table D.1</td>
<td>The raw data from the study of Easy with Eve.</td>
<td>150</td>
</tr>
</tbody>
</table>