Applying the Cognitive Flexibility Theory to Teaching Web Engineering

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Abstract

Web engineering constitutes the employment of an engineering approach to the development of Web applications. Its main teaching objectives are for students to learn what an engineering approach represents and how measurement can be applied.

This paper presents the application of the Cognitive Flexibility Theory as an instructional theory to teach Web Engineering principles.

Results obtained over the last three years suggest that the CFT seems valuable for teaching Web engineering, as indicated by the boxplots of exam marks (regarding the Web engineering part of the exam).

Keywords: Web engineering teaching, cognitive flexibility theory, teaching methods.

1 Introduction

Web engineering constitutes the employment of an engineering approach to the development of Web applications. It comprises several theoretical concepts (measurement principles, development cycle etc) initially difficult to understand by students with no previous practical experience in project development. In addition, its main teaching objectives are for students to learn what an engineering approach means and how measurement can be applied. It also demonstrates how hypermedia and Web research is employed in an engineering approach to develop applications.

Web engineering as a discipline is still very much in its infancy and as yet there is no standard syllabus available.

This paper presents the application of the Cognitive Flexibility Theory (CFT) as an instructional theory to teach Web Engineering principles.

Section 2 describes the CFT principles. Section 3 describes how the Web engineering syllabus was adapted to the CFT. Section 4 presents an informal evaluation of the CFT's effectiveness over the last three years. Finally, in Section 5, we give our conclusions and comments for future work.

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2 The Cognitive Flexibility Theory

CFT is a conceptual model for instruction, based on cognitive learning theory. Its intent is to facilitate the advanced acquisition of knowledge and to serve as the basis for expertise in complex and poorly structured knowledge domains (Spiro, Feltovich, Jacobson, and Coulson 1995).

According to Spiro et al. (1995) all domains which involve the application of knowledge for unconstrained, *naturally occurring situations (cases)*, are very poorly structured. Examples include medicine, history and literary interpretation. Even in well structured knowledge domains such as basic arithmetic, the process of application (applying arithmetic) to solve "real-life" problems is also poorly structured.

A poor structure is not in itself a serious problem for *introductory learning* as learners are not expected to master complexity or independently transfer their acquired knowledge to new situations.

However, when conceptual mastery and flexible knowledge application become paramount, the complexity and across-case diversity characteristics of ill-structured domains needs to be addressed.

The main principles of CFT (Spiro, Feltovich, Jacobson, and Coulson 1995) can be listed as follows:

- Instruction should reflect the complexity that faces practitioners, rather than treating domain problems as simple linear decision making processes. As such CFT emphasises inter-connectedness and avoids oversimplifying instruction.
- CFT also gives emphasis to case-based instruction, rather than basing instruction on a single example or case. It is important that a variety of cases be used to illustrate the content domain.
- CFT supports context-dependent knowledge, best acquired in relevant situations that are likely to be encountered by the student as a practitioner.

CFT has already been used in the design of hypermedia and Web applications for education and its effectiveness for teaching poorly structured domains has been confirmed by several experiments (Carvalho, and Dias 1997, Jacobson, and Spiro 1995, Rana, and Bieber 1997).

3 Applying the CFT to Web Engineering

3.1 Introduction

The effectiveness of the CFT for teaching poorly structured domains has been confirmed by its use in the design of hypermedia and Web applications. However, to date it has not been applied as a teaching method in a classroom environment. Consequently, rather than developing a hypermedia/Web application to teach Web engineering using the CFT principles, we decided to incorporate the CFT into our classroom teaching practice and informally evaluate its effectiveness. A formal experiment was not feasible so far as, over the last three years, we were unable to split the class because of timetabling constraints, space constraints, and the availability of lecturers.

Web engineering was taught for a six week period, for three consecutive years (2000, 2001, 2002), to an average of forty-two Honours and postgraduate Computer Science students at the University of Auckland, attending a Hypermedia and Multimedia Systems (HMS) course. The course lasted for twelve weeks, starting with an introduction to Web and hypermedia systems (simple and advanced), and concentrated on a number of specific issues of multimedia production. In addition, it also focused on Web engineering aspects and how they can be applied to hypermedia and Web development. The CFT was only applied to the Web engineering content.

The students were given at least three assignments, of which two related to Web engineering, as described:

- Assignment A (group assignment) - required students to use a WWW search engine to locate sites on the Web; coverage of core HTML tags and structure of HTML documents/web sites; creation of a simple homepage; design of a multi-page Web application; re-design an existing Web application; loading of the Web pages onto a Web server. The main objective of this assignment is to familiarise students with the basics behind Web development, such that learning effects are reduced for the next assignment.
- Assignment B (individual assignment) - required students to develop a Web application to teach a chosen topic, containing at least 20 Web pages and structured according to the CFT principles. In addition, students were asked to measure the effort spent planning, designing, implementing and testing their applications, and also to measure the application's size (number of Web pages, number of graphics etc). Students could develop their applications using HTML, SHTML or XML. In addition, they were given 120 minutes of tuition on the CFT principles. The two main objectives of this assignment are: i) Expose students to using measurement to understand and improve their Web development processes; ii) Help students comprehend the CFT.

3.2 Themes and Case studies

The CFT suggests the use of case studies and themes (theory) with the preparation of a matrix describing those themes applied to each case study. The themes, case studies and the matrix of themes and case studies used to teach Web engineering are presented below:

Themes:

- Web Development Fundamentals
- Goals of the Web
- Large Scale Web Applications
- Functional Characteristics
- Non-Functional Characteristics
- Goal of Web Engineering
- Important Activities during the development of a Web application
- Process modelling and Management
- Waterfall model
- Incremental and Iterative models
- Tools to support the Development Process
- Linking Issues
- Making Applications Relevant
- Making Applications Complete & Correct
- Making Applications Usable
- Cognitive Management
- Effect of the Development Approach
- Productivity Issues
- Cognitive Management
- Reuse issues
- Maintenance issues
- What is Measurement?
- Measurement Objectives
- The Scope of Web Metrics
- Web Measurement in Practice

Case studies:

Case studies were based on the following Web/hypermedia models and technologies:

1) Web models:

- HDM (Hypermedia Design Model) (Garzotto, Paolini and Schwabe 1993)
- OOHDM (Object-Oriented Hypermedia Design Model) (Schwabe, and Rossi 1994)

2) Web technologies

Matrix of Themes and Case studies:

Themes ↓ Case studies →	HDM	OOHDM	Web technologies
Web Development Fundamentals	✓	✓	
Goals of the Web	✓	✓	
Large Scale Web Applications	✓	✓	
Functional Characteristics			✓
Non-Functional Characteristics			✓
Goals of Web Engineering	✓	✓	✓
Important Activities during the development of a Web application	✓	✓	
Process modelling and Management	✓	✓	
Waterfall model	✓	✓	
Incremental and Iterative models	✓	✓	
Tools to support the Development Process			✓
Linking Issues	✓	✓	✓
Making Applications Relevant			✓
Making Applications Complete & Correct			✓
Making Applications Usable			✓
Cognitive Management			✓
Effect of the Development Approach	✓	✓	✓
Productivity Issues		✓	✓
Reuse issues		✓	✓
Maintenance issues	✓	✓	✓
What is Measurement?	✓	✓	✓
Measurement Objectives	✓	✓	✓
The Scope of Web Metrics	✓	✓	✓
Web Measurement in Practice	✓	✓	✓

Table 1: Matrix of Themes and Case studies

3.3 How the CFT was adopted in the Teaching Scenario

The CFT allows the traversal of information from different perspectives and following different paths. However, during classes the lecturer was responsible for determining the paths to be followed and which theme(s) and/or case(s) would be investigated.

Each class lasted for one hour, with three classes per week. The class dynamic used was:

- Classes would in general start by explaining a theme or set of themes.
- Following the explanation of a theme, relevant case studies, would then be presented.
- The theme would be applied to each case study and sometimes a comparison of case studies would also be introduced.

To help make classes more interactive case studies were presented by groups of students and a class discussion would follow, applying themes to case studies.

4 Informal Evaluation of the CFT's Effectiveness

To informally evaluate the effectiveness of the CFT as a teaching practice we used boxplots showing the distribution for the exam marks regarding only those marks for the Web engineering part of the exam. (see Figure 1).

Boxplots give a good indication of the distribution of the marks and can help explain the behaviour of the summary statistics. They are based on non-parametric statistics (Pickard, Kitchenham, and Linkman 1999) and show the median value as the central tendency for the distribution. The length of the box from lower tail to upper tail gives an indication of the spread of the distribution. The position of the median in the box and the length of the boxplot tails show how skewed the distribution is. If the upper and lower tails are approximately equal and the median is in the centre of the box the distribution is symmetric. If the distribution is not symmetric the relative lengths of the tails and the position of the median in the box indicate the nature of the skewness. The length of the box relative to the length of the tails gives an

indication of the shape of the distribution. A boxplot with a small box and long tails represents a very peaked distribution, a boxplot with a long box represents a flatter distribution.

The exam allocated 50% or the total marks, corresponding to 50 points, for Web engineering (used the CFT) and another 50% for the remaining topics taught during the course. Lecturers marked their own components.

As previously discussed, the exam had two parts: non-Web engineering questions and Web engineering questions (WEQ). Questions in the WEQ group used levels, according to Bloom's taxonomy of learning objectives (Krathwohl, and Bloom 1956), Comprehension, Analysis and Evaluation.

The Taxonomy is presented in Table 2:

Learning Objectives	Description
Knowledge:	The recall of specifics, universals, methods, processes, or patterns. Remembering.
Comprehension:	The person "knows" the material and can use it but cannot relate it to other material or see its broader implications. The lowest level of understanding.
Application:	The use of abstractions (e.g., principles, ideas, theories) in particular and concrete situations.
Analysis:	The breakdown of a communication into its constituent elements such that the relations among the ideas is made explicit.
Synthesis:	Working with parts and combining them in such a way as to constitute a structure.
Evaluation:	Judgements about the value of material and methods for given purposes.

Table 2: Bloom's Taxonomy of learning objectives

Figure 1 shows that the medians and corresponding distributions for the 2001 and 2002 groups were very similar. Their distributions are peaked around the median, where their boxes, containing 50% of marks, are roughly between marks 35 and 44, and smaller than the box for the 2000 group, which is between marks 29 and 43. The spread of their distributions is also lower than the spread for the 2000 group. The distribution for group 2000 was nearly symmetric, resembling a normal distribution. One boxplot has an outlier, not uncommon for the type of data used in this study as there are many factors that can influence a student's outcome in the exam (e.g., illness, fatigue etc). In general results show that for groups 2001 and 2002 75% of their marks are above 35, which means that 75% of students from each group scored at least 70% on Web engineering, which is remarkable. For the group 2000, 75% of students scored at least 58% on Web engineering, which is in itself not a bad result either. Summary statistics for all three groups are presented in Table 3, where the data indicates that the skewness for all groups was smaller than 1, suggesting distributions that do not differ significantly from a normal, symmetric distribution. These results suggest that even if the use of the CFT does not improve learnability, it certainly does not hinder it.

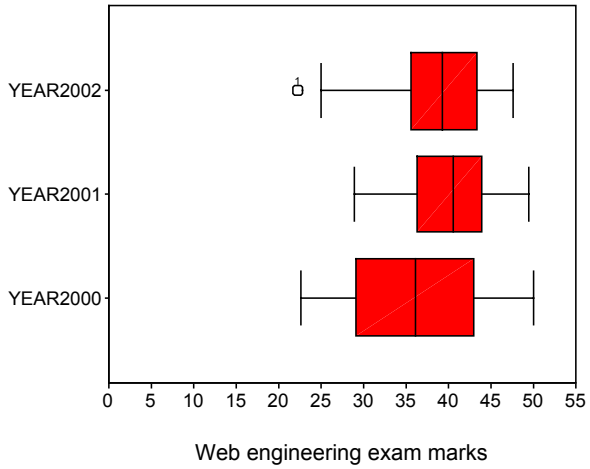

Figure 1: Boxplots for Web engineering exam marks

Statistics	YEAR2000	YEAR2001	YEAR2002
Mean	36.24	37.23	38.2368
Median	35.70	38.10	39.2500
Std. Deviation	7.898	7.845	6.43311
Skewness	.123	-.880	-.729
Minimum	23	29	22.25
Maximum	50	50	47.50

Table 3: Summary Statistics for Web engineering exam marks

Several factors could have contributed to the difference between group 2000 and groups 2001/2002:

- Groups 2001 and 2002 were exposed to improved classes based on comments received from the 2000 class, thus increasing their usefulness and adequacy.
- Lack of familiarity with the CFT. Students who attended the course during 2000 had their Web engineering classes delivered over the last six weeks of the semester. Therefore during the first six weeks they were presented with a more traditional teaching method first and only then were exposed to the CFT style. We believe that the use of the CFT as a teaching practice during the entire semester would have helped students immerse themselves in the use of the CFT, perhaps resulting in smaller variability in how much they learnt.

5 Conclusions and Future Work

This paper has presented the use of the CFT to teaching Web engineering. Further experimentation is clearly necessary to formally evaluate how effective the CFT is to the acquisition of complex knowledge compared to other conventional teaching methods. This forms part of our future work.

The advantages of using the CFT are that case studies can be examined using different perspectives, enriching the knowledge obtained by students. The material is organised in a way that allows students to acquire higher-level thinking skills and also to use learning levels, such as Analysis, Synthesis and Evaluation (Krathwohl, and Bloom 1956).

The domains of knowledge to which the CFT may show useful are those in which knowledge is not well-structured and each situation in practice has several possible interpretations depending on the perspective of the user. Examples of such domains are Web engineering, software engineering, human-computer interaction, medicine, history etc.

However, structuring the syllabus using the CFT is time consuming, in particular without the availability of libraries containing educational material structured according to the CFT, ready for re-use.

As part of our future work, we plan to develop a set of tools to help automate the generation of Web pages structured according to the CFT. Once achieved we can consider a library of themes and case studies for reuse by other members of staff. In addition, we also plan to investigate whether cognitive skills may influence the acquisition of knowledge using the CFT.

6 Acknowledgments

The author wishes to thank Dr. Nile Mosley for his helpful comments on a previous version of this paper.

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