The Cognitive Flexibility Theory: an Approach for Teaching Hypermedia Engineering

Emilia Mendes
Department of Computer Science
The University of Auckland
emilia@cs.auckland.ac.nz

Nile Mosley
Department of Computer Science
Auckland University of Technology
nile_mosley@yahoo.com

Steve Counsell
Department of Computer Science
Birkbeck College
steve@dcs.bbk.ac.uk

Abstract
Hypermedia engineering constitutes the employment of an engineering approach to the development of hypermedia applications. Its main teaching objectives are for students to learn what an engineering approach means and how measurement can be applied.
This paper presents the application of the Cognitive Flexibility Theory as an instructional theory to teach Hypermedia Engineering principles.
Early results have shown that students presented a greater learning variability (suggested by their exam marks) when exposed to the CFT as a teaching practice, compared to conventional methods.

1. Introduction

Hypermedia engineering constitutes the employment of an engineering approach to the development of hypermedia 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.

Hypermedia 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 Hypermedia Engineering principles.

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

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 [6].

According to Rand Spiro et al. [6] all domains which involve the application of knowledge to 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 [6] can be listed as follows:

- Instruction should reflect the complexity that faces practitioners, rather than the treating of 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 applications for education and its effectiveness for teaching poorly structured domains has been confirmed by numerous experiments [1,2,5].

3. Applying the CFT to Hypermedia 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 applications. However, to date it has not been applied as a teaching method in a classroom environment. Consequently, rather than developing a hypermedia application to teach Hypermedia engineering using the CFT principles, we decided to incorporate the CFT into our classroom teaching practice and evaluate informally its effectiveness.

Hypermedia engineering was taught for a six week period to forty-one 4th year Computer Science students at the University of Auckland, attending a Hypermedia and Multimedia Systems (HMS) course during the first semester of 2000. The course lasted for a twelve-week period, starting with an introduction to 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 three assignments, described as follows:

- Assignment 1 (group assignment) - required students to use a WWW search engine to find some 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 site; create a new web site for the Matakohe Kauri Museum, improving on the existing site; load the web pages onto a web server.
- Assignment 2 (individual assignment) - required students to develop a Web site to teach a chosen topic, containing at least 50 Web pages and structured according to the CFT principles. Students could develop their applications using HTML, SHTML or XML. They were taught for 120 minutes about the CFT principles.
- Assignment 3 (group assignment) - required students to design, implement and evaluate a multimedia application; in addition, they were required to give a 15-minute presentation of their application to the class. Implementation of the application used an authoring package (Director) or Java.

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 hypermedia engineering are presented in the Appendix, for shortage of space.

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 the one responsible for determining the path 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 as follows:

- Classes would in general start by explaining a theme or set of themes.
- Following the explanation of a theme, relevant case studies, according to the matrix presented in table1) would then be presented.
- The theme would be applied to each case study and sometimes a comparison of case studies would be introduced as well.
- To make classes more interactive sometimes 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 (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 [4] 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 lenght 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 points for Web engineering (used the CFT) and another 50 for the remaining topics taught during the course. Lecturers marked their own components.

As mentioned earlier, the exam had two parts: non-Hypermedia engineering questions (NHEQ) and Hypermedia engineering questions (HEQ). Questions in the NHEQ group used levels, according to Bloom's taxonomy of learning objectives[1] [3], Knowledge, Comprehension and Application. Questions in the HEQ group used levels Application, Analysis and Synthesis.

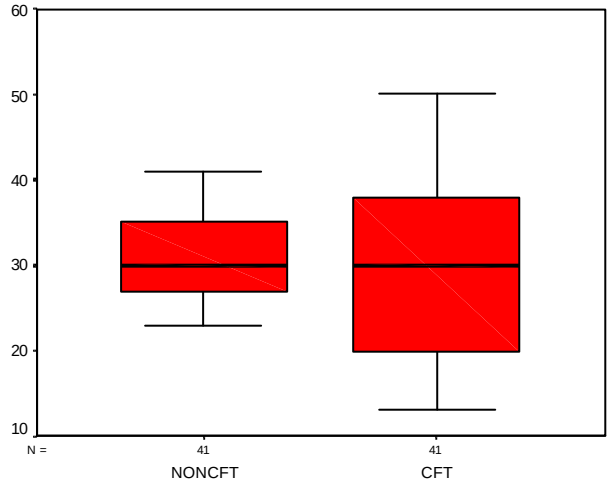

Figure 1: Boxplots showing the distribution of marks for the contents not taught using the CFT (non-CFT) and those taught using the CFT (CFT).

Figure 1 shows that the medians for both groups were very similar. The non-CFT group shows a peaked distribution, whereas the CFT group shows a flatter distribution. The highest and lowest grades were obtained by the CFT group. Several factors could have contributed to these results:

- Difference in the types and number of questions used on both groups and corresponding learning levels considered. The number of questions for the NHEQ group was four times greater than the number of questions for the HEQ group. In addition, they were grouped and presented on the first pages of the exam script.
- Concerning the non-hypermedia engineering topics, students were advised before the exam about which type of questions to expect and which topics to concentrate on. This approach may be a confounding factor, biasing the results obtained for the NHEQ. No advice was given for the hypermedia engineering part.
- Lack of familiarity with the topic of Hypermedia engineering. Students were presented anew the concepts behind hypermedia engineering, whereas several concepts presented on the other half of the course were already familiar to several students (Web site design, HTML, JPEG, XML etc).
- Familiarity with conventional teaching practices. Most students were non-english speakers as a first language. 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 Hypermedia 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 [3].

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 hypermedia engineering,

[1] 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.

software engineering, human-computer interaction, medicine, history etc.

On the other hand, 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 to be reused. In addition, the marks obtained for groups NHEQ and HEQ may suggest that for some students, being exposed to unconventional teaching practices hinder their understanding, whereas for others, it improves their understanding. Further evaluation is necessary to investigate whether cognitive skills may influence the acquisition of knowledge using the CFT.

As part of our future work, we also 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.

References

[1] Carvalho, A. A., and Dias, P., Hypermedia Environment using a Case-Based Approach to Foster the Acquisition of Complex Knowledge. Proceedings of ED-MEDIA'97, Calgary, Canada, June, (1997).

[2] Jacobson, M. J., and Spiro, R. J., Hypertext Learning Environments, Cognitive Flexibility, and the Transfer of Complex Knowledge: An Empirical Investigation, J. Educational Computing Research, Vol. 12, No 4, pp. 301-333, (1995).

[3] Krathwohl, D. R., and Bloom, B. S.. Taxonomy of educational objectives : the classification of educational goals, London : Longmans Publs., (1956).

[4] Pickard, L. M.., Kitchenham, B.A., and Linkman, S.J., An investigation of analysis techniques for software datasets, Proc. Sixth International Symposium on Software Metrics, IEEE Computer Society Press, Los Alamitos, CA, (1999).

[5] Rana, R., and Bieber, M., Towards a Collaborative Hypermedia Educational Framework., Proceedings of Thirtieth Annual Hawaii International Conference on System Science (HICSS), pp. 610-619, Maui, January, (1997).

[6] Spiro, Rand J., Feltovich, Paul J., Jacobson, Michael J., and Coulson, Richard L., Cognitive Flexibility, Constructivism, and Hypertext: Random Access Instruction for Advanced Knowledge Acquisition in Ill-Structured Domains, In L. Steffe & J. Gale (Eds.), *Constructivism*, Hillsdale, N.J.:Erlbaum, (1995).

Appendix

Themes:

- Hypermedia Development Fundamentals
- Goals of Hypermedia
- Large Scale Hypermedia Applications
- Functional Characteristics
- Non-Functional Characteristics
- Goal of Hypermedia Engineering
- Important Activities during the development of a Hypermedia 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 in Hypermedia
- Maintenance in Hypermedia
- What is Measurement?
- Measurement Objectives
- The Scope of Hypermedia Metrics
- Hypermedia Measurement in Practice

Case studies:

Case studies were based on the following hypermedia models, methodologies and systems:

Hypermedia models:

(A)HDM (Hypermedia Design Model) (1)
(B)OOHDM (Object-Oriented Hypermedia Design Model) (2)

Hypermedia methodologies:

(C)RMM (Relationship Management Methodology) (3)

Hypermedia systems:

(D)VIKI (4)
(E)SEPIA (5)
(F)Intermedia (6)
(G)Microcosm (7)
(H)The Web (8)
(I) Webcosm. (9)

The matrix of themes and case studies used to teach hypermedia engineering is presented in Table 1.

	A	B	C	D	E	F	G	H	I
Hypermedia Development Fundamentals	X	X	X	X	X	X	X	X	X
Goals of Hypermedia	X	X	X	X	X	X	X	X	X
Large Scale Hypermedia Applications	X	X	X						
Functional Characteristics				X	X	X	X	X	X
Non-Functional Characteristics				X	X	X	X	X	X
Goal of Hypermedia Engineering	X	X	X	X	X	X	X	X	X
Important Activities during the development of a Hypermedia application	X	X	X	X	X	X	X	X	X
Process modelling and Management	X	X	X	X	X	X	X	X	X
Waterfall model	X	X	X						
Incremental and Iterative models	X	X	X						
Tools to support the Development Process				X	X	X	X	X	X
Linking Issues	X	X	X	X	X	X	X	X	X
Making Applications Relevant				X	X	X	X	X	X
Making Applications Complete & Correct				X	X	X	X	X	X
Making Applications Usable				X	X	X	X	X	X
Cognitive Management	X	X	X	X	X	X	X	X	X
Effect of the Development Approach	X	X	X	X	X	X	X	X	X
Productivity Issues				X	X	X	X	X	X
Cognitive Management				X	X	X	X	X	X
Reuse in Hypermedia	X	X	X	X	X	X	X	X	X
Maintenance in Hypermedia				X	X	X	X	X	X
What is Measurement ?	X	X	X	X	X	X	X	X	X

Measurement Objectives	X	X	X	X	X	X	X	X	X
The Scope of Hypermedia Metrics	X	X	X	X	X	X	X	X	X
Hypermedia Measurement in Practice	X	X	X	X	X	X	X	X	X

Table 1: Matrix for Hypermedia Engineering Cases and Themes

References for the Appendix

(1) Garzotto, F., Paolini, P., and Schwabe, D., "HDM - A Model for the Design of Hypertext Applications", Proceedings of Hypertext'91, 313-328, ACM Press, San Antonio, Texas, December, (1991).

(2) Schwabe, D. and Rossi, G., "From Domain Models to Hypermedia Applications: an Object-Oriented Approach", Workshop on hypermedia design and development, Edinburgh, September, (1994).

(3) Balasubramanian, P., Isakowitz, T., and Stohr, E.A., "Designing Hypermedia Applications", Proceedings of the twenty-seventh Annual Hawaii International Conference on System Sciences, 354-365, Hawaii, (1994).

(4) Marshall, C.C. and Shipman III, F. M., "Spatial Hypertext: designing for Change", Communications of the ACM, Special Issue on Hypermedia Design, August, (1995).

(5) Streitz, N.A., and Hannemann, J., "Elaborating Arguments: Writing, Learning, and Reasoning in a Hypertext Based Environment for Authoring", In: D. H. Jonassen and H. Mandl, eds., Designing Hypermedia for Learning, 407-438, Berlin, Heidelberg: Springer-Verlag, (1990).

(6) Beeman, O. W., Anderson, K.T., Bader, G., Larkin, J., McClark, A.P., McQuillan, P. and Shields, M., "Intermedia, A Case Study of Innovation in Higher Education", Final Report to The Annenberg/CPB Project on A Network of Scholar's Workstations in a University Environment: A New medium for Research and Education, February, (1988).

(7) Fountain, A.M., Hall, W., Heath, I., and Davis, H., "Microcosm: An Open Model for Hypermedia With Dynamic Linking", Proceedings of ECHT'90, 298-311, (1990).

(8) Berners-Lee, T., Cailliau, Luotonen, R., Nielsen, H. F., and Secret, A., "The World Wide Web. Communications of the ACM, 37(8), 76-82, August, (1994).

(9) G. Hill, "Webcosm Technical Overview, Multicosm Ltd.", Technical manual, http://www.multicosm.com, 1998.