UNIVERSITY OF SOUTHAMPTON
FACULTY OF PHYSICAL AND APPLIED SCIENCES
ELECTRONICS AND COMPUTER SCIENCE

A COMPETENCE-BASED SYSTEM FOR RECOMMENDING STUDY MATERIALS FROM THE WEB

By
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Thesis for the degree of Doctor of Philosophy in Computer Science

June, 2012

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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Doctor of Philosophy

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Adaptive hypermedia systems, such as intelligent tutoring systems, aim to reduce reliance upon a teacher. However, such systems have some drawbacks such as inconsistency when estimating a learner's knowledge level, and a lack of a pedagogically informed approach to teaching and learning. These drawbacks may be addressed by a competency model. Such a model has the benefits of an improved pedagogical approach to e-learning and a more consistent profile of learners' competences. Such a model also renders competences machine processable, sharable, and modifiable.

The aim of this research is to investigate and design a competence-based system which provides appropriate study materials from the Web to the learner without any intervention from the teacher. Each step within the system for deriving the study material links from the learners' competences is described in detail.

A competence structure is designed from a set of intended learning outcomes. An XML-schema represents the information within a competence structure to support machine processing.

Experiments were carried out to evaluate the competence-based system for recommending links by considering the learner's reaction, by comparing the learning improvement between the competence-based approach and other approaches, and by exploring the effects of search engines used and keywords on the search results.

From these experiments, some conclusions have been drawn, such as: learning paths with more nodes are more helpful, and Web links of a competence node with a lower level of Bloom's taxonomy showed higher ratings than those with a higher level of Bloom's taxonomy. In addition, a competence-based system is accepted by learners at the reaction level. A freely-browsing and a competence-based system produced equal improvements in learners' learning. Different types of search engines (Google and Google API) and categories of keywords (SM and CA+SM+CO) show no significant differences between the qualities of study material links in helping learners achieve their competences. Furthermore, the links from Google were found to be as good as those from an educational search engine.

Some future work is suggested, for example, more exploration of a complex competence structure and learning paths, improvements on the usability and accessibility of the application, and more in-depth consideration of self-assessment.

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Declaration of Authorship

I, **Athitaya Nitchot,**

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

COMPETENCE-BASED SYSTEM FOR RECOMMENDING STUDY MATERIALS FROM THE WEB

I confirm the following:

- This work was done wholly or mainly while in candidature for a research degree at this University.
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- Where I have consulted the published work of others, this is always clearly attributed.
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- Either none of this work has been published before submission, or parts of this work have been published as:

1. Nitchot, A., Gilbert, L. and Wills, G. (2010) A Competence-based System for Recommending Study Materials from the Web (CBSR). In: The 9th International Conference on Information Technology Based Higher Education and Training (ITHET 2010), 29 April - 01 May 2010, Cappadocia, Turkey.
2. Nitchot, A., Gilbert, L. and Wills, G. (2010) Towards a Competence based System for Recommending Study Materials (CBSR). In: The 10th IEEE International Conference on Advanced Learning Technologies, 5 - 7 July 2010, Sousse, Tunisia.
3. Nitchot, A., Gilbert, L. and Wills, G. (2010) A Competence Model to Design Assessment Questions for Self-Study. In: 2010 International Computer Assisted Assessment (CAA) Conference: Research into E-Assessment, 20th & 21st July 2010, Southampton, UK.
4. Nitchot, A., Gilbert, L. and Wills, G. (2011) Competence-based System for Recommending Study Materials from the Web: Design and Experiment. In: ED-MEDIA

2011-World Conference on Educational Multimedia, Hypermedia & Telecommunications, 27 June - 1 July 2011, Lisbon, Portugal.

5. Nitchot, A., Gilbert, L. and Wills, G. (2011) Designing XML-Schema of a Competence Structure from Course Intended Learning Outcomes. In: The 14th IASTED International Conference on Computers and Advanced Technology in Education, 11 - 13 July 2011, Cambridge, UK.

6. Nitchot, A., Gilbert, L. and Wills, G. (2012) Competence Web-based System for Suggesting Study Materials Links: Approach & Experimental Design. In: EdMedia 2012 - World Conference on Educational Media and Technology, Denver, CO, USA.

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Date:

Acknowledgements

I express my appreciation to all who provided me the encouragement and support in various ways towards the completion of my thesis.

In the first place, I express my deep and sincere gratitude to Mr. Lester Gilbert and Dr. Gary B Wills for their supervision, valuable advice, and patience, and for giving stimulating suggestions on my research and the writing of this thesis. Their guidance helped me throughout the time of the research and I really appreciate their insightful comments. From Lester and Gary I have learnt much about how to write papers and perform academic research.

Additionally I thank Onjira Sitthisak, Yulita Hanum P Iskandar, Roziana Ibrahim, Dade Nurjanah, Noura Abbas, Priyanka Singh, and Ani Liza Asnawi for their helpful suggestions and for being such wonderful colleagues.

I am indebted to other colleagues in the School of Electronics and Computer Science, University of Southampton for giving me constructive comments on my research, including my writing of this thesis.

I would also like to thank my Thai friends in Southampton, Amonlaya kosaiyakanont, Pornrawee Thunnithet, Khampee Noonkhan, Tossaporn Joochim, Pundita Jadsri, Kriangsak Damchoom, Adisak Intana, and Woraluck Wongse-Ek, for their support, royalty, and encouragement.

Lastly, I thank my family - my father, my mother, and my two sisters for patiently listening to me whenever I need someone to talk to. I thank them all for giving me their time and encouragement.

The thesis was edited by Eileen Pearse (eileenpearse@mweb.co.za). With the oversight of my main supervisor, editorial advice has been sought. No changes of intellectual content were made as a result of this advice.

Definitions and Abbreviations Used

Chapter	Abbreviation/Symbol Used	Description
1	–	–
2	CDT	Component Display Theory
3	IMS-RDCEO	IMS Reusable Definition of Competency or Educational Objective Specification
	LOs	Learning Objects
4	KR	Knowledge Representation
	XML	Extensible Markup Language
	OMDOC	Markup Format and Data Model for Mathematical Documents
	RDF	Resource Description Framework
	SPARQL	SPARQL Protocol and RDF Query Language
	OWL	Web Ontology Language
	W3C	World Wide Web Consortium
	SGML	Standard Generalized Markup Language
	URI	Uniform Resource Identifier
5	AH	Adaptive Hypermedia
	ITS	Intelligent Tutoring System
	AHS	Adaptive Hypermedia System
	WWW	World Wide Web
	AI	Artificial Intelligence
6	HCF	Highest Common Factor
	DAG	Directed Acyclic Graph
	AQA	Award Body for A-levels, GCSEs and Other Exams
	OCR	Oxford Cambridge and RSA Examinations
	Edexcel	Pearson Company, the UK's Largest Awarding Body
	GCSE	The General Certification of Secondary Education
	ERD	Entity-Relationship Model
7	ER	Entity-Relationship
	BFS	Breadth-First Search
	FIFO	First In, First Out
8	GoogleAPI	Google Application Programming Interface
	MANOVA	Multivariate Analysis of Variance
	ANOVA	Analysis of Variance
	CTR	Click Through Rate
	SM	Subject Matter Content
	CA	Capability
	CO	Context
	N	Sample Size
9	Std. Deviation	Standard Deviation
	SE	Standard Error
	Sig.	Statistics Significant Value
	df	Degree of Freedom
	p	Probability
	α	Alpha Probability
	m	Number of Tests of Significance
	CI	Confidence Interval
	vs	Versus
10	ILO	Intended Learning Outcome
11	KIF	Knowledge Interchange Format

Chapter 1
Introduction

Web-based education is an area which makes use of resources from the Web for educational purposes and where there may be no interaction with teachers (Lynch & Lynch, 2003). The Web has become an effective resource and facilitates learning since learners can access it at any time and from any place and the Web content is relatively easily updated.

The aim of this research is to contribute a Web-based system which provides links as appropriate study materials. These links are generated, based upon competences expressed by learners. Therefore, the interaction with teachers is not required. The main objective of the system is to help the learners to find study materials from the Web as supplementary resources outside the classroom. This is not intended to replace the teacher's role or to reduce the number of teachers in the classroom. Some aspects of this subject have been explored by many researchers who have produced systems which reduce the teacher's tasks, such as an intelligent tutoring system (Brusilovsky, 2000; Contreras, Galindo, Caballero, & Caballero, 2007; Elsom-Cook, 1987). However, most systems were designed using the concept of adaptive hypermedia and embedded user modelling. Such user models are inconsistent in estimating the learner's knowledge level, are not designed to support lifelong learning, and face the difficulty of constructing models which adhere to standardized adaptive techniques. In addition, there are other problems such as high development costs, the requirement for updates if the information or knowledge changes, and the need for careful preparation in terms of describing the knowledge.

This research proposes an effective competence-based system based upon the COMBA competency model (Sitthisak, Gilbert, & Davis, 2008). The COMBA model consists of three major components: subject matter, capability, and context. Consideration of the COMBA competency model offers some benefits to a pedagogical approach, for example, it consists of an intended learning outcome, it incorporates the idea of context in categorising levels of proficiency, it provides consistency in recording a learner's level of performance, and aids lifelong learning. In addition, there are other factors for considering the COMBA competency model in this research, such as the issues of the machine processability of learner competence, and enabling the competence structure to be navigable.

This thesis offers a description of a method for constructing a competence structure from the existing intended learning outcomes of the knowledge domain. In this research there are two designed competence structures based on two knowledge domains. The first structure is based on the mathematical highest common factor (HCF). Its structure is simple and less complex. The second is a competence structure of photosynthesis for Key Stage 4 learners. It is a more complicated and larger structure. This method allows the developers to understand each step of designing a competence structure for future use.

This research's competence-based system suggests appropriate study materials as links from the Web to the learner based on his/her competences which constitute current/existing and desired competence. The current or existing competence is the estimate of the actual competence of the learner. The desired competence refers to the learner's intended learning outcome or the competence which the learner wishes to gain. After the existing and desired competences of the learner are established, there is a process for deriving different learning paths to obtain the study material links. This process is considered, based on a structure of competence elements in a specific knowledge domain. Finally, the learner is given the automatic recommendation of study materials as links from the Web. The benefits of this research's system are to identify learners' existing/desired competences, to give possible learning paths as guidance, and to provide appropriate study materials as links from the Web, according to the learners' competences.

1.1 Research Statement and Related Questions

The aim of the research is to design a system that will enable a learner to find appropriate study materials from the Web without any interaction from a teacher.

The system will be considered successful if learners are able to achieve their intended learning outcomes after they obtain the recommended study material links, based on their competences. This leads to three research questions as follows:

1. What learning path is most appropriate for helping learners achieve their desired competences?
2. Do learners accept a system at reaction level?
3. When a system is compared to other approaches to learning, which approach provides learners with a better way of improving their learning?

In order to answer the research questions, the following research plans of the system are proposed:

- Construct an appropriate competence structure for a particular knowledge domain.
- Ensure that the competence structure is machine processable, sharable, and modifiable.
- Implement and test the design of the system.
- Validate how effectively and successfully the system provides learners with study material links based on their competences.

This thesis discusses these research plans and questions, and proposes a solution. The overview of the steps in considering the plans can be seen in Figure 1-1. At the beginning, a competence structure is set up to express the relationships between competences. A competence structure can be represented as a graph, a map, a network, and so on. In addition, representation of the competence structure should be machine processable, sharable, and modifiable.

Once established, the competence structure is followed by the implementation and testing of the system design. In the final stage, some experiments were conducted to validate the effectiveness of a system and answer the research questions. Experiments explore the appropriate learning paths, the learner's reactions, and learner achievement of intended competences.

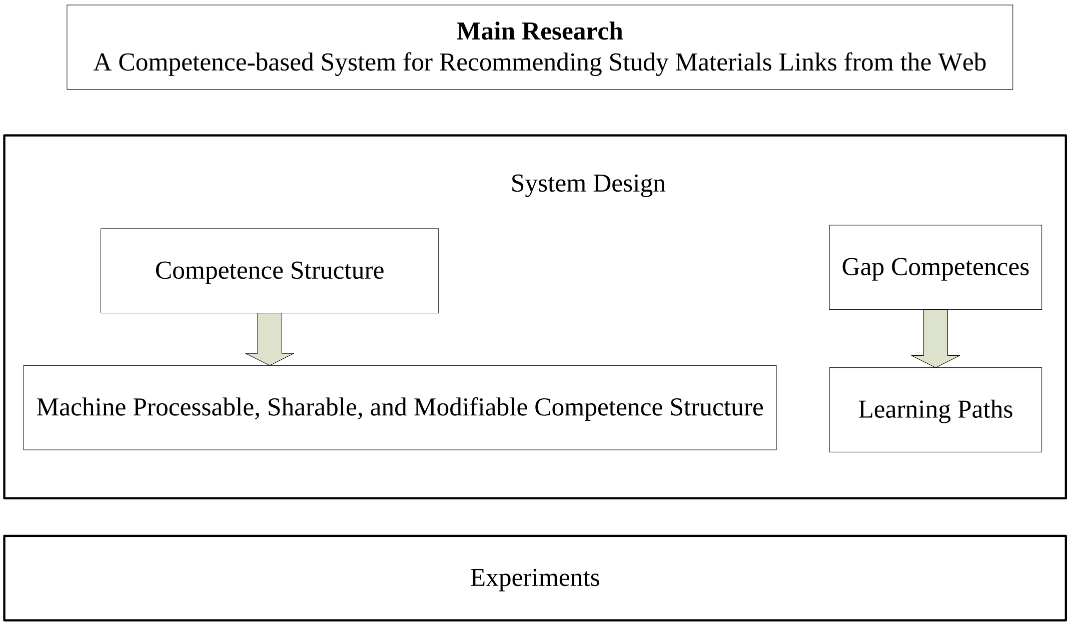


Figure 1-1: *Steps in Considering Each Question*

1.2 Structure of Remaining Chapters

The overview of following ten chapters is as follows.

Chapter 2 discusses the overview of relevant pedagogical issues in this research. The consideration of the pedagogical approach facilitates the design of an e-learning system to provide study materials from the Web which can be matched with learners' needs. Details in this chapter are e-learning transaction and the instructional design of subject matter and capability.

Chapter 3 introduces a competency model. This chapter gives a definition of competency and examples of existing competency models. There is a discussion on the competency model considered in this research and its benefits for pedagogical approach. The competence structure is then considered to represent the network or structure of learner competences.

Chapter 4 describes techniques of knowledge representation which are explored with a view to generating a competence structure that can be machine processable, sharable, and modifiable. In addition, there is a discussion of each language used to represent knowledge on the Web and its approach to representing a competence structure.

Chapter 5 discusses other methods of modelling users. Most of them are designed based on adaptive hypermedia (AH) and an intelligent tutoring system (ITS). However, the current user modelling has been shown to have some problems. There is a discussion of some drawbacks in user modelling and intelligent tutoring systems.

Chapter 6 discusses the analysis and design of a competence-based system which suggests appropriate study material links from the Web to a learner, based on his/her competences. In this chapter there is a description of the requirement analysis, the design of the system process, learning paths, and the construction of a competence structure from an existing course syllabus.

Chapter 7 describes the implementation of a competence-based system. It includes the design of a database based on a competence structure, the process of designing learning paths, the sorting algorithm to generate learning paths, and the implemented user interface with associated screenshots.

Chapter 8 deals with the experimental methodology and explanations of test statistics used to analyze each experimental result. Six experiments were conducted to evaluate the competence-based system for recommending links by considering the learner's reaction, by comparing the learning improvement between the competence-based approach and other approaches, and by exploring the effects of search engines used and keywords on the search results. For each experiment, the information on experimental overview, methodology, materials used, and procedure is given.

Chapter 9 presents the statistical results of the data from each experiment separately.

Chapter 10 discusses results and possible reasons for obtaining the outcomes for each experiment. In addition, some approaches to further studies will be provided.

Chapter 11 acknowledges some limitations to this study and proposes directions for further studies to address the drawbacks. The contributions made by this work are discussed, followed by some concluding remarks.

6

Chapter 2
Pedagogy

2.1 Introduction

In order to design an effective e-learning system, both technical and pedagogical issues must be considered. This chapter gives an overview of relevant pedagogical issues including the structure of an e-learning transaction, and the design of instructional experiences.

2.2 Pedagogy Overview

The word ‘pedagogy’ comes from the ancient Greek word ‘paidagogos’. This refers to the slave who supervised or led children’s instruction. Some sources give the usual definition of pedagogy as “art or science of teaching” (Beetham & Sharpe, 2007). One definition states that ‘pedagogy’ is “the art of teaching and refers to the strategies, methods and styles of instruction” (Leach & Moon, 2000). De Boer and Collis (2002) further define pedagogy as “the knowledge and skills that practitioners of the profession of teaching employ in performing their duties of facilitating desired learning in others”. Teachers are advised to have an understanding of pedagogy in order to provide study materials that match the learner’s needs. Pedagogy is any effective behaviour or activity designed to impart knowledge. It is used in the process of teaching and learning and is connected with students’ learning and outcomes (Mehanna, 2004). Hennessy et al. (2007) highlighted the importance of pedagogy in technology-integrated science teaching. The results of the experimental studies they conducted, suggested that the understanding of how the teacher capitalises on the technology supports the student to construct links between scientific theory and empirical evidence (Hennessy, et al., 2007). Collaborative interdisciplinary research generated by computer scientists, educators, designers and others should be engaged in order to develop e-learning systems (Vrasidas, 2004). The impact of pedagogy is also important to web-based education and distance learning. The pedagogical design of web-based distance education courses is critical to the success of the learner (Boulton, 2002). Considering the approach of this research, pedagogy is an essential part since it underlies the proposed competence-based system with its emphasis on supporting learners to achieve their intended learning outcomes.

2.3 E-Learning Transaction

E-Learning transaction (Figure 2-1) refers to the lowest unit of analysis in learning and teaching (Gilbert & Gale, 2008). An e-learning transaction is a generalization and an abstraction from Laurillard's conversational model (Laurillard, 1993) which is a model that describes the learning and teaching environment in higher education. For higher level education, learning and teaching dialogue must take place at both a theoretical and a practical level (Laurillard, 1993). Laurillard's model illustrates that the interactions are explicit and these interactions are considered from the viewpoint of designing technology. For example, technology can involve the telling or imparting of knowledge to the learner in a narrative way (University of Manchester - Blackboard Training Resources 2009). This is to help learners to find huge volumes of materials or information which will affect their learning outcomes.

An e-learning transaction (Figure 2-1) has a purpose which is its intended learning outcome. The purpose indicates the objective of the e-learning development, including the use of any learning materials or teaching assets.

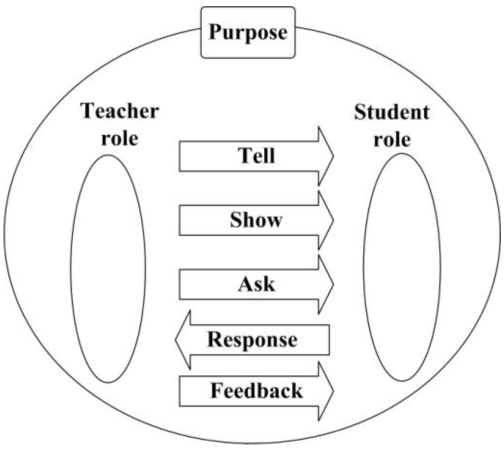


Figure 2-1: *E-Learning Transaction (Gilbert & Gale, 2008)*

An ideal e-learning system should incorporate the fuller use of an e-learning transaction. The intended learning outcome (ILO), which is an important part of the pedagogical design of the system, is used. Consideration of the transaction will aid the analysis and design of learning and teaching situations. Considering this transaction helps the teachers, designers, and developers to focus on providing effective transactions for learning rather than on simple information transmission (Gilbert, Sim, & Wang, 2005). This transaction emphasizes the learning objective or purpose which is an integral component of an e-learning (Gilbert & Gale, 2008), assessment, and feedback system (Whitelock, Gilbert, & Gale, 2011). E-learning transactions are considered in this research because the purpose or intended learning is a major part of a competency model and the 'tell' part in this transaction refers to the design feature of a competence-based system.

Only two parts of the e-learning transaction are considered in this research. First is the 'purpose' or intended learning outcome which is incorporated in the competency model (to be discussed in Chapter 3). Second is 'tell' which refers to the provision of information to the learner. A third part of the e-learning transaction is 'show' which refers to an elaboration of the information provided, usually by examples (Gilbert, et al., 2005). In recommending study material links to learners, however, only the 'tell' of an e-learning transaction is instantiated. While study material links might contain a video demonstrating an object or showing information about it, and thus comprise a 'show', this is not a designed aspect of the competence-based system to be implemented.

2.4 Intended Learning Outcome

The main discussion in this section is the intended learning outcome, also known as the educational objective, which is a component of the e-learning transaction (Figure 2-1). The learning outcomes describe what learners need to be able to do to complete the course satisfactorily (Macdonald, 1999). An intended learning outcome has long been a central component in the design and structure of educational or training systems, particularly in schools and in industrial training (Gagne, Wager, Golas, & Keller, 2004; Reigeluth, 1999). The point of indicating learning outcomes is to identify how to ascertain whether the students do understand, appreciate or see in a new way (Laurillard, 1993). In addition, clear expectation on the part of students which is noted by an intended learning outcome, is a vital part of students' effective learning (Ramsden, 1992).

The definitions of an intended learning outcome in the literature are similar. However, they have different approaches to levelling and analysing the learning outcomes. Macdonald (1999) suggested the use of SOLO (Structure of the Observed Learning Outcome) (Biggs & Collis, 1982) for levelling learning outcomes, which ranged from irrelevance or incompetence to expertise. On the other hand, this approach represents a generic framework rather than describing differences in understanding a specific topic. And then, Gagne, Wager, Golas, and Keller (2004) identify nine levels of skill and propose a learned capability to be used within these levels.

In this research, an intended learning outcome is considered based upon COMBA competency model (Sitthisak, et al., 2008). The intended learning outcome comprises two key elements: a statement of the topic, domain content or subject matter, and a statement of the learner's capability with respect to such subject matter. The composition of the intended learning outcome can be viewed as in Figure 2-2.

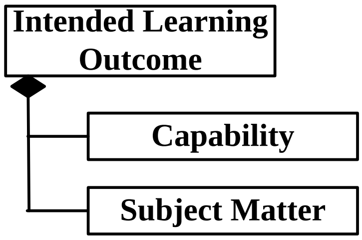


Figure 2-2: *Composition of Intended Learning Outcome Which is Abstracted From COMBA Model Proposed By Sitthisak, Gilbert, and Davis (2008)*

2.4.1 Subject Matter Content Categories

Subject matter is normally categorized into four fields based on Merrill's analysis (Merrill, 1994). They are: fact, concept, procedure and principles. A specific technical definition of each category is provided in Table 2-1 (Gilbert & Gale, 2008).

Table 2-1: *Definition of CDT Categories of Subject Matter (Gilbert & Gale, 2008)*

CDT Categories	Definition
Fact	Fact pair
Concept	Name of concept Superordinate concept class Attribute-value pairs that classify objects
Procedure	Name of procedure used in situation to achieve a goal via a set of steps using tools
Principle	Name of principle applied in situation involves cause-effect relationships between objects or events.

Understanding the categories of subject matter content facilitates this research to classify a knowledge domain of subject matter in the form of study materials which will be provided to a learner. The task analysis of the subject matter content will be discussed later. Task analysis in instructional design is a process of analyzing and expressing the nature of learning content so that a learner knows how to perform (knows what to do) (Jonassen, Tessmer, & Hannum, 1998). The objective is to represent the nature of subject matter content in the form of a diagram which is based on CDT categories. In this research each element in a fact pair is represented as a circle as shown in Figure 2-3.

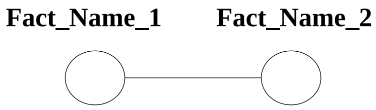


Figure 2-3: *Overview of Task Analysis of a Fact Pair*

A concept is represented as a triangle. There are attribute-value pairs associated with a concept. These attribute-value pairs are facts. An overview of the task analysis of a concept is shown in Figure 2-4. There are three relationships which connect each shape in a task analysis of the concept: 'is a kind of' links a concept and its superordinate class; 'where' connects a concept with its attribute-value pairs: 'value' pairs up two fact values which are combined as one attribute.

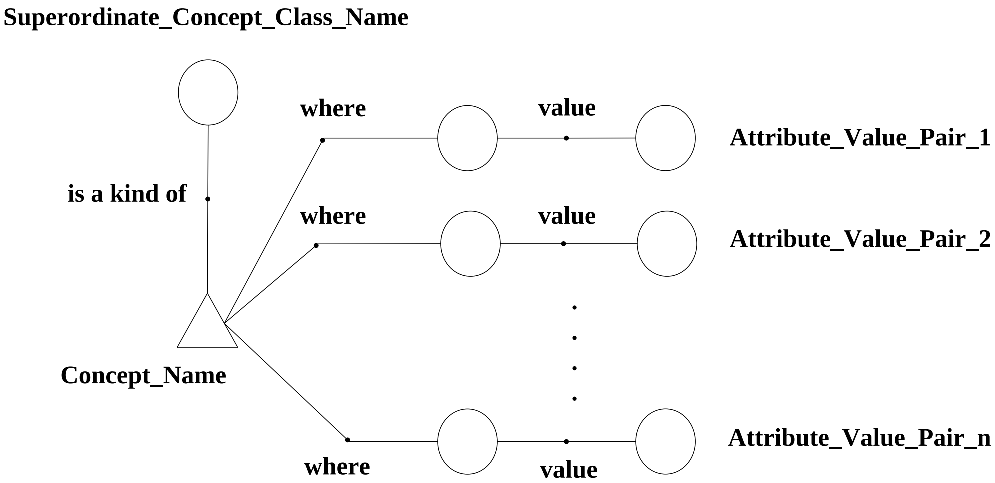


Figure 2-4: *Overview of Task Analysis of Concept*

Procedure contains a set of steps which are represented as squares. An overview representation of procedure is shown in Figure 2-5.

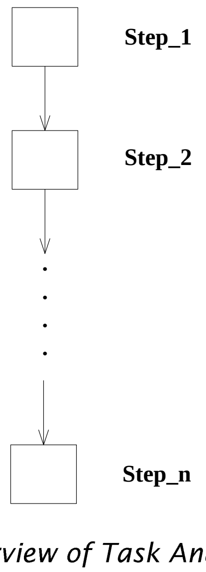


Figure 2-5: *Overview of Task Analysis of Procedure*

Principle involves cause and effect relationships. The principle is represented as a pentagon. Causes are facts which are shown on the left-hand side of the pentagon. The right-hand side shows the effects which are also facts. An overview representation of the task analysis of the principle is shown in Figure 2-6.

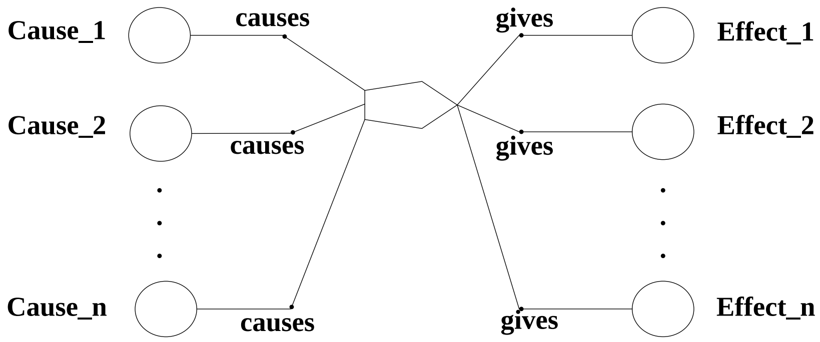


Figure 2-6: *Overview of Task Analysis of Principle*

2.4.2 Capability Categories

The e-learning objective or what is meant by the intended learning outcome, can generally be expressed in the statement "The learner will be able to X where X is a performance" (Gilbert & Gale, 2008). This performance refers to the ability or capability that is associated with the idea postulated by Bloom (Bloom, 1956) and Mager (Mager, 1997). Bloom's taxonomy is known for the classification of different educational objectives. There are three categorized domains: cognitive (knowledge), affective (attitude) and psychomotor (skills). The cognitive domain (Bloom, 1956) involves knowledge and the development of intellectual skills. The affective domain (Krathwohl, 1964) involves the manner in which one deals with things emotionally, for example, feelings, values, motivation and attitudes. The psychomotor domain (Simpson, 1972) includes physical movement, coordination, and use of the motor skill areas. The focus of this research will be on the cognitive domain since most traditional education tends to emphasize the skills in this domain. Taxonomy in the cognitive domain contains six major categories: know, comprehend, apply, analyze, evaluate, and synthesize. Table 2-2 summarises an explanation and the keywords or verbs for each category of the revised Bloom's taxonomy for capability in the cognitive domain (L. W. Anderson, et al., 2000).

Table 2-2: *Description, Example of Verbs of Bloom's Taxonomy of Capability in Cognitive Domain (L. W. Anderson, et al., 2000; Chapman, 2009; Dalton & Smith, 1986; Gilbert & Gale, 2008)*

Category/Level	**Description**	**Capability Verbs**
Know	Exhibit memory of previously-learned materials by recalling facts, terms, basic concepts and answers.	Name, label, define, state, recognise, list, recall, identify
Comprehend	Demonstrate understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions, and stating main ideas.	Explain, classify, summarise, extrapolate, interpret, convert
Apply	Use new knowledge. Solve problems to new situations by applying acquired knowledge, facts, techniques and rules in a different way.	Calculate, solve, construct, use, prepare, predict, demonstrate
Analyze	Examine and break information into parts by identifying motives or causes. Make inferences and find evidence to support generalizations.	Compare, contrast, infer, explain
Evaluate	Present and defend opinions by making judgments about information, validity of ideas or quality of work based on a set of criteria	Appraise, argue, evaluate, criticise, assess, discriminate
Synthesize	Compile information together in a different way by combining elements in a new pattern or proposing alternative solutions	Compose, originate, design, create

2.5 Summary

This chapter has reviewed a pedagogical approach and has focused on its importance in the design of an education technology or system for learners. The important issues such as learning and teaching activities, whose purpose or intended learning outcome is an e-learning transaction, have been highlighted. An ideal e-learning system should be developed, based on such a transaction. However, only two parts ('tell' and 'show') are considered in this research. A consideration of the intended learning outcome is also important. It identifies what learners need to be able to do to complete the course satisfactorily. In this research, learning outcomes are considered based upon the

COMBA model's (Sitthisak, et al., 2008) definition of an intended learning outcome, which takes the form of capability and subject matter. Bloom's taxonomy (Bloom, 1956) and Merrill's analysis (Merrill, 1994) are considered for the classification of capability and subject matter, respectively. An intended learning outcome is a part of the competency model under consideration. This model will be introduced in the next chapter.

Chapter 3
Competency Model

3.1 Introduction

The previous chapter focused on a pedagogy issue. This chapter introduces a competency model which is based upon intended learning outcomes. This chapter gives a definition of competency and then provides examples of existing competency models. There is a discussion of the competency model considered in this research and its benefits for a pedagogical approach. The competence structure is then applied to represent the network or structure of learner competences.

3.2 Definition of Competency

The word 'competency' refers to the ability to do a particular activity to a prescribed standard (Smith, 1996). The standard definition of competency given in the documentation of competencies (measurable characteristics) by the HR-XML consortium (HR-XML, 2004) is:

"specific, identifiable, definable, and measurable knowledge, skill, ability and/or other deployment-related characteristic (e.g. attitude, behaviour, physical ability) which a human resource may possess and which is necessary for, or material to, the performance of an activity within a specific business context."

There are other definitions of competency in the literature. One of these definitions was given by McClelland (1973), "competency can be the knowledge, skills, traits, attitudes, self-concepts, values, or motives related to job performance or important life outcomes." Friesen and Anderson (2004) defined a competency as "the integrated application of knowledge, skills, values, experience, contacts, external knowledge resources and tools to solve a problem, to perform an activity or to handle a situation." Cheetham and Chivers (2005) suggested the following general definition of competence: "effective overall performance within an occupation, which may range from the basic level of proficiency through the highest levels of excellence."

From the examples of definitions of competency and competence given, it can be seen that they are quite different in implications and classifications. Some literature suggests there should be a distinction between the term 'competence' and 'competency' (Coi, et al., 2007; Prins, et al., 2008). Prins et al. (2008) noted that "competence is given a generic or holistic meaning and refers to a person's overall capability whereas competency refers to specific capabilities or skills". However, for this research, both ‘competence’ and ‘competency’ are considered equivalent in definition. The word ‘competence’ is found in ‘competence structure’ and ‘learner competence’. The word ‘competency’ is found in ‘competency model’.

The concept of competence has been associated with an education system (Stoof, Martens, & van Merriënboer, 2007) and professional development (Eraut, 1994). In professional development, competences are considered as criteria for selecting the most appropriate available person for a given task (Eraut, 1994). In the education system, competence could be used to describe final attainment levels of educational programmes (Stoof, et al., 2007).

3.3 Existing Competency Models

There are existing competency standards, for example IMS RDCEO (IMS RDCEO, 2002) and HR-XML (HR-XML, 2004). Their data models are minimalist but extensible to defining competencies or learning objectives.

IMS RDCEO provides five elements in the information model: identifier, title, description, definition and metadata. However, there are some disadvantages to this competency model, such as the oversimplification of the concept of competency and the lack of provision for an adequate semantic level to support intelligent decisions; it does not take into consideration explicitly important elements such as the knowledge and skills of learners (Baldiris, Fabregat, & Santos, 2007). Nor, in addition to this, does it support a common language of competency.

HR-XML consortium’s competency schema has nine components: name, description, required, competencyId, TaxonomyId, CompetencyEvidence, CompetencyWeight, Competency and userArea. HR-XML competency can refer to knowledge, skill, ability, attitude, behaviour or a physical ability. In terms of its implementation, its aim is to be used by different people within different disciplines such as human resources management, industrial psychology and education.

A discussion of these two competency standards is given by Sampson and Fytros (2008). The discussion introduces some drawbacks to these competency standards, such as the titles and descriptor elements in these models not being directly machine understandable. Moreover, both standards adopt a competence description but do not take a proficiency level into consideration, although it is important to the competency concept (Sampson & Fytros, 2008). They proposed their competency model as shown in Figure 3-1.

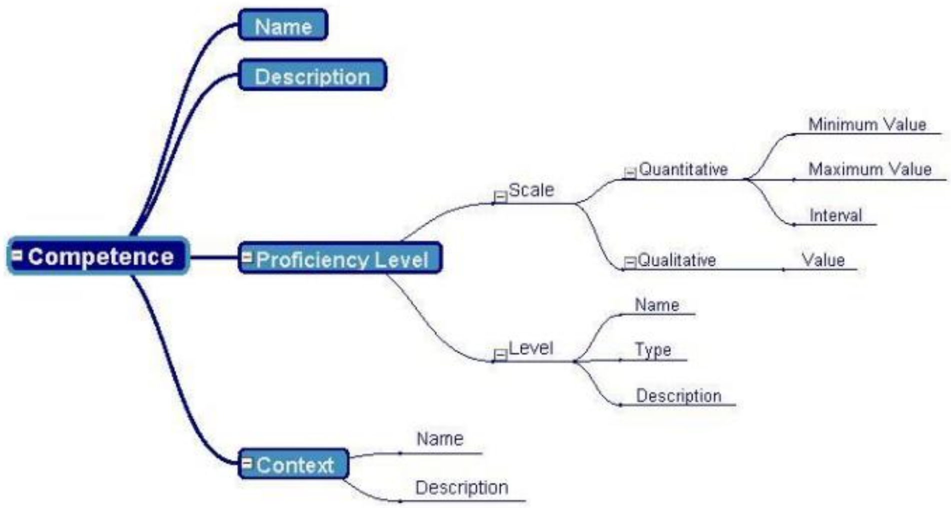


Figure 3-1: *Competency Model Elements (Sampson & Fytros, 2008)*

The proficiency level in this competency model refers to skills, knowledge, and attitudes. However, the meaning of proficiency is still vague. It can be either skills or knowledge. This is incompatible with considering an intended learning outcome as a combination of capability (skill) and subject matter (knowledge).

3.3.1 COMBA Competency Model

The proposed model for this research draws on the multidimensional competency model (called COMBA) proposed by Sitthisak, Gilbert and Davis (2008). This considers the learners' learnt capability instead of their knowledge level and views competences and learnt capabilities as a multidimensional space (Sitthisak, et al., 2008). The COMBA model (Figure 3-2) consists of three major components: subject matter, capability, and context.

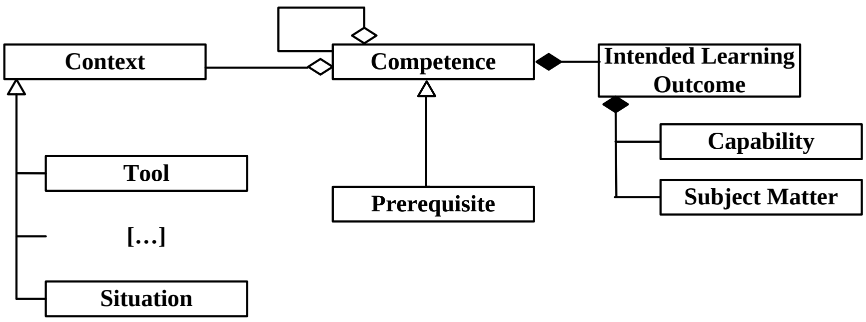


Figure 3-2: *Competency Model Derived From COMBA model Proposed By Sitthisak, Gilbert, and Davis (2008)*

3.3.2 Pedagogical Approach to the COMBA Competency Model

The consideration of pedagogy is essential to this thesis because it underlies the proposed system with its emphasis on supporting individual learners to achieve their intended learning outcome. From Figure 3-2, it is obvious that the COMBA model incorporates the intended learning outcomes which can be formally described as the combination of ‘capability’ and ‘subject matter’. Hence the COMBA model supports the pedagogical approach to the learning transaction.

In addition, the COMBA model incorporates the idea of ‘context’ when characterizing a competence. Learners may have differing levels of competence in a given intended learning outcome, depending on the context of their performance. A typical example of the profound importance of context can be seen during medical training, where a doctor might be being taught how to undertake an appendectomy. One context might be a well-equipped operating theatre in a major hospital; another might be in a tourist aeroplane cruising at 10,000 meters above the middle of the Pacific.

Importantly, the COMBA model gives consistency in recording the learner’s level of performance, since these levels are usually carefully specified in terms of the learner’s capability and in terms of the context in which the performance is to be demonstrated. The implementation of such a competency model in the proposed system concentrates on the learner’s capability and not on his/her ‘knowledge level’, which is difficult to properly characterize or estimate in the absence of an associated learner capability or context.

Consistency in recording the learner’s level of competency leads to significant advantages in using the proposed system for lifelong learning, particularly when coupled with the ability of the competency model to be rendered in an interoperable form, for example by using COMBA extensions to IMS RDCEO or HR-XML. Such a system allows the learner to use the system at any time throughout his or her life, and learners with different competence levels can obtain materials tailored according to their own competences without the need to restart from the same competence level again.

3.3.3 This Research Approach to the COMBA Competency Model

Apart from the pedagogical benefits of a COMBA competency model as mentioned in section 3.3.2, there are three main reasons why a COMBA competency model should be considered in this study.

First is the issue of a machine-processable, sharable, and modifiable representation of learner competence. Each individual learner’s competences have been clearly defined with a competency model. From each element of a learner’s competence, he or she can be connected to a prerequisite (or parent-child) relationship and formed as a structure.

Second is the navigation of a competence structure or network. In this research, this is done by identifying different ways of suggesting study material links from the Web, based on a learner’s competence. Navigating the structure offers various routes for providing learners with study material links to enable them to achieve a learning outcome.

The third issue is the identified context of a learner's competence. As stated previously in section 3.3.2, the context is considered when characterizing a competence. Learners may have differing levels of proficiency in relation to a given intended learning outcome, depending upon the types of context. The defined context of a competence distinguishes the competence from the intended learning outcome.

3.4 Competence Structure

The competence structure specifies the range of competence elements/nodes for a particular knowledge domain and highlights the relationship between competence nodes. Each node must comprise capability and subject matter. In this case, the competence node can also refer to an intended learning outcome node. When each node comprises capability, subject matter, and context, this node can be referred to exclusively as a competence node. Considering a competence structure in this study, makes it possible not only to identify the relationships between learner's competences, but also to navigate through a structure. It gives the learner a variety of routes for obtaining study material links in order to achieve a learning outcome.

3.4.1 Benefit of a Competence Structure

A competence structure has a benefit. The design of a competence structure enables it to be conducted by one person. The process of designing a competence structure is understandable. The structure can be embedded within the system and used by many learners for learning the same knowledge domain. However, since the competence structure should be constructed or designed by the developer not a teacher, the developer should be an expert in the specific knowledge domain in order to construct the structure of the competence elements properly. Otherwise the developer may require consultation with an expert in the knowledge domain before building a competence structure. A possible solution to the problem of constructing a competence structure could be to use the existing competence structure (if any) to develop a competence structure from existing knowledge (or subject matter) structures.

3.4.2 Samples Structures of Competence

Competence structure can be represented in several data structures such as tree structure, graph, concept map, and so on. Each competence node represents one competence which is the combination of capability, subject matter, and context. Some competence nodes may be composed of only capability and subject matter. In such a case, these competences can refer to intended learning outcomes. There are some existing competence structures. One sample is a tree of nursing competencies from the UK Royal College of Nursing introduced by Sitthisak, Gilbert, and Davis (2009). This competence structure is shown in Figure 3-3. The relationship between nodes is parent-child with no ordering on the same level. A parent-child relationship identifies what the learner must be able to do before something else can be learned. The nodes in this structure are all intended learning outcome nodes, which are independent of the context. Some competence nodes in this structure, for example C11, C12 and C10, are in a shaded area called 'prerequisite'. One competence node (C22) is a common competence node of the C20 and D competence nodes. The relationships between competence nodes are 'enabling' relationships. For example, in order to do 'A' learners should be able to do 'D'.

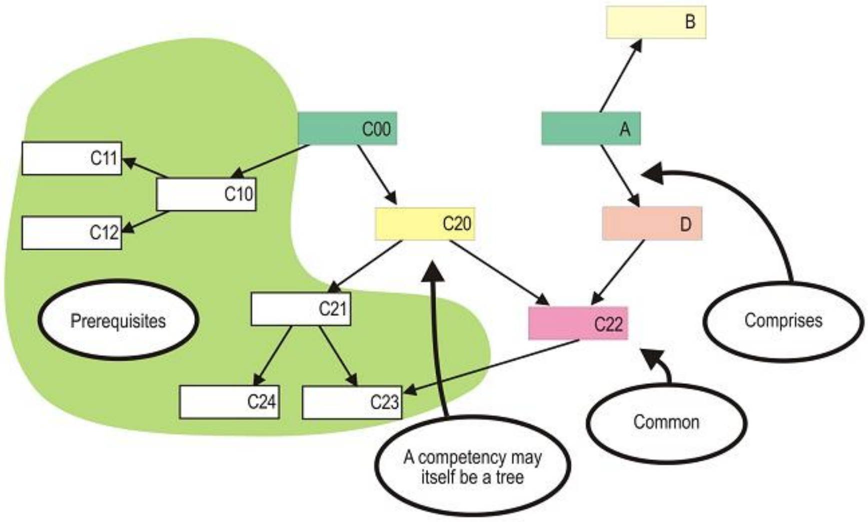


Figure 3-3: *Nursing Competency Tree from the UK Royal College of Nursing (Sitthisak, et al., 2009)*

Another competence structure was developed by Iskandar, Gilbert, and Wills (2010). This competence structure is shown in Figure 3-4. Similar to the competence structure in Figure 3-3, the nodes in Figure 3-4 are also all intended learning outcome nodes, which are independent of the context. There are three types of relationship: optional, required and precedence. Here, a 'required' relationship is similar to an 'enabling' relationship in Figure 3-3.

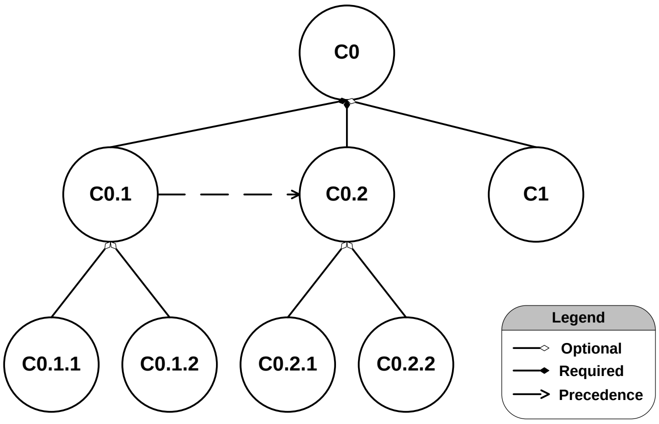


Figure 3-4: *Conceptual Model of Learning Outcomes in the Motor Skill Domain (P Iskandar, et al., 2010)*

In this research, the sizes of competence structures are categorized as: small, medium, and large. Small competence structures contain 1 to 20 competence nodes. Medium competence structures contain 20 to 100 competence nodes. Large competence structures contain more than 100 competence nodes. The size of the two examples of competence structure given (Figure 3-3 and Figure 3-4) is small.

Apart from these two competence structures, there are other competence structures which were designed from different aspects of competence. One competence structure was developed by Kickmeier-Rust, Albert, and Steiner (2006) as shown in Figure 3-5. One node represents a competence state which is a set of all available competencies of a person. The prerequisite relationships are defined within this set of competencies. Each competency in a state represents a problem or subject matter which a learner is required to solve.

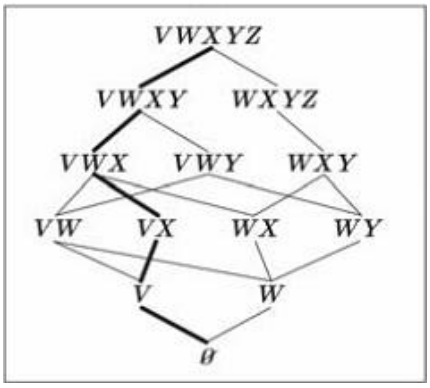


Figure 3-5: *Competence Structure Established by the Prerequisite Function (Kickmeier-Rust, et al., 2006)*

Another competence structure was proposed by Heller, Steiner, Hockemeyer, and Albert (2006). However, this structure represents a competence-based knowledge structure. It is extended from a knowledge structure as is shown in Figure 3-6. They introduced two other sets of learning objects (LOs) and related skills for solving problems corresponding to each node within the structure. Nonetheless, this structure is based on the knowledge-based representation.

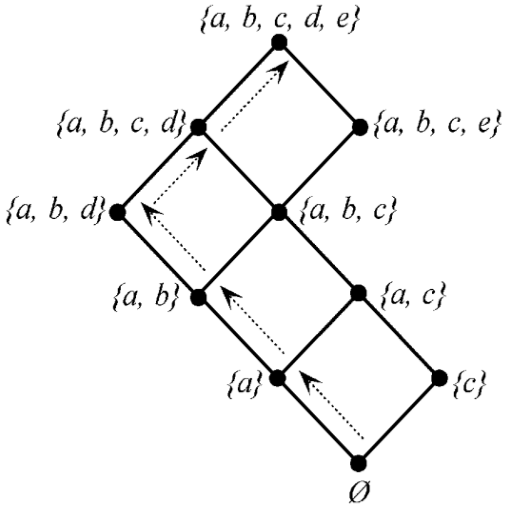


Figure 3-6: *Overview of Knowledge Structure of Domain Q = "a, b, c, d ,e" (Heller, et al., 2006)*

Unlike the competence structures in Figure 3-3 and Figure 3-4, each node of the competence structures in Figure 3-5 and Figure 3-6 represents a competence state comprising competencies. Here, a competency represents a problem-solving ability or an action verb, for example, stating the Pythagorean Theorem. The competencies are implicitly intended learning outcomes. There is no consideration of the context of the competencies. The relationships between competence states are prerequisite relationships (or parent-child relationships). This type of relationship is similar to an enabling relationship in Figure 3-3 and the 'required' relationship in Figure 3-4. However, these relationships are represented as straight lines without arrows. The traversal of the competence structure is from bottom to top of the competence state. The learning paths are represented as bold lines in Figure 3-5 and arrow lines in Figure 3-6.

Another representation of competences was introduced by Albert, Hockemeyer, Mayer, and Steiner (2007). This structure is represented in Figure 3-8. Its design is considered in terms of structures of defined concepts and actions as shown in Figure 3-7. The concept refers to the structural information of the proposed networks. Actions refer to the behaviours which are structured as hierarchical. They also suggest the adoption of Bloom's taxonomy (Bloom, 1956) for utilizing the taxonomies of learning activities. Each node of the competence structure contains a set of concepts and corresponding actions with a prerequisite relation.

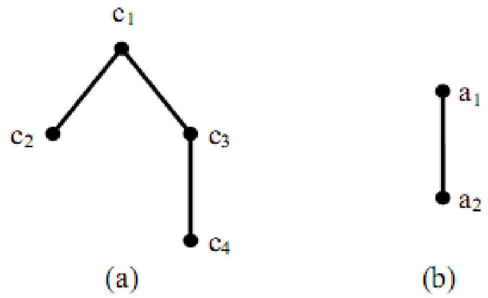


Figure 3-7: *Structure Defined (a) Set of Concepts and (b) Set of Actions (Albert, et al., 2007)*

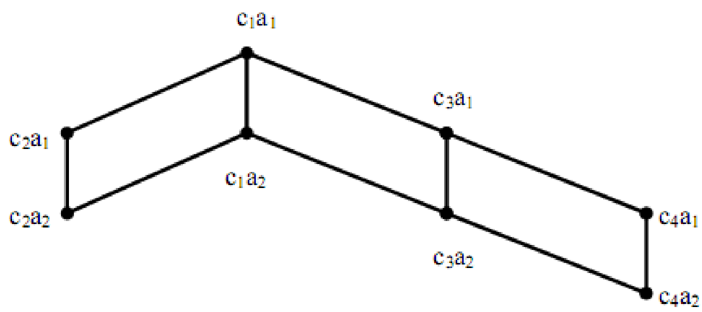


Figure 3-8: *Prerequisite Relation on the Skills Induced by the Structure in Figure 3-7*

The competence structure in Figure 3-8 was designed using the two structures of defined concepts and actions. A competence node is a combination of concept and action. The relationships between competence nodes are the prerequisite relation, which implicitly refers to the 'enabling' relationship in Figure 3-3, and the 'required' relationship in Figure 3-4.

In this research, the competence structures were developed in a similar way to the competence structures in Figure 3-3 and Figure 3-4. The nodes in a competence structure are called 'competence' nodes, which comprise capability, subject matter and context. However, some competence nodes may be composed of only capability and subject matter. Competence states are not considered in this research since they make it difficult to traverse a structure. Traversing between competence states in the structure is not only required but traversing between competencies in each state is also needed. It is easier to traverse from a competence node to another node where the nodes have only one competence.

The relationships in the competence structure in this research should be explicit. They are the parent-child relationships (or enabling relationships) and are represented as arrows, which point to the child competence nodes. This is to indicate that learners should master the child nodes before the parent nodes. Samples of competence structures constructed in this research are given in Chapter 6 (Figure 6-7 and Figure 6-13).

3.5 Summary

The consideration of a competency model is important to this research because a competence describes the ability of a learner in a certain situation or specific context and it supports a pedagogical approach. There are some drawbacks found in existing competence standards, for example, they are not directly machine processable, and the proficiency meaning is merely implied. In this research, we consider a COMBA competency model. The learner's competences have been clearly defined and there is a structure of competences. In other words, the competence elements are represented as a structure. Furthermore, existing competence structures exhibit the following problems: the competences are neither contextualised nor clearly defined and there is no clear representation of relationships between competences. The next chapter will review the different languages of knowledge representation and will discuss the approach of using them to represent a competence structure so that it can be machine processable, sharable and modifiable.

Chapter 4
Knowledge Representation

4.1 Introduction

The competence structure is discussed in Chapter 3. Implementing a competence structure in a way that makes it machine processable, sharable, and modifiable, requires a consideration of knowledge representation. This chapter provides an overview of knowledge representation. What follows is a discussion of each language used for representing knowledge on the Web and its approach in representing a competence structure.

4.2 Overview of Knowledge Representation (KR)

Knowledge Representation (KR) is a study of representing knowledge in explicit symbols. This tends to share the knowledge less ambiguously. This issue becomes important when machines start to be applied to facilitate knowledge management (Guarino, 1995). The definition of knowledge representation can be couched in different ways. Sowa (2000) defined a knowledge representation as "a multidisciplinary subject that applies theories from three fields: logic, ontology, and computation." Logic identifies the formal structure and rules of inference. Ontology refers to the kinds of things that exist in the application domain. Computation enables the applications to distinguish KR from pure philosophy.

Another notion of knowledge representation was claimed by Levesque (1986): "this is simply dealing with writing down, in some language or communicative medium, descriptions or pictures that correspond to a state of the world." However, there is still significant disagreement among researchers about many of the most fundamental issues of the current presentation scheme. The reason of this is that KR has evolved from a number of research areas (Levesque, 1986) for example, psychology, linguistics, philosophy, and logic. Levesque (1986) also suggested two major properties of forming the knowledge:

1. It must be possible to interpret KR propositionally, that is as expressions in a language with a true theory.
2. The system should act in such as way as to match the presence of the structures.

There are some related works which adopted KR techniques within an e-learning research area. Melis, Budenbender, Goguadze, Libbrecht, and Ullrich (2003) proposed ACTIVEMATH which is an open Web-based learning environment for mathematics. In this research, KR is considered to represent a content structure of mathematical learning documents. It uses the knowledge representation OMDoc (Kohlhase, 2000) which is an extension of the OpenMath XML-standard. It contains a grammar representation of mathematical objects and sets of standardised symbols (the content dictionaries). One study was conducted by Marshall et al. (2003). They proposed GetSmart which is a tool to allow individuals to create and share knowledge. Users can construct concept maps and synthesise their ideas into personal knowledge representations. In this study, XML format is applied to enhance modularity for concept map sharing. Another approach by Mendes, Martinez and Sacks (2002) is the use of a fuzzy clustering algorithm and TopicMaps to discover and represent knowledge. The relationships between learning materials are identified by fuzzy clustering and later used within adaptive link documents. TopicMaps is a tool for modelling and managing knowledge structures which are in the form of XML documents.

In view of the association of knowledge representation with this research, the way to represent the structure of competence requires an understanding of knowledge representation. The focused concepts of KR in this research are XML-based knowledge and the Semantic Web which are those of the recent developments in KR. The idea is to allow the content on the Web (competence structure in this case) to be both machine processable and humanly understandable.

4.2.1 The Semantic Web

The Semantic Web is an extended version of the Web as introduced by Tim Berners-Lee (Berners-Lee, Hendler, & Lassila, 2001). The notion of the Semantic Web generally implies a web of data (Halpin, et al., 2009) which can be managed by a structure that is reusable and sharable across many applications. The information within the Semantic Web is in the form of well-defined meanings with common formats and this helps computers and people to achieve better cooperation (Berners-Lee, et al., 2001). There are two things that the Semantic Web provides: common formats for integrations and combinations of data drawn from heterogeneous sources (Halpin, et al., 2009).

The understandable pattern of the Semantic Web is an essential feature, hence the knowledge representation of data within the web is necessarily considered. Currently there are some languages which are well known such as XML (Bray & Paoli, 1999), RDF (Klyne & Carroll, 2004), and OWL (McGuinness & Harmelen, 2004). W3C Semantic Web Activity (Halpin, et al., 2009) proposed the layers of the Semantic Web as in Figure 4-1. The Semantic Web layer cake shows the layering of the current state of the art and future planned standards (Sure & Studer, 2005).

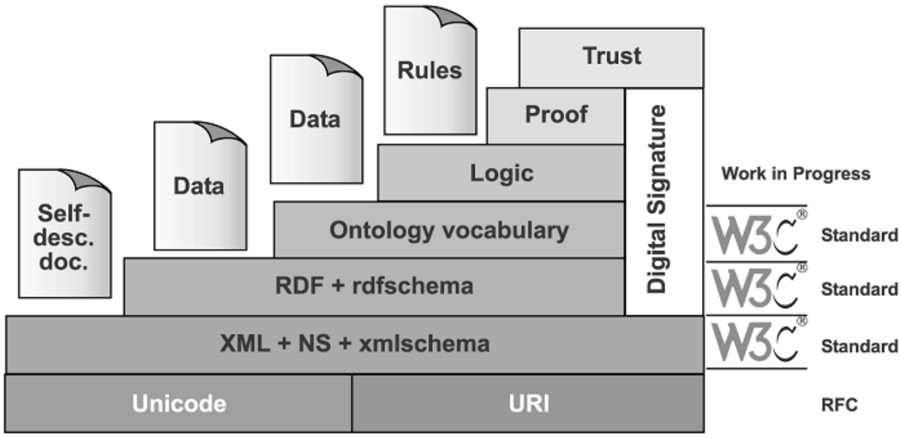


Figure 4-1: *Semantic Layer Cake (Halpin, et al., 2009)*

In many respects, the Semantic Web is employed within an e-learning area for example, representing concept and ontology in an adaptive Web-based educational system (Vasilakos, Devedzic, Kinshuk, & Pedrycz, 2004), integrating the educational systems and content providers (Devedzic, 2003), authoring educational content and instructional processes (Aroyo & Dicheva, 2004), and authoring the adaptation and personalisation (Dicheva, Aroyo, & Cristea, 2003). The adoption of Semantic Web in education can be referred to the Educational Semantic Web. Anderson and Whitelock (2004) described three fundamental affordances of the Semantic Web to educational contexts as: an information storage and retrieval, agent-based augmentation thereof, and communication. One of techniques of information storage and retrieval is Latent Semantic Analysis (Landauer, Foltz, & Laham, 1998). It allows us to closely approximate the similarity between human judgments on the meaning of words. The FRAMES project (Whitelock, 2006) is another study which uses this technique to assist the monitoring of support from tutor to student in the essay assessment process. However, this technique requires the corpus of data and its related information which are not relevant to this research. Instead, the focus is on the techniques of representing knowledge of competence structure.

In this research, three representations are considered: XML, RDF, and Web Ontology Language (OWL). The overview of each representation and a discussion of the approach to representing a competence structure are explained in sections 4.3, 4.4, 4.5.

4.3 XML (Extensible Markup Language) and XML-Schema

XML is a meta-markup language used to manage data which employs user-customized tags to organize information (Bray & Paoli, 1999; Dick, 1999). XML is an application profile or restricted form of SGML, the Standard Generalized Markup Language (Bray & Paoli, 1999). XML documents consist of storage units called entities which contain either parsed or unparsed data. There are some goals in designing XML which are established in XML 1.0 specification (Bray & Paoli, 1999):

- XML shall be straightforwardly usable over the internet.
- XML shall support a wide variety of applications.
- XML documents should be humanly legible and reasonably clear.
- XML documents shall be easy to create.

There are related specifications (Bray & Paoli, 1999), for example:

- XML Namespaces (Bray, Hollander, Layman, Tobin, & Thompton, 2009) provide a method of avoiding element name conflicts when XML documents are mixed.
- XPath (Clark & DeRose, 1999) is used to define path expressions to navigate in XML documents.
- XSLT (Clark, 1999) is used when an XML document is transformed into HTML.
- XML Validation gives well-formed XML documents and correct XML syntax.

In this research, XML validation is considered in order to give a well-formed XML document of competence structure. Such designed XML validation allows the developers to store information on competence structures, information such as capability, subject matter, context, task analysis of capability, and task analysis of subject matter of any knowledge domains with the same elements and attributes. DTD and XML-schema are the XML validation types. DTD was developed first and a later development was XML-schema (Ioannides, 2000). XML-schema is considered since it is more powerful than DTD in describing XML documents, uses a rich data type, and uses an XML-based format which can be processed by ordinary XML tools.

4.3.1 XML-Schema

When designing XML documents, it is important to consider an XML-schema. The schema defines the terms, relationships and constraints required to support communication in a particular application domain (Carlson, 2001). All schemas provide some degree of definition and documentation for an XML vocabulary. The definitions are useful both to system integration specialists (who are writing applications that process document instances of the vocabulary) and to Web application specialists (who are developing stylesheets for transforming and presenting the XML content). There are several reasons to create an XML-schema (Carlson, 2001):

- Defining and documenting the vocabulary for all users
- Validating documents when using XML parsers
- Giving structural guidance to content providers using XML authoring tools
- Providing default attribute values, enumerated lists and identifier declarations
- Defining new application or domain-specific data types

4.3.2 XML Representation of Competence Structure

In this research, there are some advantages of applying XML to represent the structure of competence. Firstly, the structure of competence is designed, based on the intended learning outcomes of a particular subject domain; normally this information is represented as the text file. The benefit of XML is that it is understandable to both machines and humans, which means that anyone can easily modify the content of the XML file. It is easier for developers to locate and fix errors. Secondly, this is the reusability issue; the content of a competence structure can be changed for future use, based on different knowledge domains. This allows the developers to reuse the XML file again. Thirdly, XML gives the flexibility of language which allows the creation of custom data structures and organizational systems. Hence the design of an XML file of competence structure becomes easy and inexpensive. Fourthly, XML has an advantage over traditional databases (RDBMs). XML structures data like a tree, while traditional databases are all two-dimensional and rely on relations to describe data that does not fit into the structure (Obasanjo, 2001).

4.4 RDF (Resource Description Framework)

The Resource Description Framework (RDF) is a general-purpose language for representing information on the Web (Beckett, 2004). There are three main concepts for designing RDF: resource, property, and statement. Briefly explained, RDF is a resource consisting of any Webpages that can be identified with a URI. It is based on the idea of making statements about resources. The following are some features of RDF (Beckett, 2004).

- Independence: anyone can create properties.
- Interchange: any RDF file can be converted to XML.
- Scalability: RDFs are simple three-part records.
- Properties, values and statements can be resources and include metadata created by other people and organisations.

RDF represents data on the Web in the form of a directed, labeled graph. SPARQL (Prud'hommeaux & Seaborne, 2008) is a language to query across the wide range of RDF information on the Web. SPARQL contains capabilities for querying required and optional graph patterns, and returning the result sets as RDF graphs (Prud'hommeaux & Seaborne, 2008).

XML is only a surface syntax for structured documents and imposes explicit semantic constraints on the meaning of these documents. Comparison of RDF and XML based on a semantic Web approach, RDF should be better than XML since we can parse the set of triples and then we can use the ones we want and ignore the one we do not understand (Berners-Lee, 1998). The reason is we can create a data model for objects (or resources) and relations among them including providing a simple semantic for the data model which can be represented in XML syntax (Berners-Lee, 1998).

Considering an approach that represents competence structure using RDF, RDF seems to be a better approach than XML. The reason for this is that the relationships between subject matters in task analysis can be represented as the property within RDF language. For example, the relationship 'value' of attribute-value pairs of a concept can be explicitly identified with RDF, whereas, the relationships in task analysis cannot be represented by using XML language.

4.5 Web Ontology Language

The definition of ontology given in section 4.2 indicates that ontology refers to the kinds of things that exist in the application domain. An ontology can also be defined as an explicit specification of a conceptualization (Gruber, 1993). This specification represents vocabulary for a shared domain of discourse such as: definition of classes, relations, functions, and other objects. OWL is a Web ontology language which is designed for use by applications which process the content of information instead of just presenting information to humans (McGuinness & Harmelen, 2004). OWL gives a better machine interpretability of Web content than that supported by XML and RDF since OWL provides additional vocabulary along with formal semantics (McGuinness & Harmelen, 2004).

OWL is the most recent development of standard ontology languages from the World Wide Web Consortium (W3C). OWL has advantages over XML and RDF since it contains more vocabulary for describing property and classes such as relations between classes and cardinality like disjointness, exactly one, equality and enumerated classes.

There are three sublanguages of OWL: OWL-Lite, OWL-DL, and OWL-Full (Horridge, Knublauch, Rector, Stevens, & Wroe, 2004). OWL-Lite is the simplest sublanguage. It is considered when the ontology contains only a simple class hierarchy and constraints. OWL-DL supports more expressiveness within classes than OWL-Lite. However, there are some restrictions with OWL-DL; for example, a class may be a subclass of many classes; a class cannot be an instance of another class (McGuinness & Harmelen, 2004). OWL-Full is the most expressive OWL. It is considered when high expressiveness is more important than the guarantee of decidability or computational completeness of the language (Horridge, 2009). OWL-Lite cannot be used to test automated reasoning.

With reference to the approach of designing a competence structure in an ontological form, there are still some limitations regarding task analysis of subject matters. Some relations within task analysis may not be applicable in the ontology design, for example, 'where', 'is a kind of', and 'value'. To explain, 'is a kind of' implicitly indicates that one class is a subclass of another class. Hence 'is a kind of' still cannot be defined within the ontology design. 'Value' can be used for two purposes: object property or data-type property with ontology design. Object properties link an individual to an individual and data-type properties link an individual to an XML-schema data-type value or an rdf literal (Horridge, 2009). A definition of 'value' as a property in ontology design remains vague. 'Where' cannot be represented as anything (class, property, or instance).

4.6 Discussion of Considered Languages

The limitations of designing a competence structure in an ontological form are discussed in section 4.5. Hence XML and RDF are considered as approaches to representing a structure of competence. When RDF and XML based on a Semantic Web approach are compared, RDF should be better than XML. The reasons for this are mentioned in section 4.4. The relationships between subject matters in task analysis can be explicitly represented in RDF. However, this research aims to propose a competence-based system for suggesting study material links based on a learner's competences. There is a process within a system which is considered, based on the structure of competence. The competence structure is modifiable and depends on different knowledge domains of subject matter content. Hence a semantic approach is important for this research. The relations within task analysis of subject matter can be defined in RDF but not in XML. However, the focused part of this research is to get the keywords from learner's competences (capability + subject matter + context) and we assume that the relations in task analysis of subject matter will not affect the search results from a search engine. Hence the structure of competence in XML form is sufficient for generating the keywords from the learner's competences.

4.7 Summary

This chapter gives an account of the literature on knowledge representation and a related discussion of representing competence structure, based upon different representations. Applying knowledge representation allows the competence structure to be machine processable, sharable, and modifiable. The semantic standards considered are XML, RDF, and Web Ontology Language. There are some limitations to representing a competence structure in ontological form, for example the vague definition of some properties within an ontology structure. As a result, the competence structure could be represented, based on XML and RDF. RDF seems to be a better option since the relationships between subject matter within task analysis can be represented as properties in RDF. However, this research confines itself to representing a competence structure through XML. The reason for this is that the relationships in task analysis which can be defined in RDF but not in XML are not taken into account during the competence-based system process. The next chapter reviews different approaches to modelling the user in e-learning systems.

Chapter 5
User Modelling

5.1 Introduction

In Chapter 3, a considered competency model (COMBA) and competence structures were discussed. Here, the learner's competences are considered for use in modelling. However, most e-learning systems still have other methods of modelling users. These systems are designed, based on adaptive hypermedia (Bra, et al., 2003; Brusilovsky, 1996, 2001) and intelligent tutoring systems (J. R. Anderson, Boyle, & Reiser, 1985; Elsom-Cook, 1987). The current design of User Modelling – a component of AH and ITS – has been shown to have some problems. There are inconsistencies in estimating a learner's knowledge, lack of support for the ability or intended learning outcome of the learner, and an inadequate design that does not support lifelong learning. These problems arise from the system design that is based on traditional adaptive hypermedia user models. This chapter introduces notions of adaptive hypermedia and User Modelling including the drawbacks of User Modelling. In addition, it reviews an intelligent tutoring system (ITS) which is one kind of adaptive hypermedia system, and ITS limitations.

5.2 Overview of Adaptive Hypermedia and its Architecture

An adaptive hypermedia system (AHS) generates a model of the preferences, knowledge and goals of a user. An AHS tends to improve the usability of hypertext and hypermedia applications by personalizing these applications based on the constructed user modelling. In fact, there were some developments on AHS before its definition was proposed by Brusilovsky (1996). Examples of these systems are Lisp-Critic (Fischer, Mastaglio, Reeves, & Rieman, 1990), ANATOM-TUTOR (Beaumont, 1994), HYPERFLEX (Kaplan, Fenwick, & Chen, 1993), and ITEM/PG (Brusilovsky, Pesin, & Zyryanov, 1993).

The AHS can be used in the areas in which hypermedia is expected to be used by people with different knowledge and goals (Brusilovsky, 2001). One of those areas is the educational domain and this is known as adaptive educational hypermedia (AEH) (Brusilovsky, 1996, 2001). Adaptive educational hypermedia (AEH) is the application of adaptive hypermedia to the educational domain. There are some well-known AEH systems such as InterBook (Brusilovsky, Eklund, & Schwarz, 1998), AHA! (Bra, et al., 2003), ELM-ART (Brusilovsky, Schwarz, & Weber, 1996).

A good example of the architecture of AHS is given by Ohene-Djan, Gorle, Bailey, Wills, and Davis (2003). This indicates the commonalities among the models and components in adaptive hypermedia (AH) and this architecture is a standardized 'plug 'n' play' or reusable architecture for future AH development.

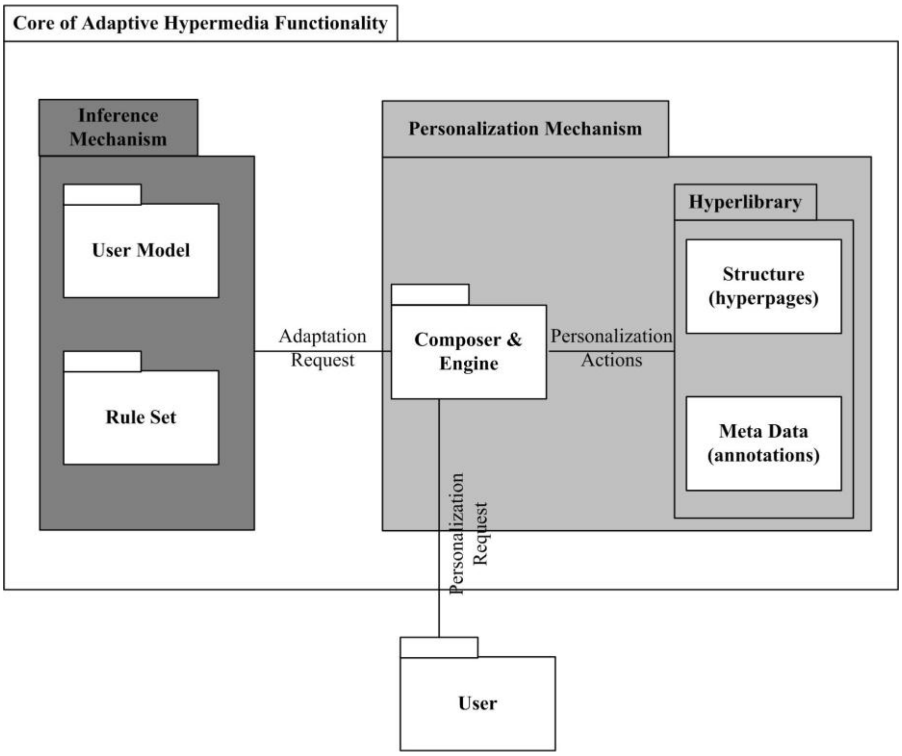


Figure 5-1: *Architecture of Adaptive Hypermedia (Ohene-Djan, et al., 2003)*

In Figure 5-1, two main components of the architecture can be seen: personalization and inference mechanism. The personalisation mechanism deals with the functionalities of user-initiated tailoring, while the inference mechanism covers the additional functionalities of system-initiated tailoring. This research focuses on user modelling within the inference mechanism component. However there are different techniques for adaptation, such as adaptive presentation and adaptive navigation support (Brusilovsky, 1996). The idea of adaptive presentation is to adapt the content of the page or interface accessed by a particular user, based on designed user modelling. Adaptive navigation support techniques help users to find their paths in hyperspace by adapting the ways of presenting links to a particular user, based on designed user modelling (Brusilovsky, 1996). Adaptive systems use the benefits of user models in order to adapt their content and navigational possibilities to the particular user.

5.3 User Modelling in an Adaptive Hypermedia System

The user model in adaptive hypermedia is one of the important components of adaptive hypermedia architecture. The User Model is known historically as a user profile and is also known as a student model in the Intelligent Tutoring System (ITS) (Polson & Richardson, 1988). The user model represents the level of individual users' knowledge and behaviour and this level affects their learning and performance (Kavcic, 2000). Adaptive systems use the benefits of user models in order to adapt their contents and navigational possibilities to the particular user. There are six popular fields: the user's knowledge, interests, goals, background, individual traits and context of work (Brusilovsky & Millán, 2007). Whereas, for many years, the focus has been on the first five fields, the context of the user's work is a relatively new research direction within AHS. The user's knowledge normally refers to the subject being taught or the domain represented. It focuses on the subject-based information rather than the learner's intended learning outcomes. User interests refer to personal interests for example, personal style. A goal (or task) represents the immediate purpose for a user's work within the adaptive system and focuses more on the subject matter. The user's background describes the set of features related to the user's previous experience, for example, the user's profession, job and work experience. 'Individual traits' is the aggregate name for user features that together define a user as an individual, for example, personality traits (introvert/extravert) (Brusilovsky & Millán, 2007). The context can be viewed as user location, physical environment, social context and affective state (Brusilovsky & Millán, 2007). Of the six fields for modelling users, none of them refers to competency or competence (or the intended learning outcome incorporated within the context).

User models are generally divided into two main categories which are the overlay and stereotype models (Cannataro & Pugliese, 2004). In terms of overlay modelling, the user's state of knowledge is described as a division of the expert's knowledge in that domain (Kavcic, 2000). The user is described through a set of attribute-value pairs where values are quantitative, such as percentage, or qualitative such as 'good' and 'excellent'. Overlay models are powerful and flexible; they can represent a user's knowledge of individual topics. But overlay models have a problem of initialization (Wu, 2002). An overlay model requires a fixed set of attribute-value pairs. It is very hard to identify values for all users when new values are found (Brusilovsky, 1996).

Stereotype user modelling attempts to cluster all possible users of an AHS into several groups. All users in the same stereotype will be treated with the same adaptation techniques (Brusilovsky & Millán, 2007). A stereotype user modelling approach categorizes the users into stereotypes (such as novice, intermediate, advanced, or expert) or a group of users that have a common characteristics or attributes (Cannataro & Pugliese, 2004). Stereotype user modelling is a simpler model and is much easier to maintain (Brusilovsky, 1996). However, a stereotype model is less powerful than an overlay model and most of the efficient adaptation techniques are only applicable with an overlay model.

5.4 Comparison Chart of Adaptive Hypermedia System (AHS)

As stated above, some adaptive hypermedia systems (AHS) lack support for the capabilities of users wishing achieve their intended learning outcomes. Table 5-1 shows the overall results and the comparison of some features relating to the notion of competency. The comparison chart is not intended to illustrate the drawbacks of user modelling. Explanations of such drawbacks are described in section 5.5.

Table 5-1: *Comparison Chart of AH Systems*

Features / Systems	User Model	Competency		Feedback (Automatically generates the feedback to the user)	Feedback (Allows interaction between teacher and learner)
		Prerequisite (Consider the required level of learner)	Support the aspect of capability of learner to achieve intended learning outcome		
InterBook (Brusilovsky, et al., 1998)	Overlay and stereotype	No (*)	No	No	Yes
ELM-ART (Brusilovsky, et al., 1996)	Overlay and stereotype	No (*)	No	No	No
AHA! (Bra, et al., 2003)	Overlay	No (*)	No	No	Yes
PUSH (Höök, et al., 1996)	Overlay and stereotype	No (*)	No	No	No
ADAPTS (Brusilovsky & Cooper, 1999)	Multi-aspect overlay user model	No (*)	No	Yes	No
Intelligent Tutoring system (Contreras, et al., 2007)	Not mentioned (In the paper, they represente d a user model as learner model)	No (*)	No	Yes	No

(*)Although it is not explicitly mentioned in the paper reference, it is likely that this model does not support the prerequisite level of learning.

Table 5-1 compares selected adaptive hypermedia systems in terms of their support for learner competences and in the provision of learning feedback. It is obvious that none of the systems support the aspect of the capability of the learner to achieve his/her intended learning outcome. It is also clear that a learner can use the systems without pre-setting the prerequisite or required level of learning. Some systems, such as InterBook and AHA!, allow interaction with the teacher through feedback. The intelligent tutoring system and ADAPTS give the learners feedback automatically. However, none of the systems provide feedback which enhances the ability of users or the users' competences after they use the system. To explain this problem, the systems do not update their user models when the learner has already achieved the previous competence. For example, if the users are beginners then they may get some feedback based on the level of beginners again when they return to the system – instead of getting feedback that presumes a higher/an improved level of competence.

5.5 Drawbacks of User Modelling

This section discusses the drawbacks of user modelling, in general. Kobsa (1993) discusses the application of user modelling and makes the point that the user modelling components draw mostly on assumptions about the user, which may not necessarily be correct. User modelling therefore inherently involves the risk of misunderstandings. In addition, the authoring process of creating the user model is difficult since this is a complex task, good models of users are deficient and there are no standardized approaches to adaptive techniques in the system.

Sitthisak, Gilbert, and Davis (2007), highlighted similar problems for adaptive assessment, for example the inconsistency of adaptive assessment systems in estimating a learner's knowledge level. Another problem is the issue of supporting lifelong learning in adaptive assessment systems since there are difficulties in updating rules, content and assessment within these systems. To briefly explain this problem, the scenario of a learner using AHS can be considered. Let us imagine the learner starts with a desire to gain a new or improved competence. The AHS provides the relevant study materials and the learner ideally gains that competence. If the same learner uses the system again in order to gain another competence, the user modelling in AHS typically does not provide materials which are as relevant to the next competence. This is because it does not know that the learner has completed the previous competence. In other words, when the learner reuses the adaptive system, it does not update its user model. In addition, the estimate of a learner's knowledge in current user models does not readily render it compatible with an interoperable format and this in turn leads to problems supporting lifelong learning.

There is also a problem of generalization with the overlay model and the less powerful stereotype model, which are described in section 5.3. Moreover, the six fields for modelling users (a user's knowledge, interests, goals, background, individual traits and work context) normally do not refer to a learner's competences or intended learning outcomes, which are important to the pedagogical design of e-learning systems. Hence, the current user modelling in AHS does not suit the requirement for the design of the system in this research. This system is designed to recommend study material links to learners based on their competences (or learning outcomes), which are not included in the six fields for modelling users. In addition, there are limitations over the current techniques for modelling a user (overlay and stereotype).

5.6 Intelligent Tutoring System and its Limitations

Section 5.2 gives the details of adaptive hypermedia and its architecture. There is one kind of system called an intelligent tutoring system which is designed, based on the idea of adaptive hypermedia approach. An intelligent tutoring system is designed to reduce teachers' tasks. However there are some limitations within this system, hence this section reviews the overview of an intelligent tutoring system and its limitations.

5.6.1 Overview of an Intelligent Tutoring System

An intelligent tutoring system is one kind of intelligent computer-assisted instruction (ICAI) which simulates understanding of the domain the system teaches, and can respond especially to the student's problem-solving strategies (J. R. Anderson, et al., 1985). The ITS system provides the student with the same instructional advantages that a sophisticated human tutor can provide. The design and development of ITS systems lie at the intersection of computer science, cognitive psychology and educational research (Nwana, 1990). Most ITS systems are designed the basis of on an artificial intelligent (AI) approach since they attempt to produce in a computer behaviour which, if performed by a human, would be described as 'intelligent' (Elsom-Cook, 1987). Intelligent tutoring system architecture consists of four modules (Wenger, 1987):

1. The interface module: graphical user interface or simulation of the task domain the learner is learning. This module is the communicating component of the ITS, which controls interaction between the student and the system.
2. The expert module: domain model or cognitive model containing a description of the expert knowledge. This module is designed by an expert.
3. The student module: the emerging knowledge and skill of the student.
4. The tutor module: teaching strategies which refer to the mismatching between a student's behaviour or knowledge and the expert's presumed behaviour or knowledge.

There are other architectures to be found in the literature but most of them are similar to these four modules, for example, Anderson, Boyle and Reiser (1985) replaced an expert model with the bug catalogue, which is an extensive library of common misconceptions and errors for the domain.

5.6.2 Examples of ITS Systems

This section reviews some examples of intelligent tutoring systems. Samples of these systems are chosen for this thesis because they are related to the principle of an ITS and provide a significant contribution to the ITS research area.

1. SCHOLAR

SCHOLAR is the first ITS to be constructed. It was an innovative system when considered in its historical context. SCHOLAR was created by Jaime Carbonell (1970). SCHOLAR was an early effort in the development of computer tutors capable of handling unanticipated student questions and of generating instructional material in varying levels of detail (Carbonell, 1970). The knowledge in the expert knowledge module is that of the geography of South America which was represented in a semantic network. SCHOLAR has not been widely used due to some fundamental limitations such as difficulty with representing procedural knowledge using semantic nets. However SCHOLAR introduces many methodological principles that have become central to ITS design, for example student modelling and separation of tutorial strategies from domain knowledge (Nwana, 1990).

2. GUIDON

GUIDON is an ITS for teaching diagnostic problem solving and it was developed by Clancey (1987). This project represents the first attempt to adapt a pre-existing expert system into an ITS. GUIDON's goal is to teach knowledge from the famous expert system, MYCIN (Shortliffe, 1976), a medical expert system that suggests treatment for bacterial infections. It attempts to transfer expertise to the students exclusively through case dialogues where a sick patient is described to the student in general terms (Clancey, 1987). Then the student is asked to assume the role of a physician and ask for the information he/she thinks might be relevant to the case. This project produced many important findings about designing ITSs. For example, it clearly demonstrated that an expert system is not a sound basis for tutoring (Elsom-Cook, 1987).

3. ELM-ART (an Intelligent Tutoring System on World Wide Web)

ELM-ART (Brusilovsky, et al., 1996) is an example of an ITS adapted to a WWW platform. It is used to support learning programming in Lisp. ELM-ART is developed from ELM-PE (Weber & Mollenberg, 1994), an Intelligent Learning Environment that supports example-based programming, advanced testing and debugging facilities. ELM-ART provides all the course materials in hypermedia form. It presents the materials to the students and helps them with learning and navigating the course materials. In addition, the student can investigate all examples and solve all problems on line. To support the student navigating through the course, the system uses two adaptive hypermedia techniques: adaptive annotation and adaptive sorting of links.

5.6.3 Limitations of an Intelligent Tutoring System

An intelligent tutoring system is an alternative way for the learner to obtain the learning materials without any intervention from another human being; however, there are some limitations to an intelligent tutoring system as follows:

1. ITS does not specify every interaction with the student, but only the general problem-solving principles from which these interactions can be generated (J. R. Anderson, et al., 1985).
2. The study materials are already well constructed. If the content or any information regarding knowledge changes, then the system requires updating.
3. An intelligent tutoring system is only as effective as the various models it relies on to adequately model expert, student and tutor knowledge and behaviour. Thus, building an ITS needs careful preparation in terms of describing the knowledge and possible behaviours of experts, students and tutors.
4. Most intelligent tutoring systems deal with an artificial intelligence (AI) hence there is a major problem of high development costs. Also, the response times of machines could be slow (Polson & Richardson, 1988). However it still reduces the overall costs by reducing the need for human instructors.
5. Many intelligent tutoring systems are developed and work on a specified platform (hardware dependency). It is necessary to port them to other platforms to solve the hardware dependency problem. Besides development costs, there are also migration costs (Okazaki, Watanabe, & Kondo, 1997).
6. The e-learning transaction (Gilbert & Gale, 2008) in Figure 2-1 includes the elements: 'purpose', 'tell', 'show', 'ask', 'response' and 'feedback'. Some ITS systems, such as the intelligent tutoring system (Contreras, et al., 2007) and ELM-ART (Brusilovsky, et al., 1996), provide sets of learning materials, questions and generate feedback for the learners. Thus, these systems incorporate all parts of an e-learning transaction, but their 'purpose' refers to the subject matter rather than an intended learning outcome. Other ITS systems, such as SCHOLAR (Carbonell, 1970) and GUIDON (Clancey, 1987), provide sets of questions and generate feedback for learners. Hence, only the 'purpose', 'ask', 'response' and 'feedback' parts are included in the designs of such systems, and the 'purpose' is considered based on the subject matter. As a result, ITS is not considered in this research since only the 'purpose' and 'tell' part are required and the 'purpose' should refer to the learner's competences or intended learning outcomes.

5.7 Other Issues

User control (or learner control) refers to the potential for a learner to direct the learning activities and decide when they want to learn (Bencomo, 2002). User control may be categorised into indirect and direct user control. Indirect user control is when the user has a small degree of control and must follow what the system provides (Kay, 2001). Such systems are AHS and ITS systems. Direct user control is when the user has more control. The system in this research is designed for direct user control, where learners can express their competences, and the system offers study material links based on these competences. Learners can decide whether the study materials are relevant and restart with other competences if necessary.

Metacognition refers to the knowledge and awareness of one's own cognitive processes and the ability to control those processes (Efklides & Vauras, 1999; Mayer, 1998). In the previous paragraph, it was explained that ITS systems support all parts of the e-learning transaction; consequently learners are able to monitor and control the use of these types of system on their own. However, learners sometimes do not plan their learning activities, fail to monitor their learning or manage their learning by engaging in help-seeking behaviour (Azevedo, 2002). Self-reflection occurs after each learning effort and normally involves self-judgement and self-evaluation (Zimmerman, 2002). Some ITS systems also support the 'ask' part, which provides assessments or tests after the learning has happened.

This research proposes a system for recommending study materials from the Web. The system is based upon a competency model and involves only two parts of the e-learning transaction ('purpose' and 'tell'). 'Purpose' refers to a learner's competences or intended learning outcomes. Links to study materials are provided to learners based on their competences. The system supports direct user control, where users (or learners) have a greater degree of control. Users can identify their learning outcomes and receive links for these outcomes. However, the system does not support metacognition and self-reflection. Other systems such as ITS systems do support metacognition and self-reflection, but none of them considers the intended learning outcomes.

5.8 Summary

This chapter reviews User Modelling of adaptive hypermedia (AH) and Intelligent Tutoring System (ITS) research areas. AH and ITS utilize their user models to adapt their content and navigational possibilities to particular users. However, there are some limitations to such user models, such as their inconsistency in estimating the level of learners' knowledge and the difficulty of constructing models which adhere to standardized adaptive techniques. As yet, none of the adaptive systems support the aspect of learners' capability to achieve intended learning outcomes. The problems with user modelling of AH and ITS have been presented in this chapter. The next chapter describes a requirement analysis, design of competence-based system, and method of constructing a competence structure from existing course learning outcomes.

Chapter 6
Analysis and Design of a Competence Structure and its Application

6.1 Introduction

The literature on pedagogy, competency model, knowledge representation, and user modelling has been reviewed in Chapter 2, Chapter 3, Chapter 4, and Chapter 5 respectively. This chapter discusses the analysis and design of a competence-based system which suggests appropriate study material links from the Web to individual learners based on their competences. This chapter begins with the requirement analysis. In this section, a use case diagram is provided. The following section illustrates the design of the system process which deals with learner competences and how this provides appropriate study materials as links from the Web to learners. The design also considers a competence structure appropriate to a particular knowledge domain including the competence node relationships. This structure of competence is an essential component within the system. In addition, this chapter also describes an instruction for constructing a competence structure from an existing course syllabus and its mapped XML-schema. The details are illustrated in this chapter.

6.2 Requirement Analysis

Section 6.2 on requirement analysis establishes the requirements for designing a competence-based system. In this section, the use case diagram is proposed to describe the learners and how they use the competence-based system. The use case diagram illustrates the functions, features, and services that are provided to the learners. Figure 6-1 shows the use case diagram of a competence-based system.

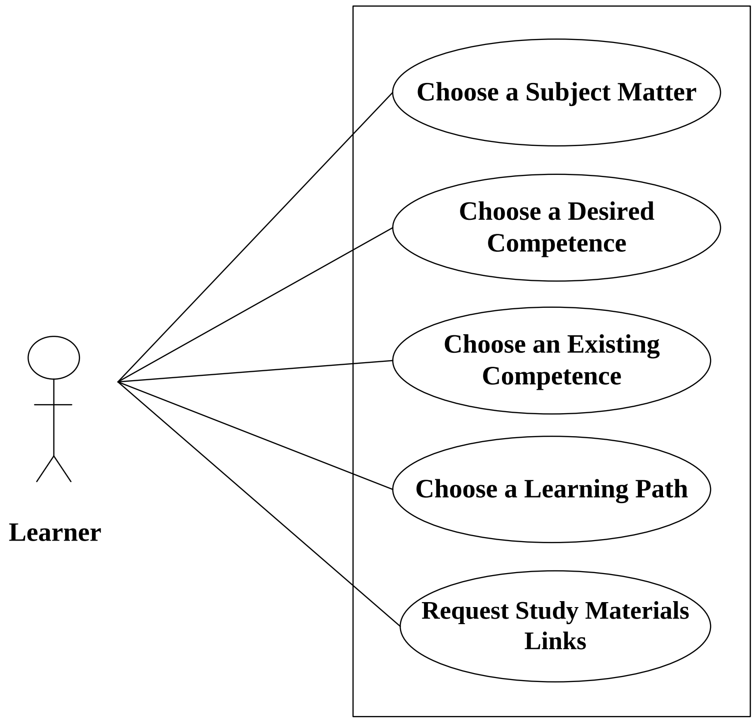


Figure 6-1: *Competence-Based System's Use Case Diagram*

There are five main functionalities which are provided to a learner:

- Choosing a subject matter
- Choosing a desired competence
- Choosing an existing competence
- Choosing a learning path
- Choosing study material links

For the initial step, a learner is required to choose a targeted subject matter and then follow with his/her competences. For this research, there are two kinds of learner competences: desired competence and existing competence. Desired competence refers to the intended competence which the learner wishes to gain. The current or existing competence is the estimate of the actual competence of the learner. From the chosen competences, a list of learning paths is generated for a learner. Once a learner chooses a learning path, he/she can request study material links based upon it.

Here, the study material links result from the search engine, given that the keywords are competences in a learning path. For example, a competence like 'define a common factor' is one of the competences in a chosen learning path. A competence-based system constructs search engine keywords such as 'define, 'common', and 'factor'. The links resulting from these keywords are study material links for obtaining a competence like 'define a common factor'. These links could be an online dictionary or Wikipedia, which explain the common factor definition. Figure 6-2 shows a screenshot of Google search results for the keywords 'define', 'common' and 'factor'. The first five top links are for an online dictionary, online mathematical lessons and an encyclopedia. Figure 6-3 shows a screenshot of a page of the first result link for the keywords ‘define’, ‘common’, and ‘factor’.

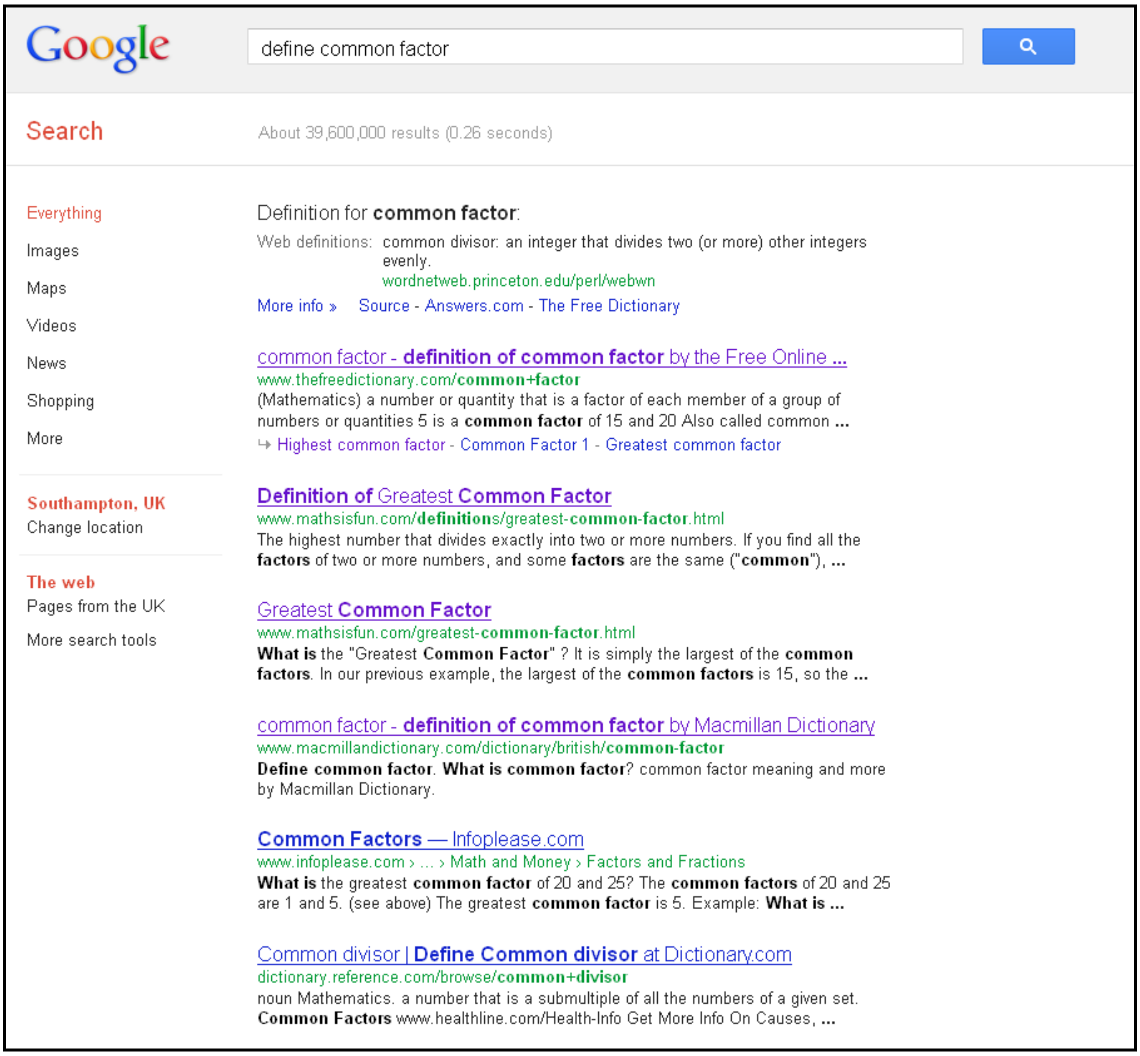


Figure 6-2: *Screenshot of Google Search Results for the Keywords ‘define’, ‘common’, and ‘factor’*

Figure 6-3: *Screenshot of a Page of the First Result Link for the Keywords 'define', 'common', and 'factor'*

6.3 Process within the System

The overview of the process within the system design, illustrated at Figure 6-4, shows how the system deals with learners' competences and how it recommends appropriate study material links from the Web to learners so that learners can achieve their intended learning outcomes. The process within the system is considered, based on the use case diagram shown in Figure 6-1.

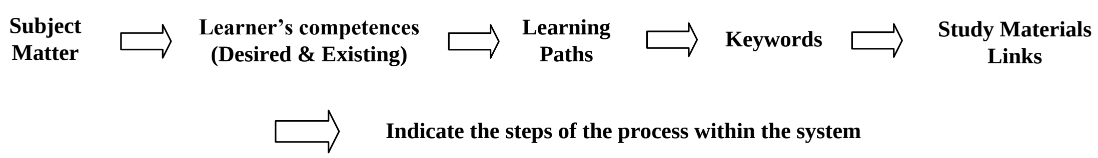


Figure 6-4: *Process within System*

First, a sub-process is required to construct a learner's competence structure (section 6.4) so that the system can generate lists of targeted subject matter and competences for learners to choose from. After the chosen subject matter and competences (desired and existing) are obtained, the system then generates a list of learning paths. The system constructs a Google search based on the chosen learning paths, and then suggests the resulting links to learners.

The reason for considering competence statements as the keywords for a search engine is explained as follows. The research statement "an approach to design a system that will enable a learner to find appropriate study materials from the Web without any interaction from a teacher" indicates that it is necessary to consider the method of obtaining information on the Web. Gordon and Pathak (1999) discussed four different methods for locating information on the Web:

1. Go directly to a webpage location.
2. Hypertext links emanating from a webpage provide built-in associations to other pages.
3. Narrowcast services can push pages that meet particular user profiles.
4. Use search engines to find and then furnish information on the Web that hopefully relates to that description.

As the learner's competences are the information (input) that the system obtains from the learners, so the system should recommend study materials based on these competences. The appropriate method is to use a search engine to find the study materials from competences search queries. There are many search engines, for example, Google, Bing, Yahoo, Alta Vista and Microsoft. The type of search engine is not considered as an important point in this research: the search engine is used merely as the intermediate tool to get relevant study materials, using the learners' competences.

In this research, Google is used as the search since it gives a high probability that the first result is relevant (Hawking, Craswell, Bailey, & Griffiths, 2001). In addition, Google offers the largest index, innovative new services and highly optimised performance and usability (Mayr & Tosques, 2005). Google uses the PageRank algorithm (Brin & Page, 1998) as the primary algorithm to find search results from the input query. Google's PageRank algorithm is an information retrieval method which uses a probability distribution to represent the likelihood that a person randomly clicking on links will arrive at any particular page (Thelwall, 2003).

Google has become a popular search engine based on the frequency of its use and the simplicity of its display of query results (Pan, et al., 2007). However, there is one argument against the limitation of PageRank algorithm. The suggestion is that PageRank is not effective for identifying the best webpages in a university system because of its domination by internal links (Thelwall, 2003). Normally Google search results can contain various kinds of webpages such as blogs, forums, electronic books and electronic files. While, some of these results could contain pages with academic purposes, others may contain internal links with non-academic purposes. However, we can still rely on Google since it is an effective way to gather all resources from the Web space which is related to the learner's competences.

6.4 Constructing a Competence Structure

Consideration of a competence structure is essential as this structure will be implemented within the system in order to specify the range of competence elements/nodes for a particular knowledge domain. The competence structure highlights the relationship between competence nodes and the competence gap nodes between desired and existing competence. In this research there are two designed competence structures based on two knowledge domains: mathematical highest common factor, and photosynthesis for Key Stage 4 learners. At the first stage, a competence structure of mathematical highest common factor (HCF) was designed. It is a simple or less complex structure. The relationships between competence nodes were located by the researcher with no consideration of the real course syllabus. Later, a better method of designing a competence structure was proposed. This was to investigate a more complicated and larger structure. The experience in designing a first competence structure (HCF) was informed within the developed method. The competence structure of photosynthesis for Key Stage 4 learners was then constructed by applying the proposed method.

6.4.1 Example of Simple Competence Structure

During the initial stage of structuring the competence elements of an HCF domain, different types of structures were considered, for example, a tree structure, a concept map, and a direct acyclic graph. A tree structure was the first to be considered. However, there is usually a root node in a tree structure, but the root node cannot be identified in this domain. Hence, the tree is not an appropriate competence structure for the HCF domain.

A concept map was the second consideration. The concepts are HCF, common factor and factor. These concepts need to be tagged with capabilities. The limitation of a concept map is that it is an undirected structure. Competences need a direction since the relationship between two competence nodes is an enabling relationship. A child competence must support a parent competence. Hence, the concept map is not an appropriate structure for competences.

A directed acyclic graph (DAG) was the third consideration – as shown in Figure 6-5. A DAG is a directed graph with no directed cycles (Handley, 1994). The graph consists of nodes connected by edges. A DAG is a useful representation of the structure of competences in the HCF domain. A DAG does not require a root node and this is important since none of the nodes C03, C02 or C01 can be chosen as the root node for the competence structure. In addition, a DAG is directed and this supports the nature of a competence structure where one competence enables another.

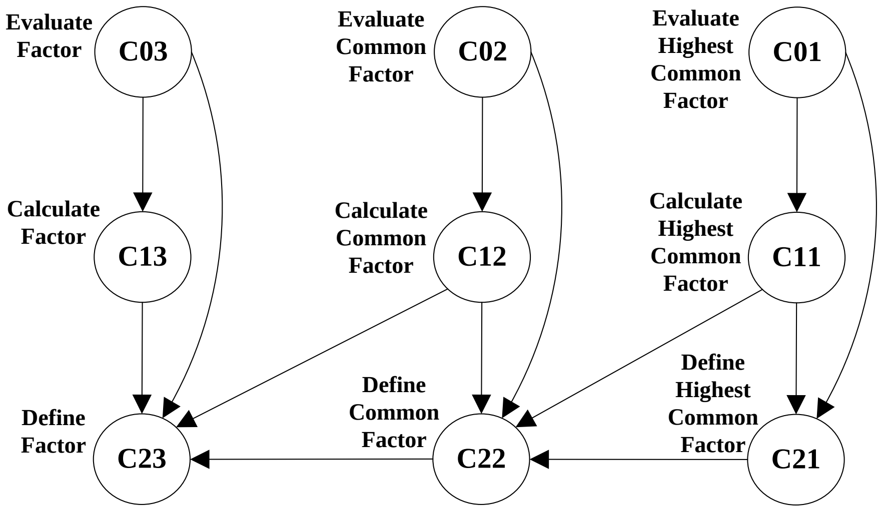


Figure 6-5: *DAG Competence Structure of Mathematical Highest Common Factor*

The size of this structure is small and it contains 9 competence nodes. There are three nodes that have no parents; these are nodes C03, C02 and C01. There is just the one leaf node, namely C23. To briefly explain the parent-child relationship between competence nodes, we can consider these examples. In order to achieve competence number C02, a learner must complete C12 and C22 beforehand. To attain C12, a learner must complete C23 and C22. To achieve C22, the learner must first achieve C23.

6.4.2 Method of Constructing a Competence Structure

In order to design a more complicated and larger structure of competence, such as a photosynthesis domain for Key Stage 4 learners, the information on intended learning outcomes for the specific subject matter content of a course is required. Then an analysis of their structure into a categorization of subject matter content is conducted and each subject matter content is tagged with a capability and a context in order to get a structure of competence.

6.4.3 Step1: Choosing Knowledge Domain

To construct a competence structure, we need to consider the intended learning outcomes of the knowledge domain. In this research, the available published intended learning outcomes in the UK education or national public syllabus, for example AQA, OCR, and Edexcel are considered. All intended learning outcomes of the photosynthesis domain at a Key Stage 4 (GCSE) from AQA - revised version (The Assessment and Qualifications Alliance, 2010) were chosen for constructing the competence structure. Full details of the intended learning outcomes can be found in Appendix A. Examples of considered intended learning outcomes are as follows:

- recall photosynthesis equation
- recall photosynthesis definition
- define chlorophyll

- interpret data showing how factors affect the rate of photosynthesis
- demonstrate a photosynthesis procedure
- predict the rate of photosynthesis in different conditions using computer simulations

6.4.4 Step2: Tasks Analysis of Subject Matters

Next, we summarise all the intended learning outcomes into a list of subject matter items. The first step is to consider the structure of the subject matter content in an e-learning system. This is undertaken by focusing on the broad understanding of the knowledge and cognitive skills of students, in order to achieve the goal. This is called in short 'subject matter content' and is normally categorized into four fields based on Merrill's analysis CDT (Merrill, 1994). For photosynthesis at Key Stage 4, the list of subject matters and their categorizations is provided in Table 6-1.

Table 6-1: *Considered Subject Matter Contents of Photosynthesis for Key Stage 4 Learners*

Subject Matter Type	Subject Matter
Fact	Photosynthesis equation, photosynthesis definition, substance, energy, sun, bulb, gas, CO_2, H_2O, O_2, plant cell, location, mesophyll cell, etc.
Concept	Chlorophyll, light, carbon dioxide, water, oxygen, chloroplast, etc.
Procedure	Photosynthesis procedure
Principle	Photosynthesis rate

Task analysis provides the relationships and structures of subject matter. At this stage, each type of subject matter is considered as a diagrammatic approach (Gilbert & Gale, 2008). Each category of subject matter has different notation representing its task analysis.

Fact can normally be represented by two elements which make a fact pair. Each element is represented as a circle. For example, the fact of 'Chemical formula of Carbon Dioxide is CO_2' is represented by a pair of two facts 'chemical formula' and 'CO_2' as shown in Figure 6-6.

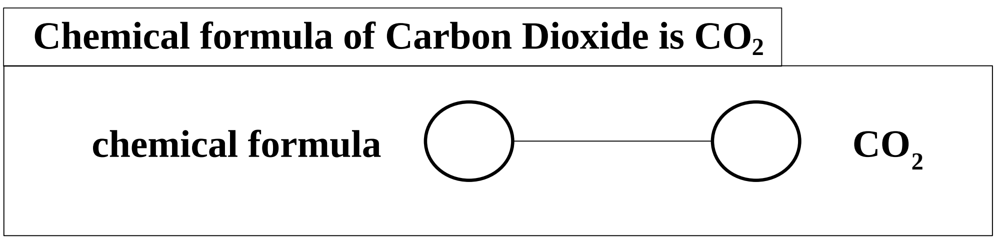


Figure 6-6: *Task Analysis of Fact 'Chemical formula of Carbon Dioxide is CO_2'*

Concept involves the concept name and its superordinate class which is normally a fact. The relationship between class and superordinate class is 'is a kind of'. Concept is represented as triangle. There are attribute-value pairs associated with a concept. For example, a concept of carbon dioxide is shown in Figure 6-7.

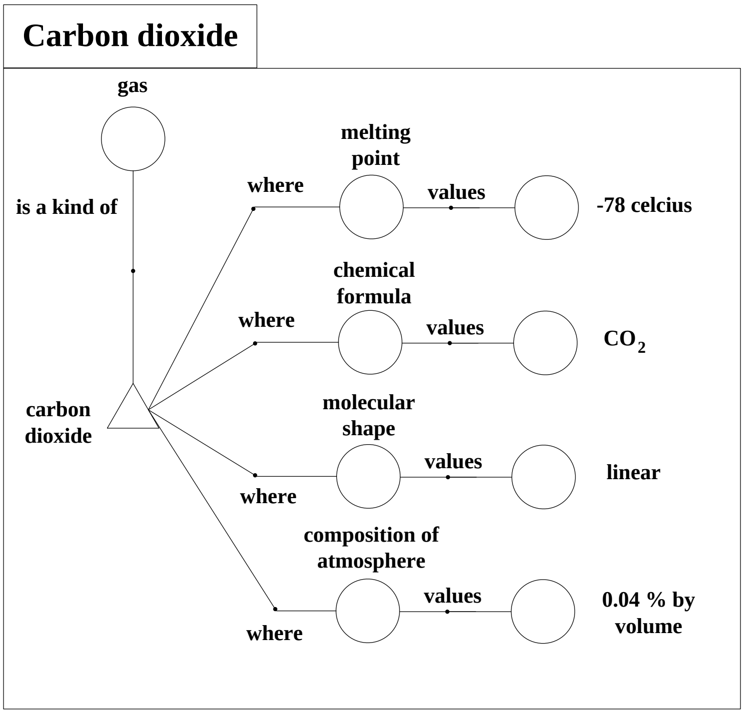


Figure 6-7: *Task Analysis of Concept of Carbon Dioxide*

Procedure consists of a set of steps. Each step is represented as a square. For example, the photosynthesis procedure is shown in Figure 6-8.

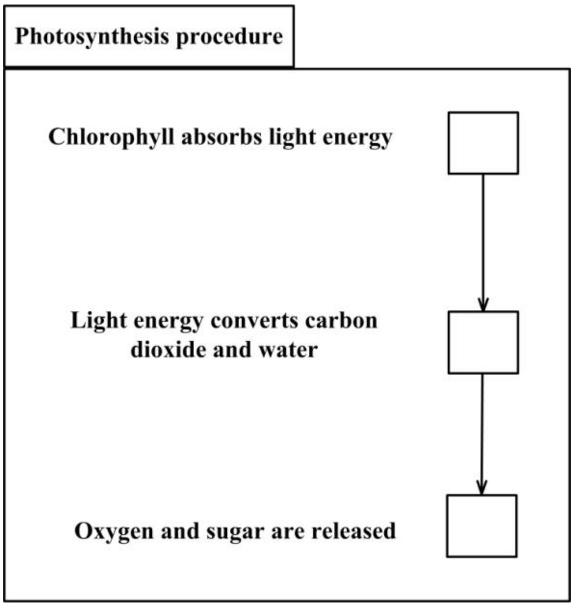


Figure 6-8: *Task Analysis of Photosynthesis Procedure*

Principle involves the specification of cause and effect. The principle itself is represented as a pentagon. For example, a principle of photosynthesis rate is shown in Figure 6-9. Causes are shown on the left side of pentagon and the right side shows the effect or result of the principle. Here, the set of causes and effect is the concept.

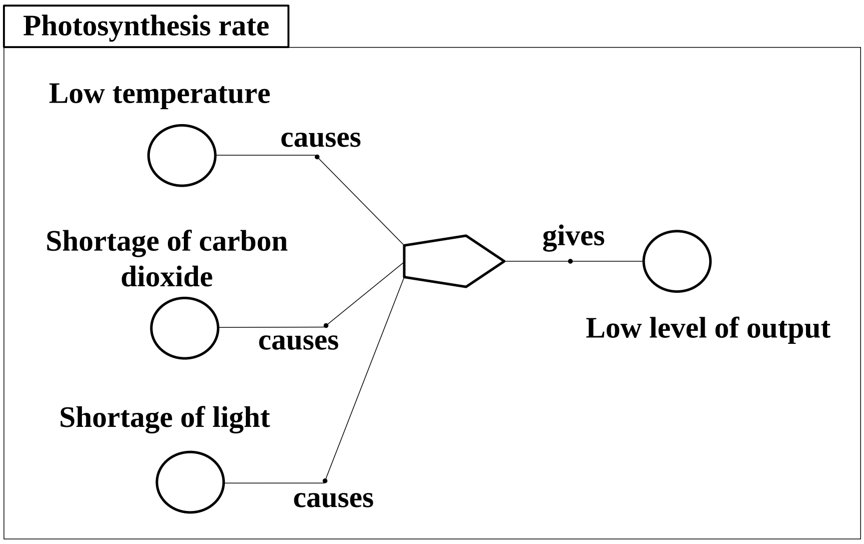


Figure 6-9: *Task Analysis of Principle of Photosynthesis Rate*

6.4.5 Step3: Decomposition Levels and Relationships of Designed Task Analysis

Task analysis of all subject matters is then levelled and the relationships are assigned. The number of levels depends on the knowledge domain. For this chosen knowledge domain, there are five levels of task analysis. The structure of all five levels can be obtained in Level 1 of task analysis which shows an overview of the above subject matters and their relationships. Levels 2, 3, and 4 show the detailed task analysis. The last level, level 5, contains only the fact values. Task analysis of five levels can be seen in Appendix B.

6.4.6 Step4: Structuring Subject Matters

During step 4, levels and relationships of designed task analysis are obtained. This information is considered. All subject matters are represented as one node, and structured. The same levels of task analysis of subject matters are in the same levels within the structure. The relationship between subject matter nodes is parent-child. An arrow points to a child node. The structure of subject matters is illustrated in Figure 6-10.

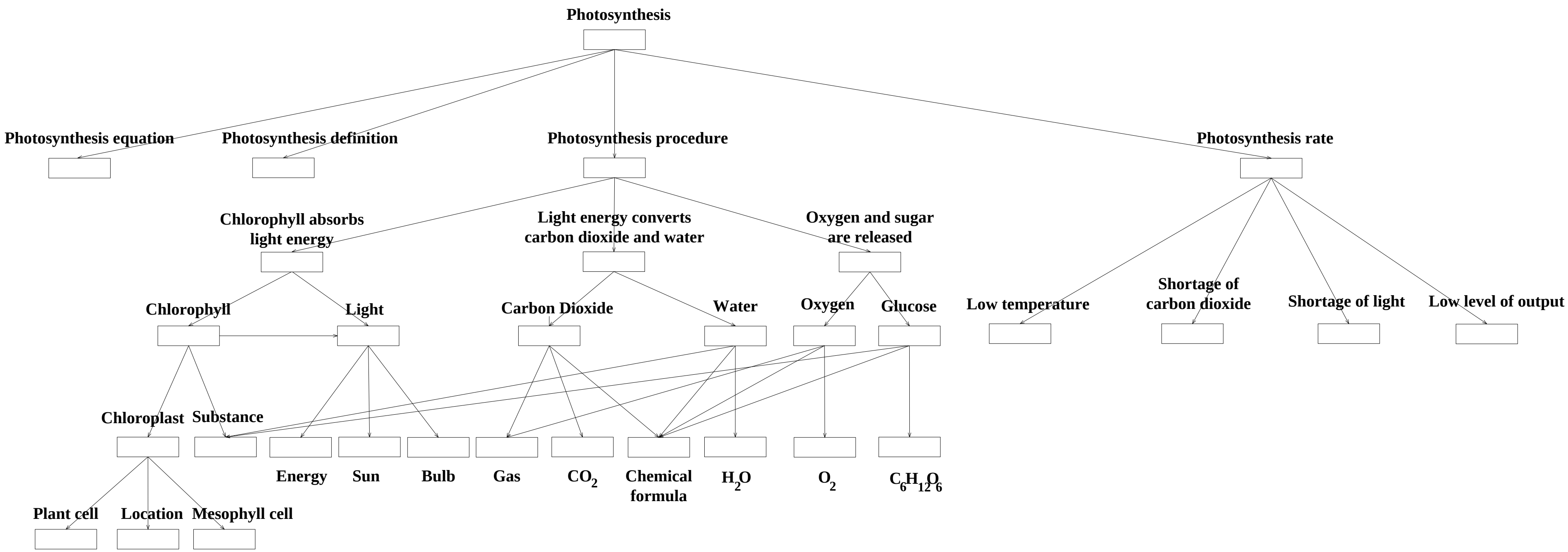


Figure 6-10: *Knowledge Structure of Photosynthesis for Key Stage 4 Learners*

6.4.7 Step5: Tagging Each Node with Capability and Context (Finalised Competence Structure)

The structure of subject matter is obtained in step 4. In this structure, one node represents only subject matter. In order to develop a structure of subject matter to a competence structure, each node of subject matter requires tagging with a corresponding capability and a context. The competence structure of photosynthesis for Key Stage 4 learners is shown in Figure 6-11.

The finalized competence structure is represented as a tree structure and the relationship between nodes of competences is still represented as a parent-child relationship. The size of this competence structure is medium and it contains 32 competence nodes. The illustrated method helps the developers to understand the process of developing the existing learning outcomes into a competence structure.

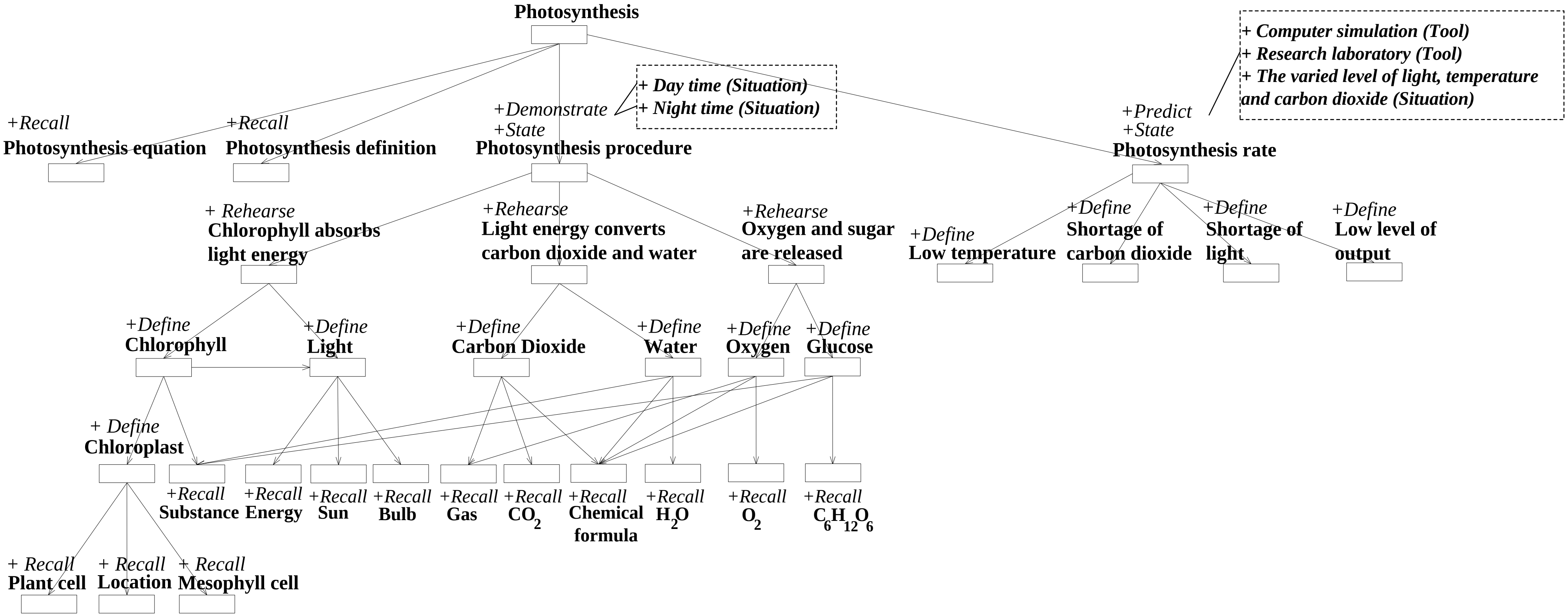


Figure 6-11: *Competence Structure of Photosynthesis for Key Stage 4 Learners Domain*

6.5 Mapped XML-Schema

There are some key points in representing a competence structure in an XML format. For example, XML enables us to focus on the definition of shared vocabularies for exchanging information and it easily reuses the content in other applications (St.Laurent, 1998). In this section, the proposed entity relationship diagram is described first, and then its corresponding XML-schema is given.

6.5.1 Entity Relationship Diagram Representing Competence Structure

An ER-diagram is considered before the XML-schema is mapped since an ERD enforces extreme simplicity, conventionally presented in graphical form and improves comprehensibility (Green & Benyon, 1996). Once the ERD of a competence structure is designed, it becomes easier to map it with the XML-schema. An entity relationship diagram (ERD) in Figure 6-12 represents all the main objectives in a competence structure, such as representation of intended learning outcomes, different types of subject matter content (including its task analysis), and representation of competences. At the initial stage of designing an ERD, database normalisation (Beeri, Bernstein, & Goodman, 1978) was considered for organising the database of a competence-based system and competence structure. There is another technique for helping the developer to analyse structures relating to human abilities rather than to computer ones. This technique is called Entity-Relationship Modelling of Information Artefacts (ERMIA) (Green & Benyon, 1996). However, such a technique is not considered at this stage.

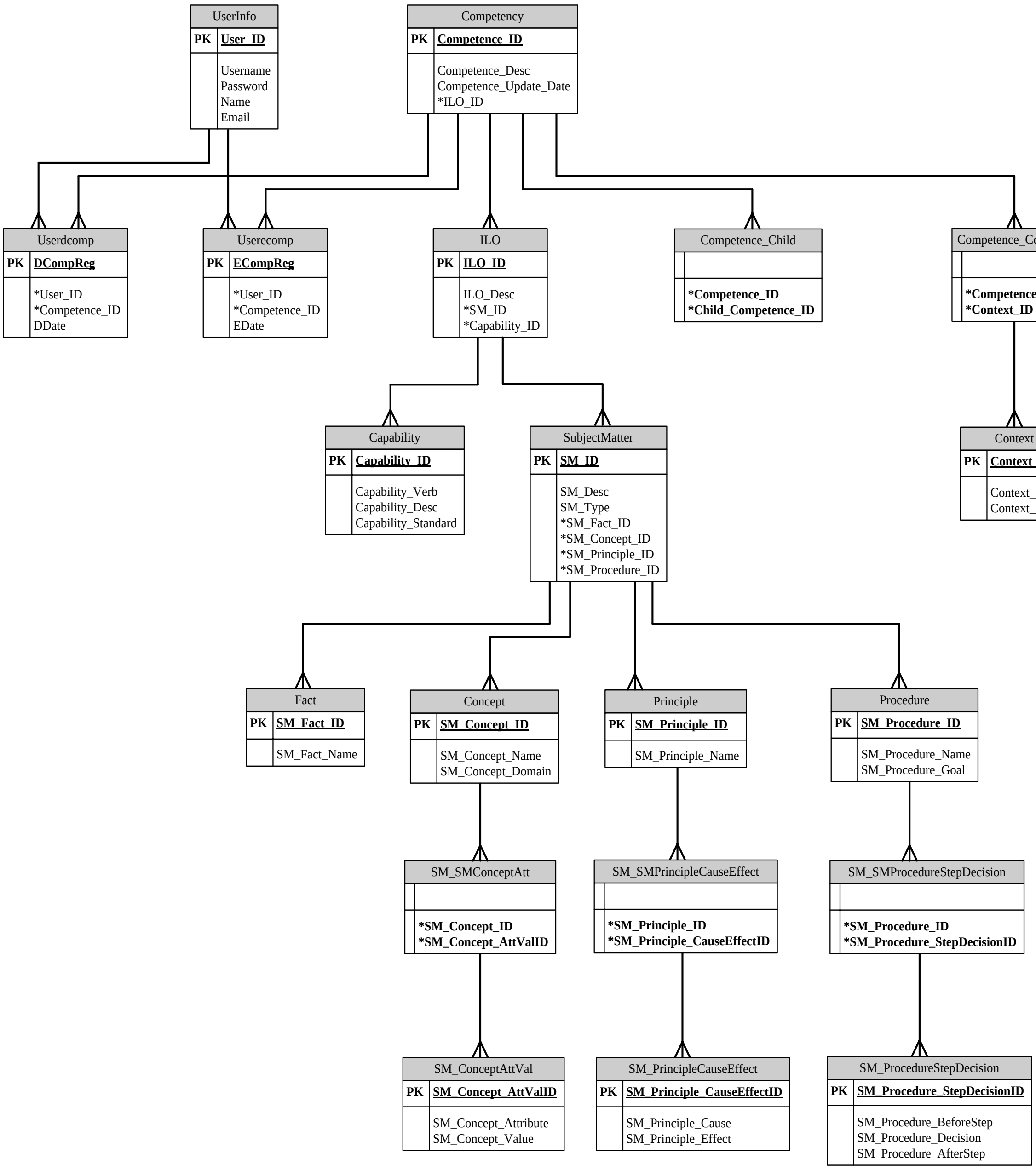


Figure 6-12: *ER Diagram of Competence Structure*

6.5.2 Mapping XML-Schema

XML-Schema defines the terms, relationships and constraints required to support communication in a particular application domain (Carlson, 2001). All schemas provide some degree of definition and documentation for an XML vocabulary. For the competence-based system it is essential to design an XML-schema since it represents a common framework for abstracting information for a competence structure. This XML-schema can be reused for any knowledge domains of subject matter content. Figure 6-13 represents the structure of an XML-schema for a competence structure. The design of this schema is based upon the proposed ER diagram in section 6.5.1. The full schema can be obtained from Appendix C.

```
<!-- declare all types of table-->
   <xsd:complexType name="UserInfoType">
      <xsd:sequence>
         <xsd:element name="User_ID" type="xsd:string"/>
         …...
      </xsd:sequence>
   </xsd:complexType>

<!-- Content of all elements / all tables -->
   <xsd:element name="Competence_Data">
      <xsd:complexType>
         <xsd:sequence>
            <xsd:element name="UserInfo" type="UserInfoType" minOccurs="0" maxOccurs="unbounded"/>
            ……….
         </xsd:sequence>
      </xsd:complexType>

<!-- Declare Primary keys  and other keys-->
      <xsd:key name="PK_UserInfo_User_ID">
         <xsd:selector xpath=".//UserInfo"/>
         <xsd:field xpath="User_ID"/>
      </xsd:key>
      ……….

<!-- declare foreign keys -->
      <xsd:keyref name="FK_UserInfoUserDComp" refer="PK_UserInfo_User_ID">
         <xsd:selector xpath=".//UserDComp"/>
         <xsd:field xpath="User_ID"/>
      </xsd:keyref>
      ……………..
```

Figure 6-13: *Mapped XML-Schema of Competence Structure*

However, this designed XML-schema is still not implemented within a competence-based system. The structure of the schema was developed for some applications which support the issues of user-friendly reusability, semantics, and modifiability among competence structures in different knowledge domains. Currently, a relational database is considered within an implementation. This should be sufficient to ensure that the process within a competence-based system can function properly.

6.6 Learning Paths

6.6.1 Obtaining Desired and Existing Competence from the Learners

The competence-based system begins by providing a choice of subject matters. Then a list of competences which are relevant to a chosen subject matter is presented. This list contains all parent competences. A parent competence is a competence which has at least one child competence node. Learners choose only one desired competence from this list. After that, all child competences of the desired competence are shown as a list. These child competences include competences which are related to chosen subject matter and other related subject matters. Learners choose one existing competence from this list. In fact, a learner could have more than one existing competence but, at this stage, this issue has not yet been explored.

The overview of this process can be illustrated in Figure 6-14. A competence structure of a HCF knowledge domain as in Figure 6-5 is considered. A list of subject matters contains 'Factor', 'Common Factor', and 'Highest Common Factor'. On the assumption that 'Highest Common Factor' is a chosen subject matter, a list of all parent competences is then presented. A learner chooses one desired competence from this list as 'Evaluate Highest Common Factor'. Then a list of all child competences of the desired competence is provided. A learner chooses one existing competence from this list as 'Define Factor'.

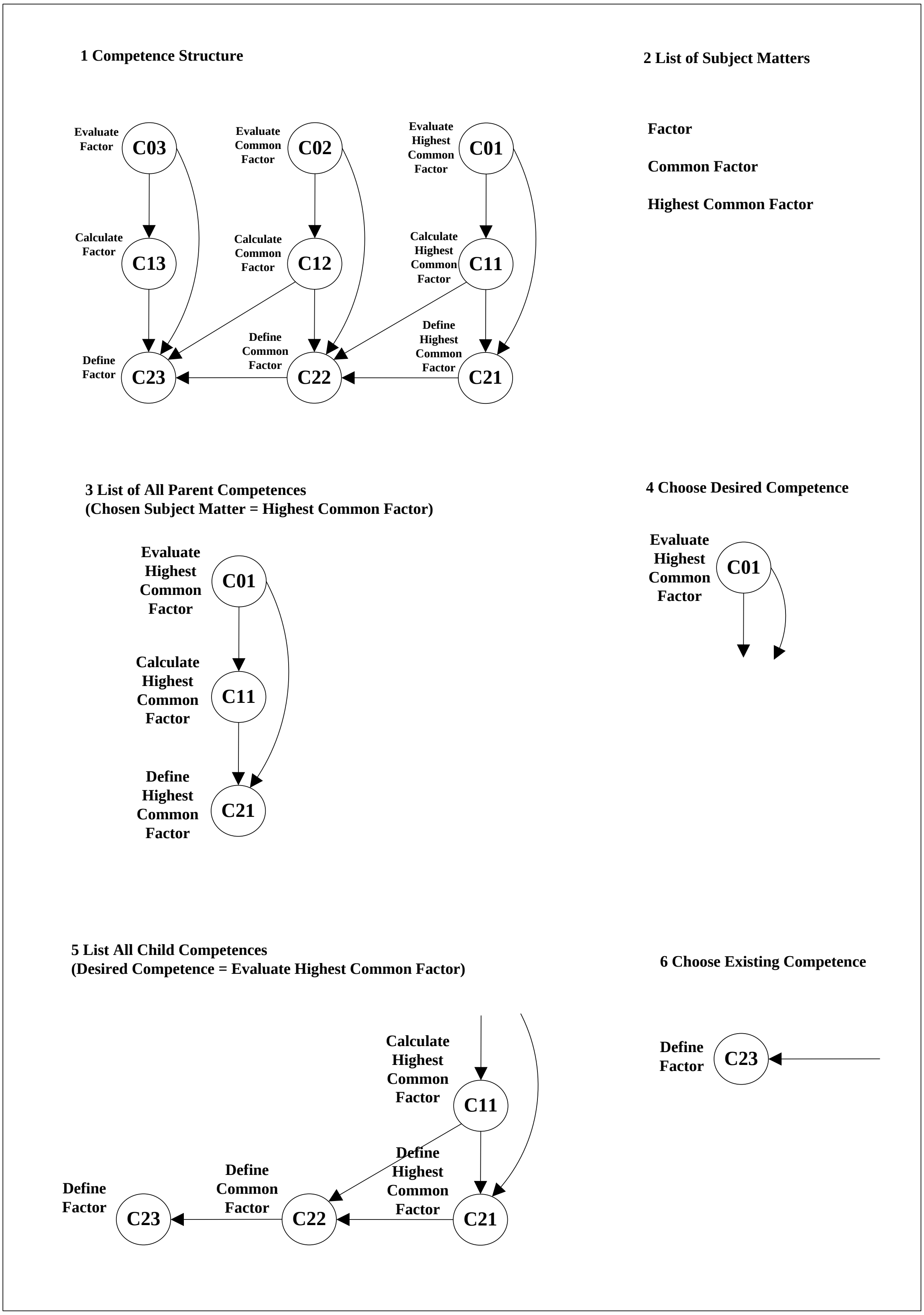


Figure 6-14: *Overview Process of Obtaining Desired and Existing Competence from Learners*

6.6.2 Three Types of Learning Paths

After the chosen desired and existing competences have been established, a list of learning paths will be provided. There are three learning paths. The paths are defined as the routes from existing competence to desired competence. Each route contains numbers of competence nodes. Competence gap nodes between desired and existing competences vary, depending on different learning paths.

1. Learning Path 1: Ignore All Gap Nodes

This learning path involves only two nodes, an existing competence and a desired competence. The search terms for obtaining study material links are considered from only a desired competence point of view, without considering any competence gap nodes. In the example of a desired competence and an existing competence in Figure 6-14, a route of learning path 1 can be shown as a dashed arrow in Figure 6-15.

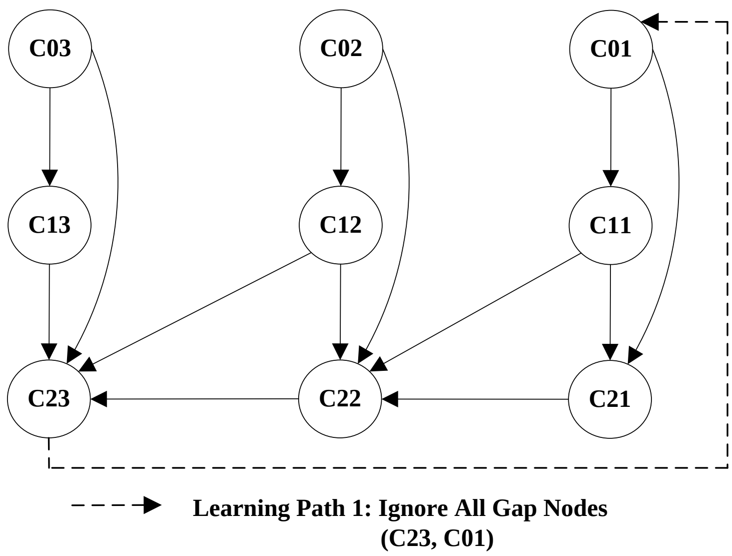


Figure 6-15: *Shown Route of Learning Path 1 Given that C23 and C01 are Existing and Desired Competence Respectively*

2. Learning Path 2: Consider Some Gap Nodes

This learning path involves not only existing and desired competences, but also some gap nodes. Here, when one node is traversed from another node, the next visited node should be one of the source's parent nodes on the route, which is shorter than a longer route to the desired competence. The routes contain some gap nodes that can be found when there is more than one parent node of a child node on the route connecting the desired and existing competences. These routes in learning path 2 exclude the one route where all gap nodes are considered. The search terms for obtaining study material links are derived from the desired competence and from some gap nodes. Following on from the example of desired and existing competences in

Figure 6-14, the routes of learning path 2 can be shown as dashed arrows in Figure 6-16.

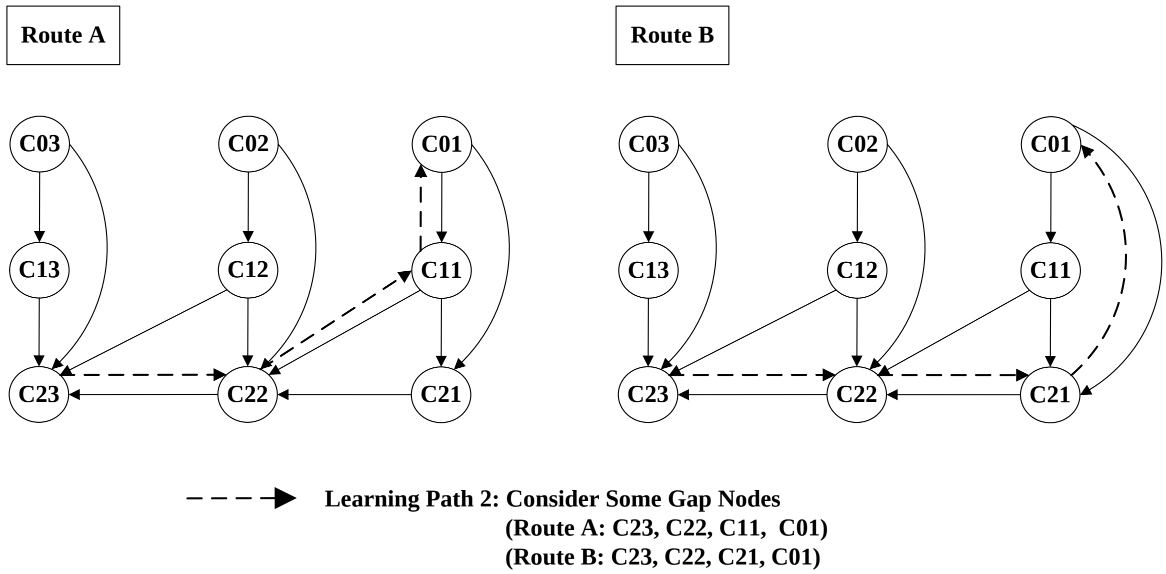


Figure 6-16: *Shown Route A and B of Learning Path 2 Given that C23 and C01 are Existing and Desired Competence Respectively*

3. Learning Path 3: Consider All Gap Nodes

As in learning path 2, when one node is traversed from another node, the next visited nodes should be only the source's parent nodes. But all competence gap nodes are considered in learning path 3. Hence the route of learning path 3 can be seen as the longest route compared to the routes of learning path 2. Following on from the example of desired and existing competences in Figure 6-14, a route of learning path 3 can be shown as a dashed arrow in Figure 6-17.

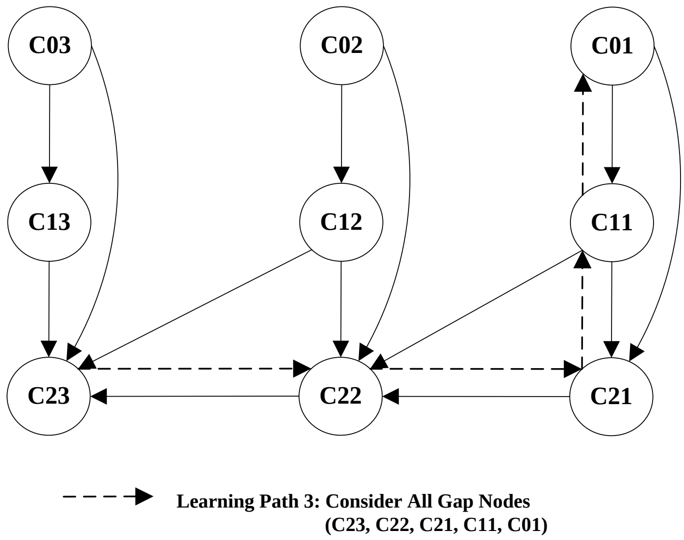


Figure 6-17: *Shown Route of Learning Path 3 Given that C23 and C01 are Existing and Desired Competences Respectively*

6.7 System Activity Diagram and Storyboard

This section provides a planned series of user interfaces provided to learners. According to the system process in Figure 6-4, an activity diagram diagrammatically represents the workflow behaviour within a system and a storyboard is then designed from the activity diagram.

6.7.1 System Activity Diagram

An activity diagram gives details of how the system interacts with a learner. It shows each step or process provided by a system to a learner. The consideration of an activity diagram facilitates the design of all interfaces. Figure 6-18 shows this research system activity diagram.

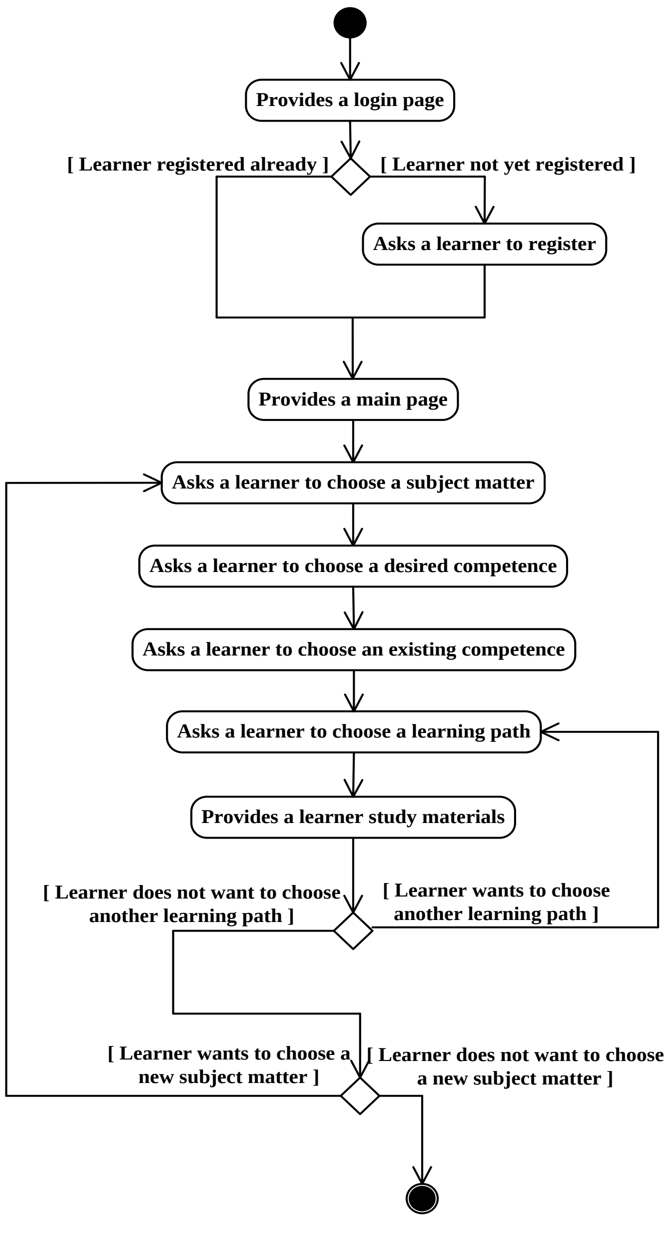


Figure 6-18: *Competence-Based System Activity Diagram*

6.7.2 System Storyboard

Designing a system storyboard allows the developers to propose the intended user interface before the real implementation. In total, there are six main pages of user interfaces, as follows. Page 1 (Figure 6-19) gives an overview of the competence-based system and gives the specified knowledge domain including the learner's prerequisites. Page 2 (Figure 6-20) allows learners to choose a targeted subject matter. Page 3 (Figure 6-21) generates a list of existing competences according to the chosen subject matter. Page 4 (Figure 6-22) generates a list of desired competences according to the chosen existing competence. Page 5 (Figure 6-23) summarises the chosen competences and lists all possible learning paths. Page 6 (Figure 6-24) allows the learner to obtain study materials based on the chosen learning path.

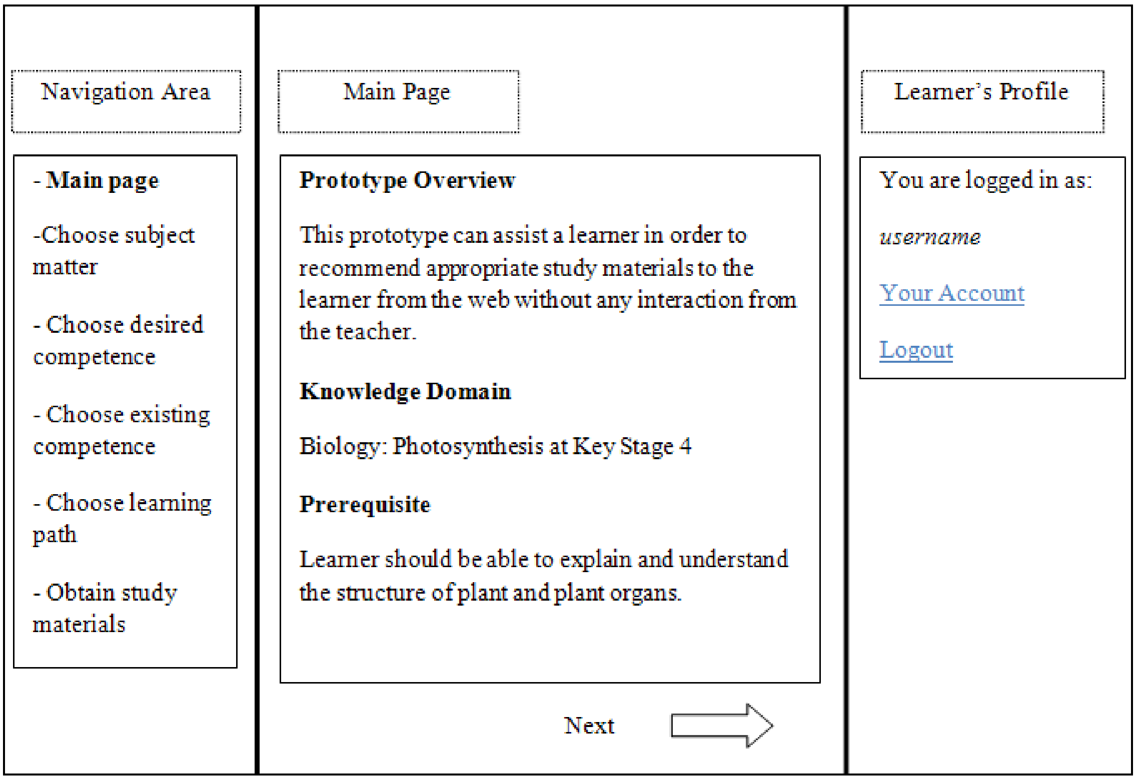


Figure 6-19: *Designed User Interface of Main Page*

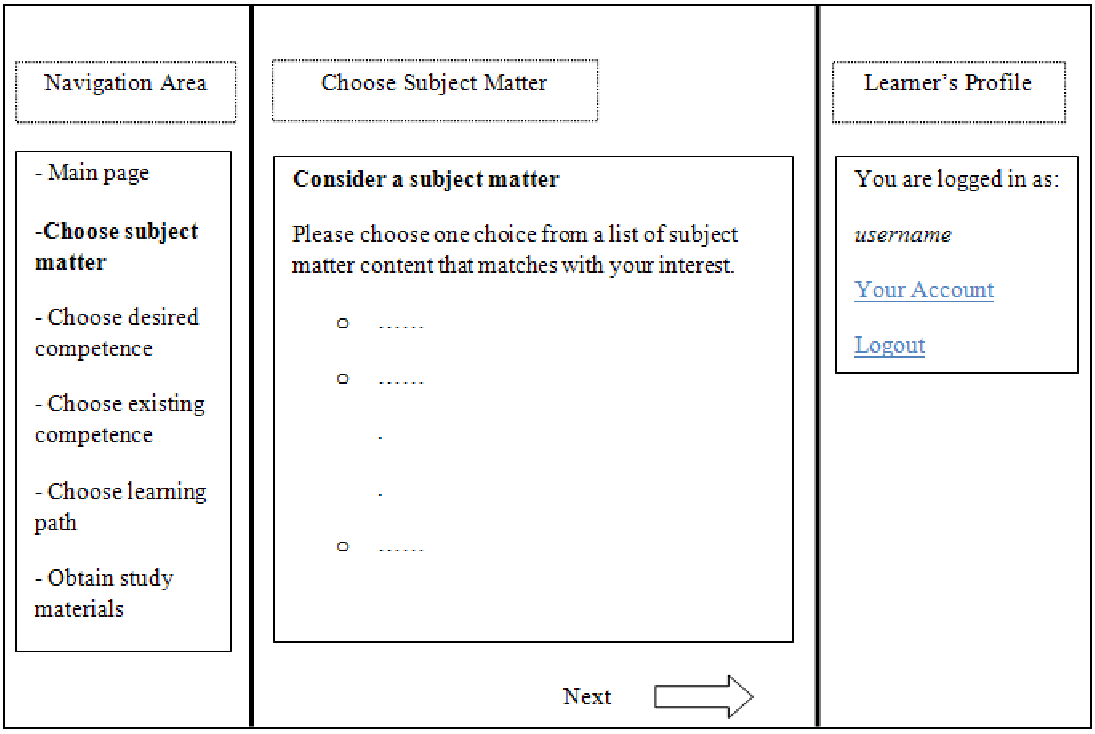


Figure 6-20: *Designed User Interface of Subject Matter Page*

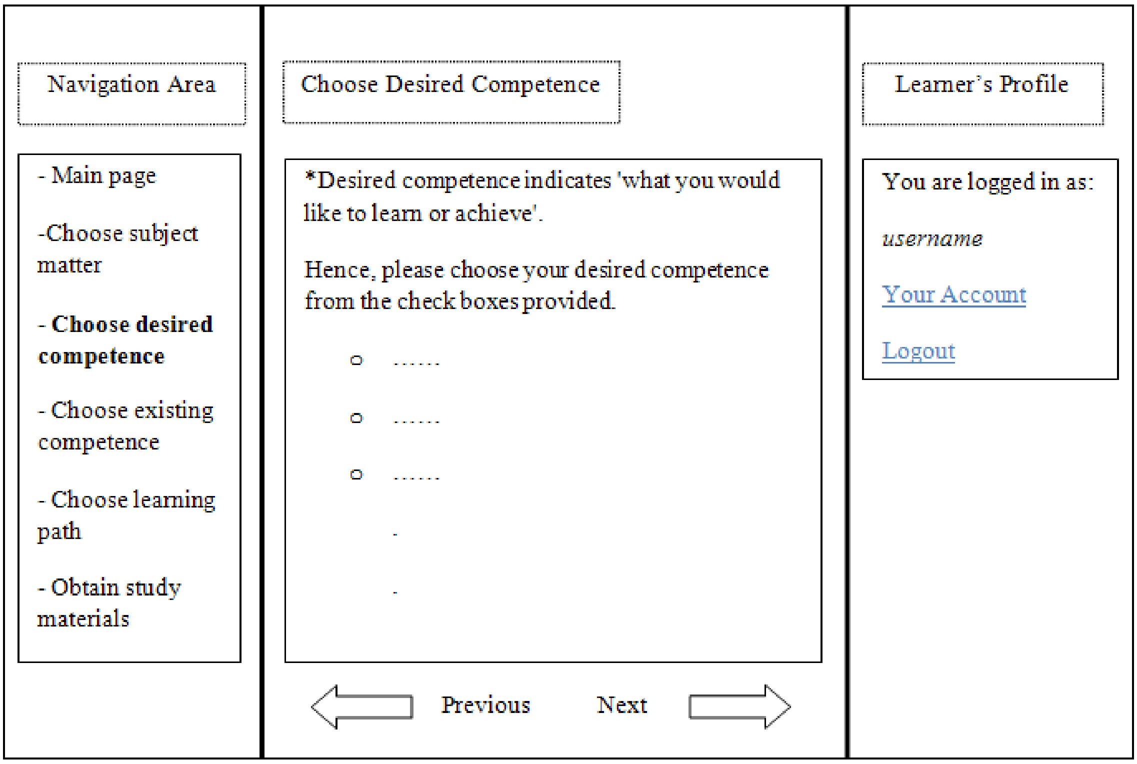


Figure 6-21: *Designed User Interface of Desired Competence Page*

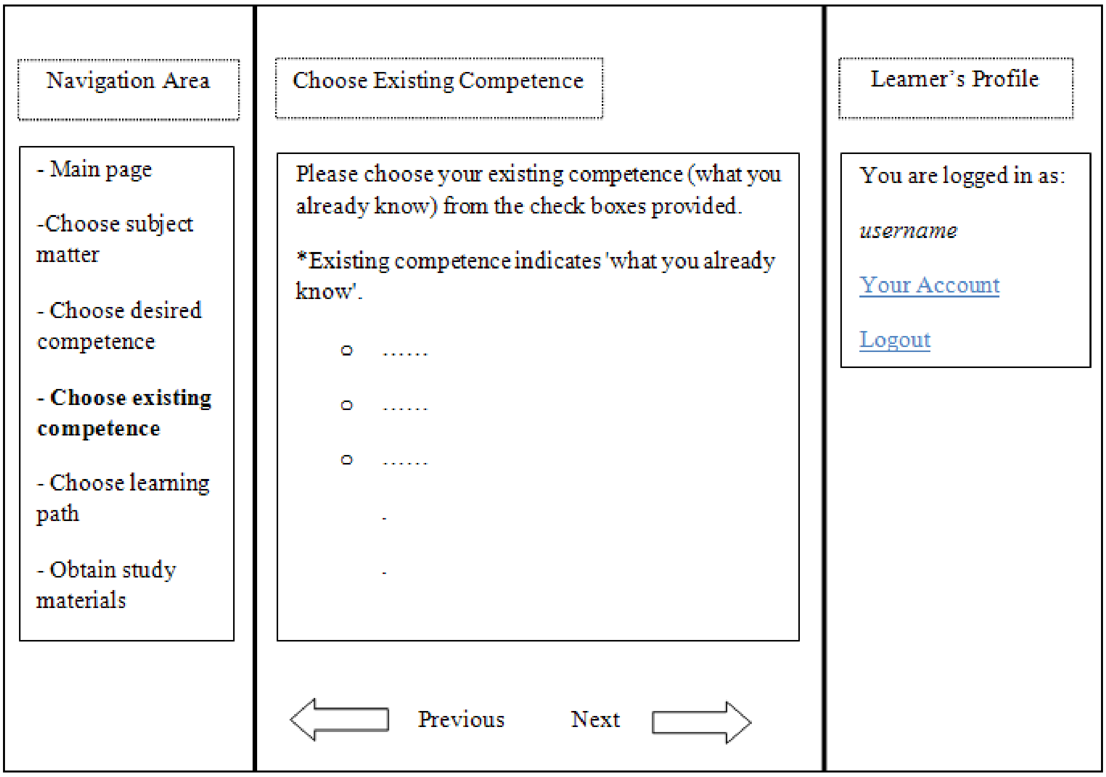


Figure 6-22: *Designed User Interface of Existing Competence Page*

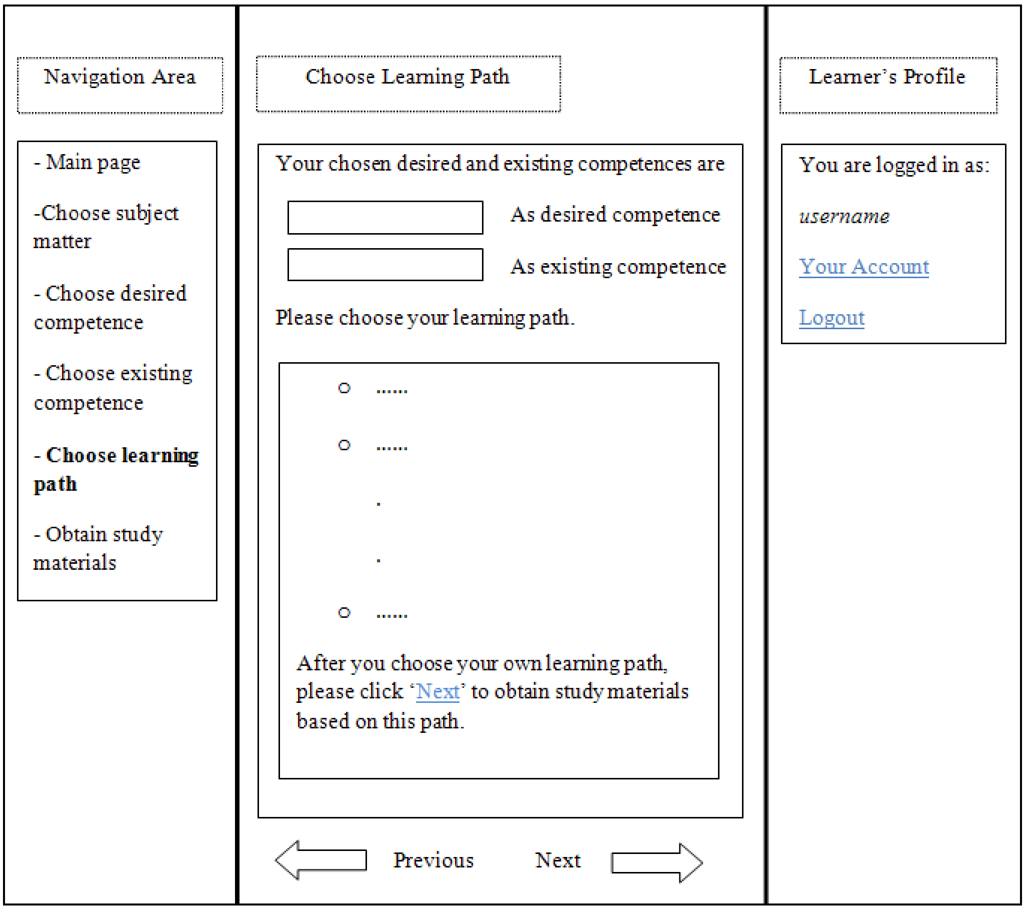


Figure 6-23: *Designed User Interface of Learning Path Page*

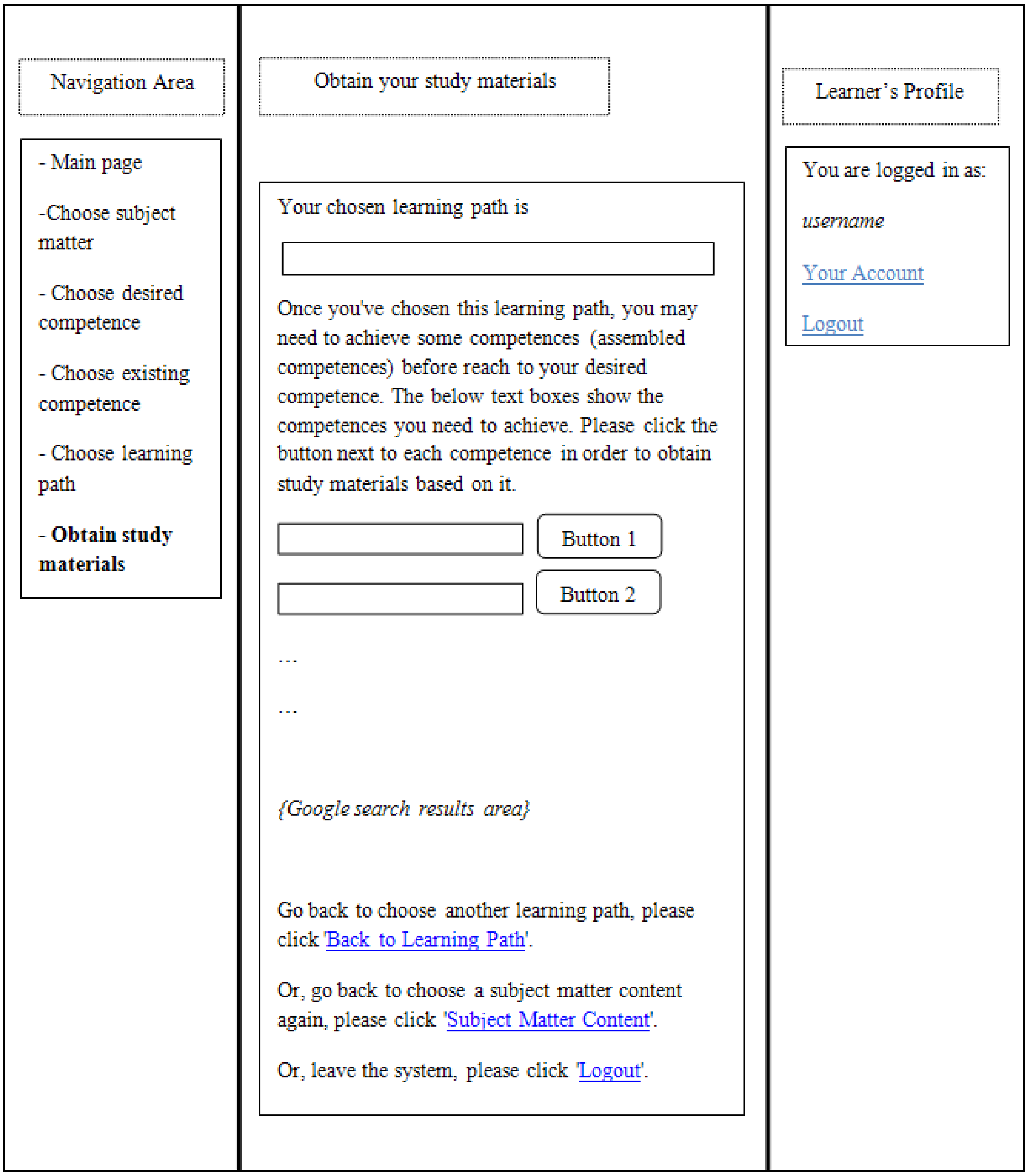


Figure 6-24: *Designed User Interface of Study Material Links Page*

6.8 Summary

Competence structure and its application are discussed in this chapter. System requirements are discussed, the competence structure being a major part of them. The system process is then presented. This illustrates how the system provides appropriate study materials as links from the Web to learners based on their competences. The relationship between competences is represented in the form of a competence structure. There is a process of developing existing learning outcomes into the competence structure. In addition, a mapped XML-schema of competence structure is proposed. This may be useful for future uses, especially for those approaches which require the advantages of usability, semantics, and modifiability. The last part of this chapter presents the system activity diagram and storyboard. These details are provided to show the sequences of interactions between the system and learners. The next chapter will illustrate an implementation of data, process, and interface. The implementation is developed by considering the system design given in this chapter.

Chapter 7
System Implementation

7.1 Introduction

A previous chapter described the design of the system process and the method of constructing a competence structure. This chapter describes the implementation of a competence-based system. It includes three main sections. The first part provides the design of a database based on a competence structure. The second part discusses the process of designing learning paths and the sorting algorithm to generate learning paths. The third part provides the implemented user interface with the associated screenshots.

7.2 Database Implementation

This section gives the details of database implementation. The ER diagram in Figure 7-1 shows all related entities, relationships, and attributes. The consideration of ERD facilitates the development of the design of a database. Entities in ERD can be referred to as tables in a database. Attributes can be referred to as fields in a database.

The featured ER diagram (Figure 7-1) is different from an ER diagram which is utilized for designing an XML-schema. This is a partial implementation because much of the data shown in Figure 6-12 is not needed in the competence-based system. The keywords gleaned from each of the competence nodes are selected from capability, subject matter, and context, without taking task analysis and subject matter categories into account.

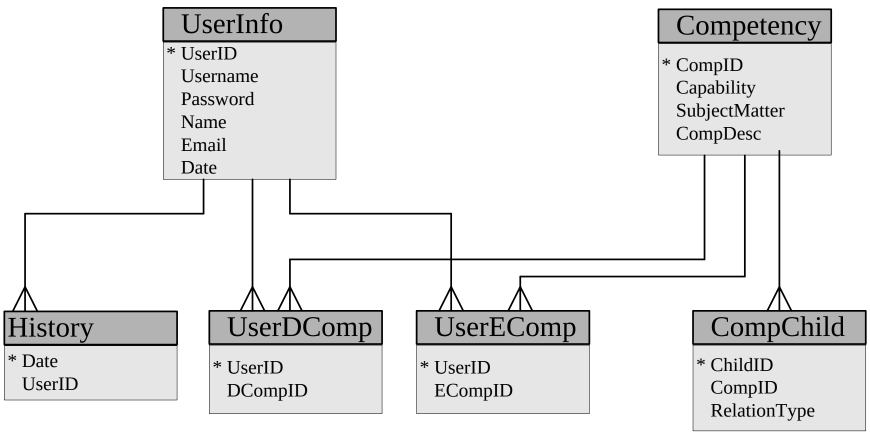


Figure 7-1: *Considered ER Diagram within an Implementation*

All required tables and fields within a database are identified in the ERD. There are six tables as follows.

1. 'userinfo' table contains the information concerning a particular learner such as, identification, username, password, name, email, and date of registration.
2. 'history' table contains information on the history of logging into the system.
3. 'userdcomp' table contains information on the history of choosing a desired competence by the learner.
4. 'userecomp' table contains information on the history of choosing an existing competence by the learner.
5. 'competency' table contains a description of one competence node.
6. 'compchild' table contains information on the parent-child relationship between two competences nodes.

There are two tables representing the information of the competence structure: 'competency' and 'compchild'. Normally a competence structure consists of the combinations of pairs of edges and nodes. The constructing of a database is based on a pair of nodes. Table 'compchild' stores the relationships between nodes of the competence structure. One record contains details of one edge between two nodes. So there are only two attributes. One attribute called 'CompID' indicates a parent node for a particular edge. Another attribute called 'ChildID' indicates a child node of a corresponding node. Figure 7-2 shows a screenshot of 'compchild' table in MySQL database.

←T→	Rel_ID	CompID	ChildID
	2	c2_2	c3_4
	3	c2_2	c3_3
	4	c2_1	c3_2
	5	c2_1	c3_1
	6	c1_3	c2_3
	7	c1_3	c2_2
	8	c1_3	c2_1
	9	c1_10	c1_7
	10	c1_9	c1_7
	11	c1_8	c1_7
	12	c1_5	c1_3
	13	c1_4	c1_5
	14	c1_6	c1_4

Figure 7-2: *Table of Competence Relationship ('compchild' Table)*

It can be seen that one record indicates only one edge in a competence structure. Hence, if a structure of competence changes (for example, a tree structure) but still contains the edges of nodes, this database could be considered.

Another table, the ‘competency’ table, contains information on one competence node, such as: description, subject matter, capability, context, and level of competence. Figure 7-3 shows a screenshot of the ‘competency’ table in MySQL database.

CompID	CompDesc	Capability	SubjectMatter	Context	CompLevel	IsLeaf
c1_1	Recall the equation of photosynthesis	Recall	Photosynthesis equation	*NULL*	5	1
c1_2	Recall the definition of photosynthesis	Recall	Photosynthesis definition	*NULL*	5	1
c1_3	State a day time photosynthesis procedure	State	Photosynthesis procedure	Day time	5	0
c1_4	State a night time photosynthesis procedure	State	Photosynthesis procedure	Night time	5	0
c1_5	Demonstate a day time photosynthesis procedure	Demonstrate	Photosynthesis procedure	Day time	5	0
c1_6	Demonstrate a night time photosynthesis procedure	Demonstrate	Photosynthesis procedure	Night time	5	0

Figure 7-3: *Table of Competence Details (‘competency’ table)*

7.3 Process Implementation

According to the system process in Figure 6-4, there are four main parts dealing with the process within implementation:

- Process dealing with subject matters
- Process dealing with learner’s competences
- Process generating learning paths
- Process considering Google search keywords

The process is coded with PHP programming language and SQL for accessing the database.

7.3.1 Process Dealing with Subject Matters

When learners log in to a competence-based system, the first thing they are required to do is choose a targeted subject matter. The competence-based system provides learners with a list of subject matter content. This list is generated from a field ‘SubjectMatter’ in the ‘competency’ table. Only subject matters from competence nodes, which are not leaf nodes, are generated. The reason for this is explained in section 7.3.2. Figure 7-4 shows the SQL query to generate a list of subject matter from ‘competency’ table.

```
$sql = "(SELECT * FROM competency WHERE compID NOT IN (SELECT dcompid FROM userdcomp WHERE userid =".$_SESSION['id_sess'].")";
$sql .= " AND compID NOT IN (SELECT ecompid FROM userecomp WHERE userid =".$_SESSION['id_sess'].") AND IsLeaf <> true) order by CompLevel ";
```

Figure 7-4: *SQL Query of Generating List of Subject Matter Content*

7.3.2 Process Dealing with Learner's Competences

There are two types of learner competence as stated in section 6.3: existing competence and desired competence. After learners have chosen their targeted subject matter, they are required to choose a desired competence. The competence-based system provides a list of desired competences to learners. The list contains all parent competences. This list is generated from a field 'CompDesc' in the 'competency' table. Descriptions of competence nodes are generated from chosen subject matter only. Figure 7-5 shows the SQL query to generate a list of desired competence.

```
$sql = "(SELECT * FROM competency WHERE subjectmatter = '".$_SESSION['SubjectContent_sess']."' AND IsLeaf <> true) order by CompLevel";
```

Figure 7-5: *SQL Query of Generating List of Desired Competence*

Next, learners are required to choose one existing competence. The competence-based system provides learners with a list of existing competences. This list is considered from a field 'ChildID' in the 'compchild' table. The list contains all the child nodes of a chosen desired competence. These child nodes are not restricted to only selected subject matter: they can be related to other subject matters as well. As stated in section 7.3.1, listed subject matters should be from competence nodes which are not leaf nodes. The reason is that it is not possible to generate a list of existing competences where the desired competence is a leaf node. The full PHP and SQL query for generating a list of desired competence can be found in Appendix D.

7.3.3 Process of Generating Learning Paths

There are three possible learning paths for any competence structures: 'ignore all gap nodes', 'consider some gap nodes', and 'consider all gap nodes'. In order to traverse a structure, techniques of breadth-first search (BFS) and first-in-first-out (FIFO) are considered.

Breadth-First Traversal (BFS) is a method of traversing a graph which can also be applied to a binary tree traversal. BFS visits all the vertices, beginning with a specified start vertex (Knuth, 1973). BFS visits the nodes level by level, so it will start with the lowest level (root node), and then it moves to the next levels until it reaches the destination (Knuth, 1973). In this research, the position of the root node in BFS is replaced with the position of the desired competence. The traversal method is pursued until it reaches the existing competence node.

FIFO (First-in, First-out) is a property of queue representation. There is an established convention that items are added to the rear of queues and are deleted from the front (Standish, 1980).

BFS combined with FIFO provides a set of actions to enumerate all paths from a root:

Action 1 Enqueue the root node.

Action 2 Dequeue a node and examine it.

- If the element sought is found in this node, quit the search and return a result.
- Otherwise enqueue any successors (the direct child nodes) that have not yet been discovered.

Action 3 If the queue is empty and every node on the graph has been examined, then quit the search and return to 'not found'.

Action 4 Repeat action 2.

From the above techniques, only learning paths 'consider some gap nodes' and 'consider all gap nodes' are listed. Learning path 'ignore all gap nodes' is simply added to the list without considering structure traversal techniques.

Consider one example of traversing a structure. From the competence structure of mathematical HCF in Figure 6-5, the list of all paths from C23 to C01 is considered. The outcomes would be:

1. **'ignore all gap nodes':** C23 → C01
2. **'consider some gap nodes':** C23 → C22 → C21 → C01,
   C23 → C22 → C11 → C01
3. **'consider all gap nodes':** C23 → C22 → C21 → C11 → C01

Using the previously mentioned technique to enumerate all paths, Figure 7-6 shows the results for two types of learning paths: 'consider some gap nodes' and 'consider all gap nodes'.

Step 1: [C01]
Step 2: [C11(C01), C21(C01)]
Step 3: [C21(C01), C22(C01,C11), C21(C01,C11)]
Step 4: [C22(C01,C11), C21(C01,C11), C22(C01,C21)]
Step 5: [C22(C01,C21), C23(C01,C11,C22), C22(C01,C11,C21)]
Step 6: [C23(C01,C11,C22), C22(C01,C11,C21), C23(C01,C21,C22)]
Step 7: [C23(C01,C21,C22), C23(C01,C11,C22), C23(C01,C11,C21,C22)]

'learning path for consider some gap nodes' **'learning path for consider all gap nodes'**

Figure 7-6: BFS and FIFO Techniques on Competence Structure

Considering the pattern of the learning path, each node represents the description of competence which is a combination of capability, subject matter and context. The overview of the shown pattern of a learning path can be illustrated in Figure 7-7.

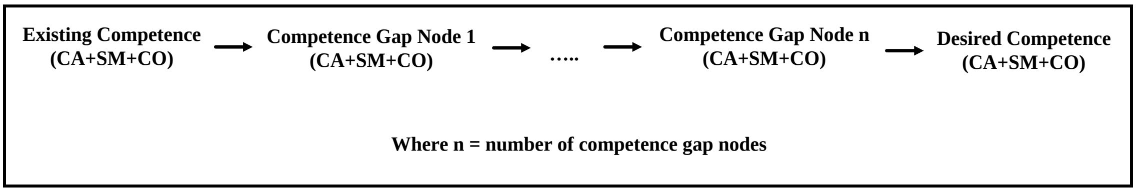


Figure 7-7: *Shown Pattern of Learning Path*

7.3.4 Process of Considering Google Search Keywords

After one learning path is chosen from the list, Google search keywords are then considered. The keywords are the words, capability, subject matter, and context. Study material links are initially suggested from the first gap node. This depends on the chosen learning path. The suggestions for study material links are considered until the desired competence is reached.

7.4 Interface Implementation

The design of user interfaces is based on the system storyboard as in section 6.7.2. User interfaces are designed with HTML language. There are six main pages as follows:

7.4.1 Login Page

A login page (Figure 7-8) is a first page that is shown to a learner. This page allows a learner to log in and the session will be started after he/she logs in.

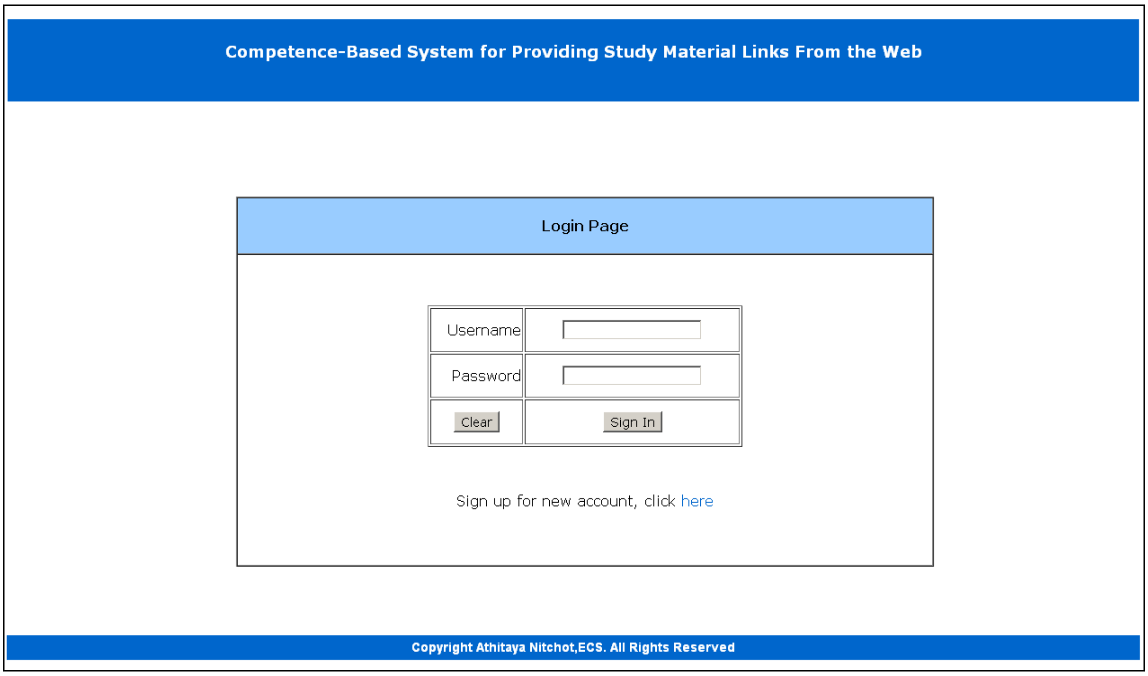


Figure 7-8: *Screenshot of Login Page*

7.4.2 Main Page

The main page (Figure 7-9) is a page to be shown to a learner after he/she logs in. This page shows only an overview of the prototype, specified knowledge domain, the learner's prerequisites and the learner's requirements.

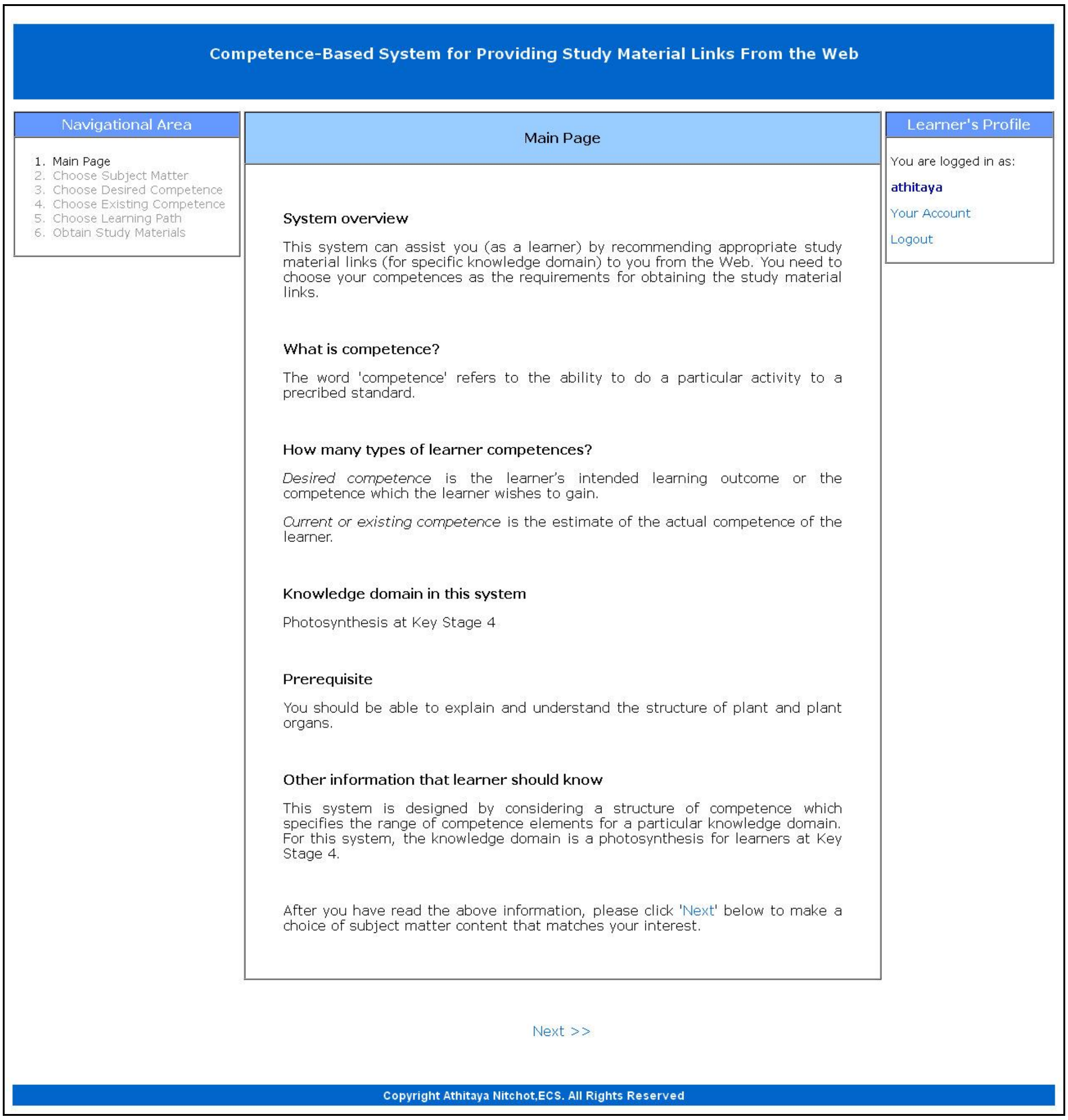
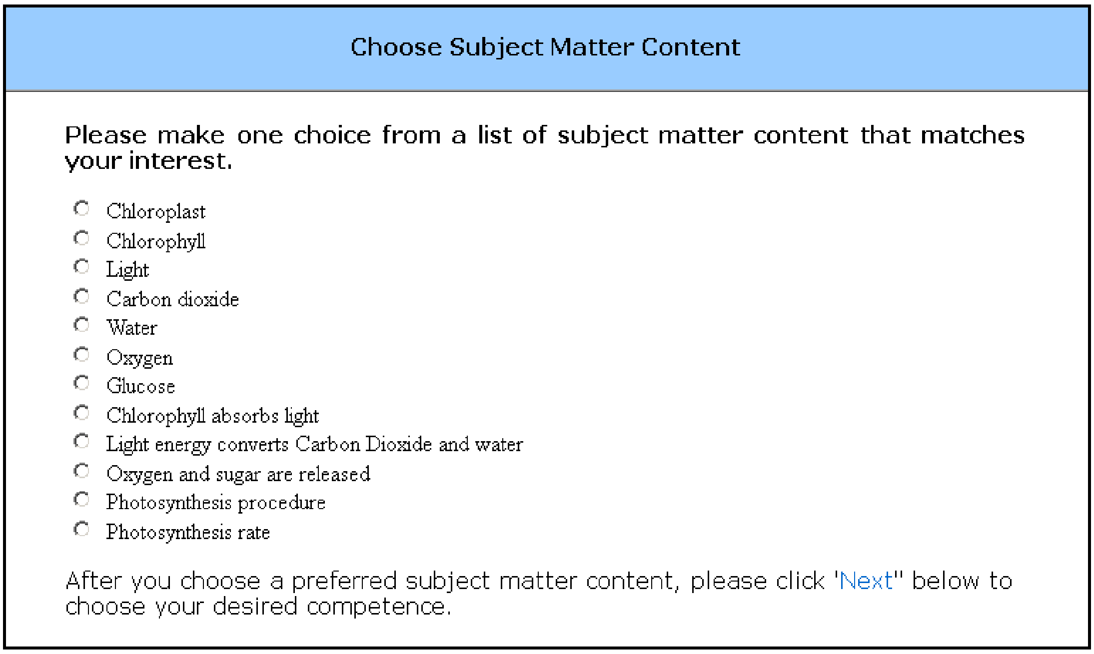


Figure 7-9: *Screenshot of Main Page*

7.4.3 Subject Matter Page

A page of subject matters (Figure 7-10) offers a list of subject matter for a learner. He/she will be required to choose a targeted subject matter.


Choose Subject Matter Content

Please make one choice from a list of subject matter content that matches your interest.

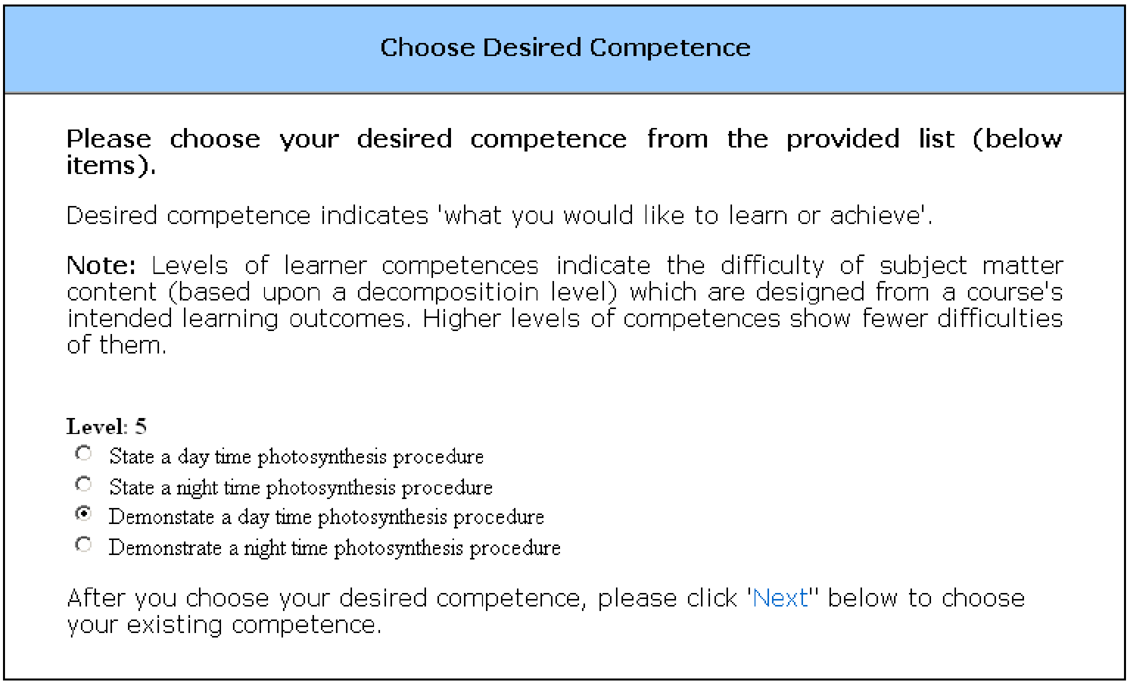
- Chloroplast
- Chlorophyll
- Light
- Carbon dioxide
- Water
- Oxygen
- Glucose
- Chlorophyll absorbs light
- Light energy converts Carbon Dioxide and water
- Oxygen and sugar are released
- Photosynthesis procedure
- Photosynthesis rate

After you choose a preferred subject matter content, please click 'Next'' below to choose your desired competence.

Figure 7-10: *Screenshot of Subject Matter Page*

7.4.4 Desired Competence Page

Looking at a desired competence page (Figure 7-11), a learner understands a desired competence and chooses his/her desired competence from the list provided.


Choose Desired Competence

Please choose your desired competence from the provided list (below items).

Desired competence indicates 'what you would like to learn or achieve'.

Note: Levels of learner competences indicate the difficulty of subject matter content (based upon a decompositioin level) which are designed from a course's intended learning outcomes. Higher levels of competences show fewer difficulties of them.

Level: 5

- State a day time photosynthesis procedure
- State a night time photosynthesis procedure
- Demonstate a day time photosynthesis procedure
- Demonstrate a night time photosynthesis procedure

After you choose your desired competence, please click 'Next'' below to choose your existing competence.

Figure 7-11: *Screenshot of Desired Competence Page*

7.4.5 Existing Competence Page

An existing competence page (Figure 7-12) allows individual learners to choose their existing competence.

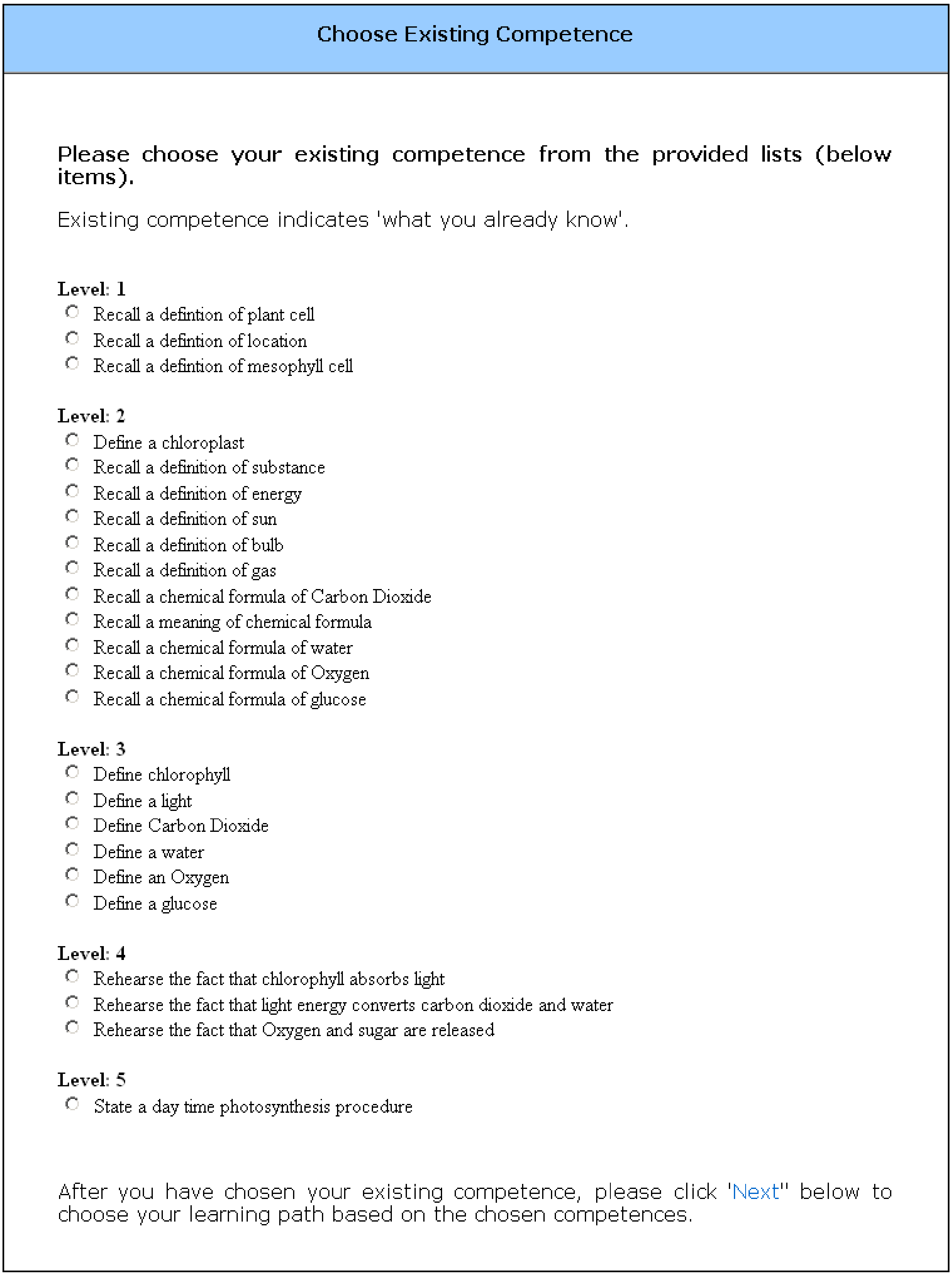


Figure 7-12: *Screenshot of Existing Competence*

7.4.6 Learning Paths Page

The learning paths page (Figure 7-13) summarises the chosen desired and existing competences. This page allows a learner to choose a learning path from a list. This list is considered from chosen desired and existing competences.

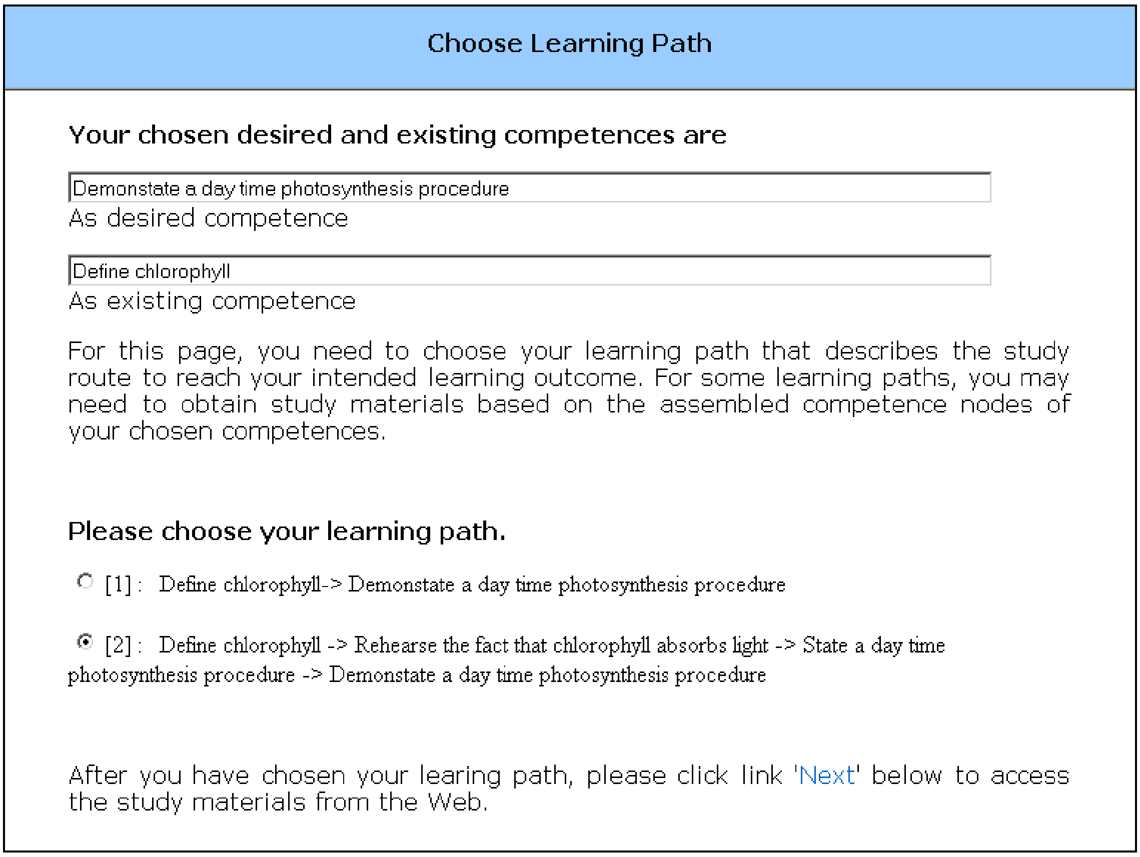


Figure 7-13: *Screenshot of Learning Paths Page*

7.4.7 Study Material Links Page

A page of study material links (Figure 7-14) summarises the chosen learning path. A learner obtains study material links from the Web based upon these competences. The search terms are considered, based on a chosen learning path.

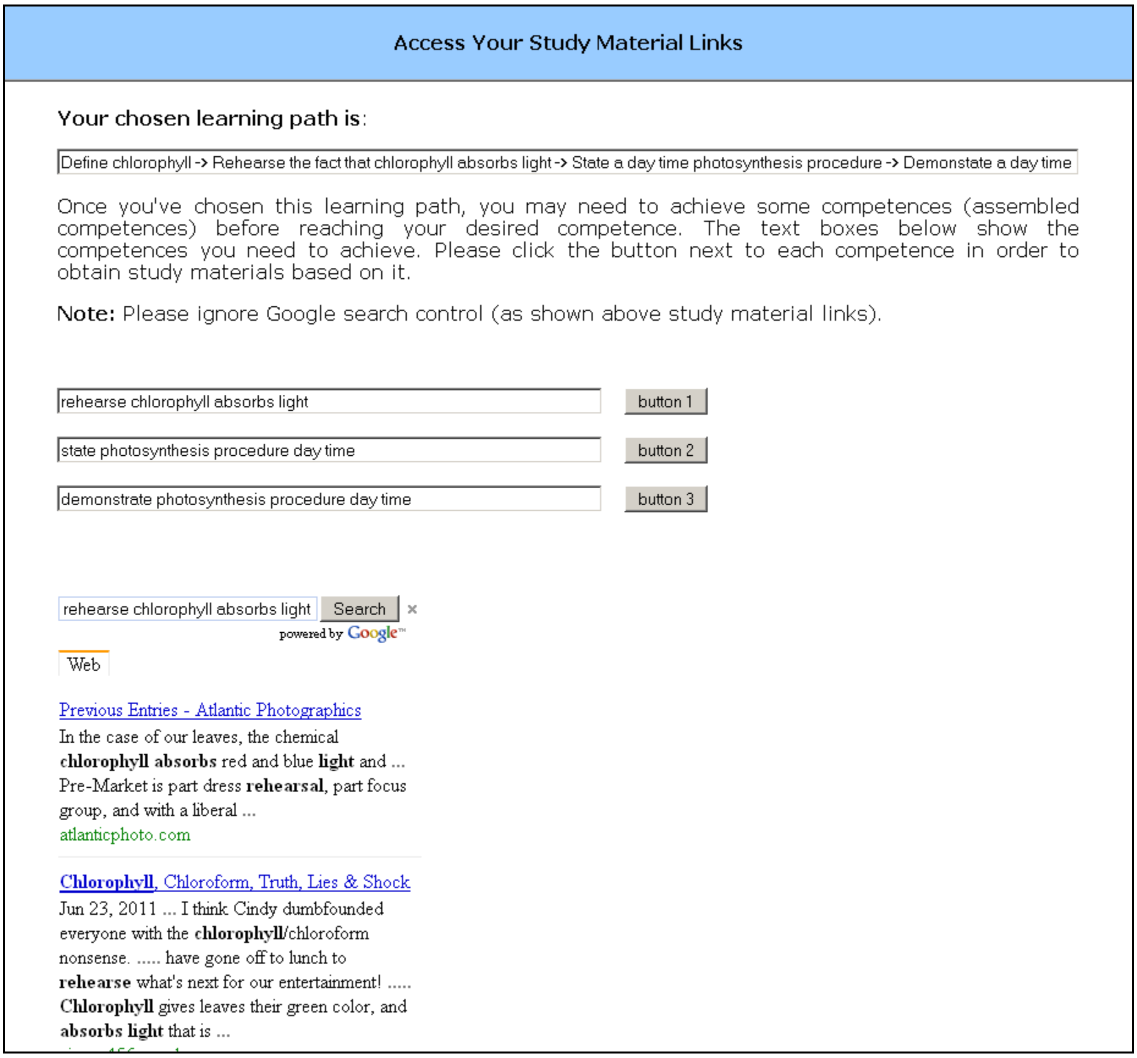


Figure 7-14: *Screenshot of Study Material Links Page*

7.5 Summary

This chapter provides information on implementation. This is followed by the design of a database and system process. There is a description of representing a competence structure in tables and fields in a database. For a process implementation, there are four considerations regarding process: process dealing with subject matters, process dealing with learner's competences, process generating learning paths, and process considering Google search keywords. In addition, there are screenshots of the designed competence-based system.

Chapter 8
Experimental Methodology

8.1 Introduction

Chapter 7 provides information on the implementation of, currently, a competence-based system, as a prototype. Six experiments were conducted to evaluate the effectiveness of this approach, and to determine the appropriate learning paths to suit learners. This chapter describes the experimental methodology, and explains the test statistics used to analyze each result. For each of the six experiments, an experimental overview is given, and the methodology, the materials and the procedures are generally discussed.

8.2 Overview of Experimental Methodology

The major aim of this research is to investigate an approach to generating different learning paths, and suggest appropriate study materials as links, from the Web to learners, based upon their chosen competences. The experimental studies explored appropriate learning paths, overall approach evaluation and comparison of a learning mode provided by a competence-based, as against any other generally-used, learning mode.

All experiments received Ethics Committee approval under reference number ES/10/09/007. The type of participants varied depending on the different experiments. Overall there were two kinds of participants: knowledge domain experts and general learners. All participants were postgraduate students at the School of Electronics and Computer Science, University of Southampton. Participants were recruited by email from the mailing list provided by the School and given information (see Appendix E) about the experiment. The estimated number of participants required was obtained using G*Power software (Buchner, Faul, & Erdfelder, 2010). The number of participants required differed, according to the nature of the different experiments.

The experiments covered two levels of Kirkpatrick's (Kirkpatrick, 2007) four levels of evaluation. Experiments I and II were an exploration of appropriate learning paths and an overall evaluation of the approach covering the first level, which is the 'reaction level'. Experiment III was a comparison of learning modes provided by a competence-based system as against another generally-used learning mode, which covered the second level, which is the 'learning level'. Experiments IV and V were further investigations following from Experiment III. These experiments explored types of search engines and the different kinds of keywords that could affect the search results in terms of learners' learning outcome achievement.

Pilot studies were conducted in all six experiments. The purpose is to see the feasibility, time, cost, and adverse events (Field, 2000). This is to improve the design of the experiment before the real one is conducted. In this research, there were three participants in each pilot study.

8.3 Experimental Questions

There were a total of six experimental questions which needed to be investigated:

1. Experimental Question I

To compare three learning paths in order to generate queries that relied on competence structure, input for which came from the users.

2. Experimental Question II

To determine users' overall reaction to Kirkpatrick's level one ('reaction') (Kirkpatrick, 2007). The analysis sought to examine significant differences in the mean ratings for each dependent variable at a particular value ('3') on a Likert scale.

3. Experimental Question III

To explore whether a competence-based learning mode was better than a freely-browsing learning mode.

4. Experimental Question IV

To explore whether the search results provided by the Google browser (www.google.com) were better than those given by Google API, in terms of achievement in competence node.

5. Experimental Question V

To explore whether the search results for capability, subject matter and context keywords were better than those from subject matter keywords in terms of an achievement in competence node.

6. Experimental Question VI

To explore whether the search results given by GoogleAPI were better than those given by iSEEK, which is an educational search engine, in terms of achievement in competence node.

Experimental questions IV and V were further studies following on from Experimental question III.

8.4 Timeline for the Conduct of Experiments

Figure 8-1 shows the sequenced timeline of the experiments that were conducted. At the first stage, the experiments were related to questions I and II. Analysis of the results from the two questions (I and II) led to a third question (III). Only the competence-based system for suggesting study material links in the photosynthesis domain for Key Stage 4 learners was considered at this stage. Since, the expected results of Experimental Question III were not conclusive, further experimental studies were undertaken to explore types of search engines and different kinds of keywords (Experimental Questions IV and V). In addition, the last experiment (Experiment VI) was a further study of significant differences between the considered search engine (GoogleAPI) and an educational search engine (iSEEK).

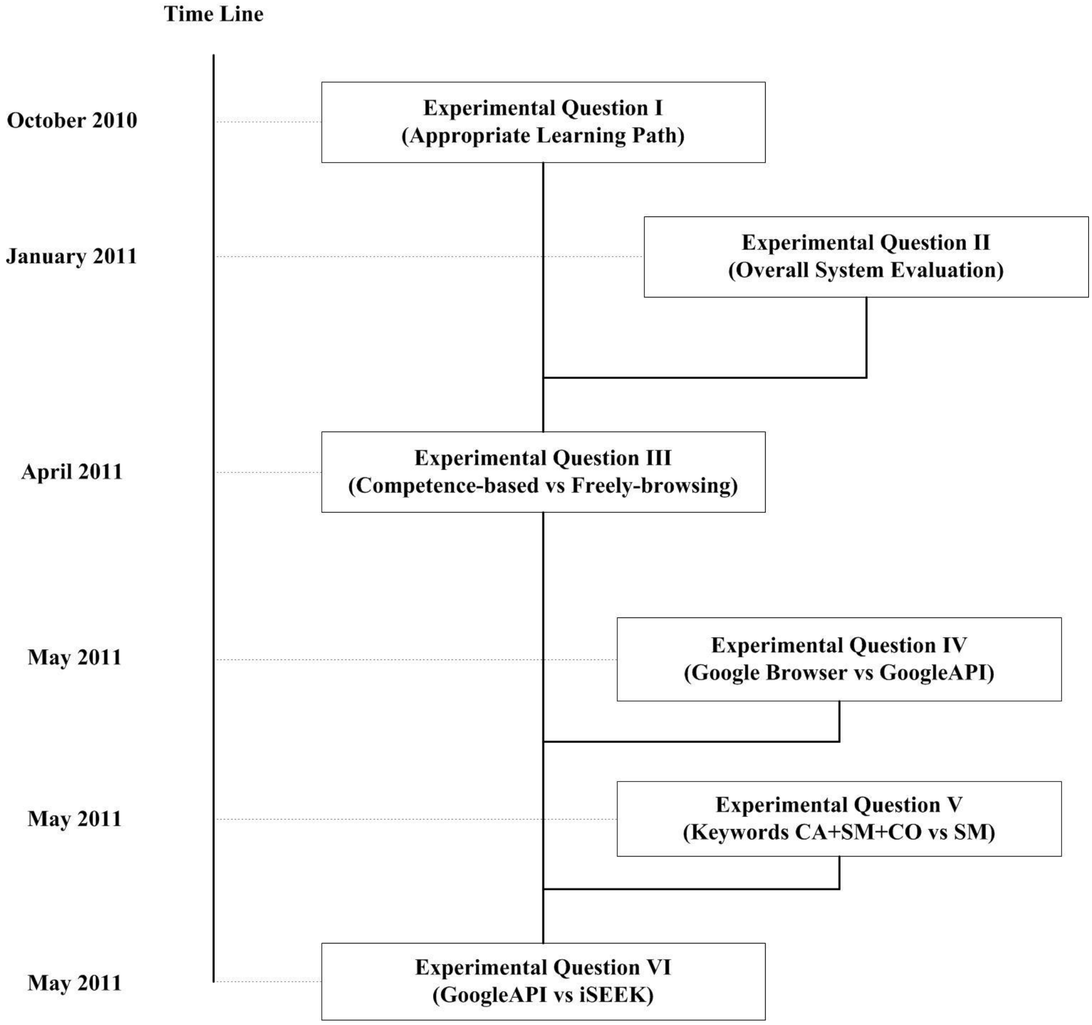


Figure 8-1: *Timeline of Conducting Experiments*

8.5 Experiment I

Two parts to this experiment were conducted to compare three learning paths. The design of the two parts was similar, but conducted in different knowledge domains, namely a mathematical HCF and photosynthesis for Key Stage 4 learners. The main aim of the experiments was to compare three learning paths to generate the query which relied on a competence structure and an input from the users. Each learning path contains different numbers of competence nodes. This is to investigate whether more competence nodes in a learning path would be more useful, based on the considered dependent variables.

The independent variables were three learning paths: ‘ignore all gap nodes’, ‘consider some gap nodes’, and ‘consider all gap nodes’. In order to reduce the effects of participant variance, the participants experienced each learning path in turn in a counterbalance Latin square design. This design is considered when one wishes to compare treatments and to control for two other known sources of variation (Box, Hunter, & Hunter, 1978). The lists of dependent variables to compare with a learning path are as follows:

1. ‘Learning outcome achievement’
2. ‘Usefulness of the competence gap nodes to help in achieving an intended learning outcome’
3. ‘Usefulness of competence gap nodes to improve learners’ motivation’

Participants in the two experiments should have had some background in the knowledge domains; in other words, they had already learnt about these two domains. The experiment covered a reaction level and required an expert review. The expected sample size for each experiment was 7, using the given values of:

- effect size f as 1
- alpha error probability as 0.05
- power as 0.8
- test-family as F-test
- statistical-test as MANOVA (and ANOVA): repeated measures, within factors

When the expected sample size was calculated by using ANOVA as the statistical test, the number obtained was 6.

8.5.1 Experimental Materials

There were three sets of materials given to the participants: a training document, scenario/instructions and a questionnaire.

The training document (Appendix F) was given to the participants so that they could have a clear understanding of the terms of the definitions as follows:

- Definition of competence
- Types of competences (desired and existing competence)
- Competence structure
- Gap nodes competences
- Learning path

The given scenario (Appendix G) describes the overview of the experiment that participants were to review and gives access to the experimental system. They were to be given a set of desired and existing competences. By following the instructions (Appendix H), they could review the accessed study material links based on the three learning paths, and express their opinions about each learning path by filling in the questionnaire.

The questionnaire (Appendix I) was designed to ask experts to review and give a rating against each learning path on a 5-point Likert scale (Trochim, 2006). A Likert scale measures the extent to which a person agrees or disagrees with the questions or statements (Likert, 1932). They are 'Strongly Disagree', 'Disagree', 'Neither Agree Nor Disagree', 'Agree' and 'Strongly Agree'. The ratings for each scale are 1, 2, 3, 4 and 5, respectively. The questions are based upon the dependent variable as shown in a Table 8-1.

Table 8-1: *Corresponding Questions with Dependent Variables (Experimental I)*

Question No.	Dependent Variables	Actual Questions
1	Learning outcome achievement	A learner will be able to achieve his/her intended learning outcome after using the study material links.
2	Usefulness of competence gap nodes to help in achieving an intended learning outcome	Using study material links based on the gap learning outcome helps a learner to achieve his/her intended learning outcome.
3	Usefulness of competence gap nodes to improve learner's motivation	Using study material links based on the gap learning outcome helps to improve a learner's motivation.

Questions 2 and 3 were not asked if participants had experienced the first learning path ('ignore all gap nodes'), since competence gap nodes were not an element of this learning path.

8.5.2 Experimental Procedure

The experimental procedure involved the following steps:

1. Participants were welcomed and thanked for agreeing to be involved in the experiment.
2. They were given information about giving consent verbally.
3. Before the experiment was conducted, all participants received training in order to have a clear understanding of the terms and definitions used.
4. The participants were asked to read the scenario and the instructions on interacting with the system and filling in the questionnaire.
5. The participants interacted with the system.
6. Questionnaires were handed out at the end of reviewing the first learning path.
7. Participants were given as much time as they required completing what they were asked to do. Each participant was involved in the experiment for 45-60 minutes.

8.6 Experiment II

Experiment II was to determine users' overall reactions to a competence-based system (Kirkpatrick, 2007). The analysis was to measure any significant difference in the mean rating for each dependent variable from the particular value '3' on the Likert scale.

Two parts were given: one part was based on the HCF knowledge domain and the other was based on a photosynthesis knowledge domain for Key Stage 4 learners. The experiment was actually conducted at the same time as the experiments relating to Experiment I. The dependent variables are as follows:

1. 'Clarity of learner's intended learning outcome'
2. 'Clarity of learner's existing competence'
3. 'Clarity of competence gap nodes'
4. 'Quality of study materials'
5. 'Ease to access information'
6. 'Requirement of teacher'
7. 'Wide range of types of study materials'
8. 'Suggestion for future use'

Scenarios and instructions were the same as in the first experiment. The questionnaire (Appendix J) was designed to ask experts to review and give a rating against the competence-based system's features on a 5-point Likert scale, namely: 'Strongly Disagree', 'Disagree', 'Neither Agree Nor Disagree', 'Agree', and 'Strongly Agree'. The ratings for each scale were 1, 2, 3, 4 and 5, respectively. The questions were based on the dependent variable, as indicated in Table 8-2.

Table 8-2: *Corresponding Questions with Dependent Variables (Experimental II)*

Question No.	Dependent Variables	Actual Questions
1	Clarity of learner's intended learning outcome	The system helps a learner to identify his/her intended learning outcome.
2	Clarity of learner's existing competence	Choices in the list of existing competence can indicate a learner's actual competence
3	Clarity of competence gap nodes	The system helps a learner to identify assembled learning outcomes.
4	Quality of study materials	The generated webpages give information related to each learning outcome.
5	Ease to access information	A learner can find sufficient information on the topic within one page.

Question No.	Dependent Variables	Actual Questions
6	Requirement of teacher	A teacher is required to help a learner in order to explain information on the links.
7	Wide range of types of study materials	The webpages provide a learner not only with a text explanation but also other types of learning resources for example, figures, picture, video etc.
8	Suggestion for future use	I would suggest this system to other people for the future use.

This experiment was conducted at the same time as Experiment I; consequently the experimental procedures are the same (see section 8.5.2). The questionnaires to evaluate the overall system were given after participants had reviewed the study material links based on all three learning paths. The expected sample size for each experiment was 8, using the given values of:

- effect size f as 1
- alpha error probability as 0.05
- power as 0.8
- test-family as t-test
- statistical test as Means- Difference from constant (one sample case)

8.7 Experiment III

Experiment III was conducted to compare whether a competence-based learning mode is better than a freely-browsing learning mode. The pictorial representations of both learning modes are shown in Figure 8-2 and Figure 8-3.

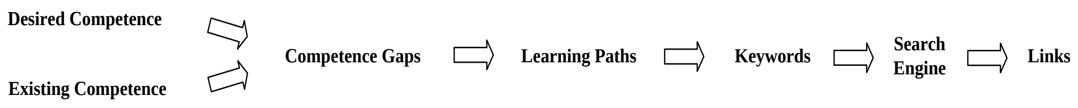


Figure 8-2 : *A Competence-based Learning Mode*

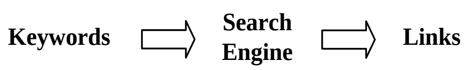


Figure 8-3: *A Freely-browsing Learning Mode*

In the competence-based learning mode, learners are given a set of subject matters to study and decide choices of competences on their own. The competence-based system generates the keywords from the chosen competences and suggests the searched links to learners. In a freely-browsing learning mode, learners are also given a set of subject matters to study, but they are required to decide the keywords to be given to the Google search engine on their own.

The experiment covered the second 'learning level' of Kirkpatrick's four levels of evaluation (Kirkpatrick, 2007). The participants could be anyone who had already learnt or who had never learnt photosynthesis at Key Stage 4. In order to test for a significant difference between the two learning modes, the learners (experimental subjects) were assigned to two groups: one group had experienced a competence-based learning mode and the other group had experienced a freely-browsing learning mode. All participants were required to take a pre-test and a post-test, before and after experiencing the respective learning modes. One participant could only interact with one type of learning mode. The given pre-tests and post-tests were the same for all participants, namely a multiple choice test consisting of 10 questions. The scores obtained from the pre-test and post-test were compared for each learning modes. The expected sample size for each experiment was 6, using the given values:

- effect size f as 1
- alpha error probability as 0.05
- power as 0.8
- number of group as 2
- test family as F-test
- statistical test as ANOVA: Repeated measures, within-between interaction

8.7.1 Experimental Materials

There were three main sets of materials given to the participants in Experiment III: a training document, scenario/instruction and a pre-test/post-test.

The training document (see Appendix K) was given to participants, so that they could have a clear understanding of the terms and definitions as follows:

- Definition of competence
- Types of competences (desired and existing competence)
- Competence structure
- Gap nodes competences
- Learning path

In addition, the training document also provided instructions on how to use a competence-based system. The training was aimed only at participants who had experienced the learning and competence-based learning modes.

The scenario and instructions (Appendix L) provided information relating to the overview of the experiments, and gave a set of subject matter content to be learnt by participants. They were firstly given a pre-test and later a set of targeted subject matters, which identified the knowledge area they needed to learn. They used this information to search study material links by experiencing an assigned learning mode.

The study duration was approximately 30 minutes. After they had finished the learning session, they completed a post-test, which was the same test as the pre-test.

The questions in the pre-test/post-test (see Appendix M) were based on all subject matters within a competence structure. The chosen subject matters were as follows:

- Photosynthesis rate
- Photosynthesis procedure
- Chlorophyll
- Carbon dioxide, Oxygen, Water, Glucose
- Chloroplast

Table 8-3 shows some corresponding pre-test/post-test questions with subject matter content.

Table 8-3: *Examples of Questions in Pre-test and Post-test (Experiment III)*

Subject Matter Content	**Questions in Pre-Test/Post-Test**
Photosynthesis rate	Which factor does not affect the rate of photosynthesis?
Photosynthesis procedure	What are the products of photosynthesis?
Chlorophyll	Which cells in leaf contain chlorophyll?
Carbon dioxide, Oxygen, Water, Glucose	Which chemical formulas represent carbon dioxide, oxygen, water and glucose respectively?
Chloroplast	A key molecule NOT found in a chloroplast is …

8.7.2 Experimental Procedure

The experimental procedure involved the following steps:

1. Participants were welcomed and thanked for taking part in the experiment.
2. They were verbally given consent information.
3. Before conducting the experiment, all participants received training in order to have a clear understanding of the terms and definitions used. Training would be required for some participants who were experiencing a competence-based learning mode.
4. The participants were asked to read the instructions on experiencing one type of learning mode and taking the pre-test and post-test.
5. The participants had a pre-test related to a photosynthesis knowledge domain (Key Stage 4).
6. The participants experienced one type of learning mode. The study duration was 30 minutes.

7. The participants had a post-test related to a photosynthesis knowledge domain (Key Stage 4).

8.8 Experiment IV

Experiment IV was developed from Experiment III. In this experiment, we investigated whether the search results given by the Google browser (www.google.com) were better than those given by Google API in terms of achievement in the competence node. This was supposed to be a blind rating that is the participants did not know which list of URLs came from which approach.

There were two main sets of materials given to a participant: scenario/instructions and a questionnaire. The scenario and instructions (Appendix N) present an overview of the experiment and the targeted competences based on which a participant is required to review study material links and the instructions as to how to rate each link. Another source provided was the questionnaire (see Appendix O), the purpose of which was to allow participants to give a rating to each link on a scale of six (1, 2, 3, 4, 5 and 6). The 6-point Likert scale was adopted in order to avoid a neutral or mid-point on the scale. Eliminating the mid-point category from the Likert scale reduces social desirability bias (Garland, 1991). In this experiment, participants were obliged to rate the links as either non-useful (1-3) or useful (4-6). The scales were:

1- This website is not related to any materials required in order to learn how to achieve a learning competence

2 - This website gives little information about how to achieve a learning competence

3 - This website gives some information about how to achieve a learning competence

4 - This website gives useful information about how to achieve a learning competence

5 - This website gives very useful information about how to achieve a learning competence

6 - This website gives, not only very useful information about how to achieve a learning competence, but also gives systematic feedback

There are 5 targeted competence nodes as follows:

- Recall a photosynthesis equation
- Recall a photosynthesis definition
- Demonstrate a day time photosynthesis procedure
- Predict a photosynthesis rate
- Define chlorophyll

For each node, the first three links from Google and Google API were generated. Hence the total number of links required was 30. However, the expected sample size (or links) for each experiment was actually 24, using the given values of:

- effect size f as 1
- alpha error probability as 0.05

- power as 0.8
- test family: F-test
- Number of groups: 2
- statistical test: ANOVA- fixed effects, special, main effects and interactions

The rates obtained were weighted during statistical analysis. A weight indicates the importance of the position of the link ranking by search engine. Referring to a system approach for offering links to learners, most users think that the first two links are important, so now we use the weighting scale in order to measure the importance of the ordering of links considered best in most users' thinking or Google's view. We needed to weight the pages, since the first-ranked page was not equally important to other ranked pages. In both types of search engine, we could obtain some identical links, but occurring in different positions.

In this experiment, we use %CTR (Click Through Rate) with Google ranking positions (Google Optimization Tutorials, 2010). Figure 8-4 shows a graphic representation of average %CTR per Google search engine rank position.

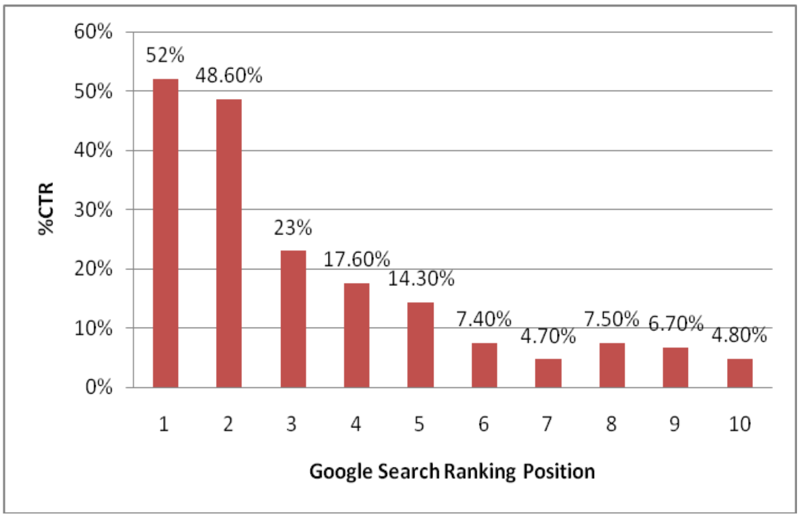


Figure 8-4: *Click Through Rate Average in Google Ranking Positions (Google Optimization Tutorials, 2010)*

In the first three links, %CTR was 52%, 48.6% and 23%. However, 23% is a relatively low amount, compared to 52% and 48.6%. Hence the percentages of CTR for the third and fourth links were combined and the new %CTR for the third link was 40.6%. The ratio was agreed to be 60:50:40, minimized to 6:5:4.

However, there are other approaches to weighting the rating. For example, one analysis based on Chitika.com (SEO Support, 2008) published statistics that generate the earning position on Google as the percentage of such traffic. The data show the overview of how the traffic is distributed among the first 20 position results. However, a limitation is that the results were only based upon one network analysis, namely Chitika. Another approach would be to use a PageRank indicator within the Google tool bar. This option indicates Google's view of the importance of the current page out of

10. But the problem with this option is that the Google toolbar sometimes does not show the scale of some links.

8.9 Experiment V

Experiment V was conducted to explore whether the search results for capability, subject matter and context keywords were better than subject matter keywords in terms of achievement in the competence node. During the experimental process of Experiment III, the keywords, which were generated by a competence-based system, were a set of capability, subject matter and context. While participants who experienced a freely-browsing learning mode were given a set of subject matter content to be learnt, they decided the keyword input themselves. Hence an experiment was conducted to determine whether the significant differences in the study material links were generated from different types of keywords.

The type of search engine decided upon was GoogleAPI, since the competence-based system uses GoogleAPI to search study material links from the Web. There were 5 targeted competence nodes (the same as in Experiment IV). For each node, the first three links based upon keywords input -SM (subject matter) and keywords input - CA+SM+CO (combination of capability, subject matter and context) were generated. Hence the total number of links required was 30.

There were two main materials giving to the participants: scenario/instructions and a questionnaire. These two materials (see Appendix N and Appendix O) were similar to the materials for Experiment IV.

8.10 Experiment VI

This experiment was to investigate whether the search results given by GoogleAPI were better than those given by iSEEK, which is an educational search engine in terms of the achievement of a competence node. The considered educational search engine for this experiment was iSEEK (www.iseek.com). It is an educational search engine that filters the search results from trusted sources, for example, universities, government, and related educational websites. Generally, users can choose to search from only educational websites or from every website available on the Web space. There is a navigation area, which allows users to choose categories of websites and determine the search results for a specific category. The categories are shown in Figure 8-5.

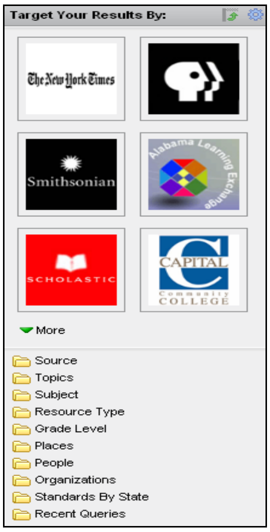


Figure 8-5: *iSEEK Navigation Area*

The explanations of some categories are as follows:

1. Source: This category differentiates the search results into three parts: iSEEK authoritative, General Web and State Standards.
2. Topics: This category differentiates the search results into several parts (depends upon the search keywords). For example, if the search keywords are 'recall energy' then the topics can be 'Energy Level', 'Space', 'High Energy Level', and etc.
3. Subject: This category differentiates the search results into several parts (depends upon the search keywords). For this example, the subjects could be 'Biology', 'Science', 'Chemistry', and 'English Language'.
4. Resource Type: This category differentiates the search results into types of documents or webpages for example, references, lesson plans, activities, literature text, and etc.
5. Grade Level: This category differentiates the search results into educational standard levels for example, high school, college, elementary, and pre-school.

This search engine has some useful features, for example user rating, share search results with friends, analysis of relevance to keywords, etc. In this experiment, the generated links were considered from default searching of iSEEK. No specific sources, topics, subjects or resources were considered for the links generated.

During the experimental process in Experiment VI, an experimental conductor listed study material links from both GoogleAPI and iSEEK, based on the same keywords (CA+SM+CO). There were 5 targeted competence nodes (the same as in Experiment IV). For each node, the first three links from GoogleAPI and iSEEK were generated. Hence the total number of links required was 30.

There were two main materials given to participants: scenario/instructions and a questionnaire. These two materials (see Appendix N and Appendix O) are similar to the materials provided for Experiment IV.

8.11 Statistical Terms/Tests Used

Some statistical terms and tests are used in this thesis. Explanations are as follows.

1. Level of significance or critical p-value

Normally most statistical tests use 5% by convention. In this research, a level of significance of 10% was also used in order to seek or explore suggestive results. Where post-hoc analyses were undertaken, techniques such as Bonferroni were used to control for type I error rate.

2. Effect size

Size of an effect indicates the size of an experimental manipulation or the strength of the relationship between variables (Field, 2000, pp. 32-33). An effect size is a standardized measure of the magnitude of an observed effect. In this research, the agreed number of effect size was 1. This represents a relatively large effect size.

3. Statistical Power

This is the ability of a test to detect an effect. Statistical power analysis exploits the relationships between the four variables involved in statistical inference: sample size (N), significance criteria, population effect size and statistical power (Cohen, 1988). The expected sample size for each experiment was based on these variables. In this research, the agreed figure for statistical power was 0.8.

4. One sample t-test

A one sample t-test was used to compare the mean score of a sample to a known value. In this experimental study, a one sample t-test was used to determine whether the mean rating for each dependent variable against the approach was significantly higher or lower than 3. This gives the answers to Experiment II. A value of 3 indicates 'Neither agree nor disagree' on the Likert scale that was used. As a t-test is used to analyse data for each dependent variable separately, Bonferroni correction (Toothaker, 1993) is then used to obtain a new significant level for the t-test.

5. Repeated Measure ANOVA

'Repeated measures' is a term used when the same participants fulfill all the conditions of the experiment (Field, 2000). During Experiment I, participants were required to review study material links based on all three learning paths, and express their opinions by giving a rating for each dependent variable against each learning path. In this experiment, the different conditions were the three learning paths. The 'Repeated-Measured ANOVA' test leads to the answers to Experiment I. This was to test for significant differences between the three learning paths, based on one dependent variable, namely 'learning outcome achievement'.

6. Repeated Measure MANOVA

The Repeated Measure MANOVA test is considered for analysis of situations where there are several dependent variables. This test was used to provide an answer for Experiment I. This was to test for significant differences between the two learning paths (learning paths 1 and 2) based on three dependent variables ('learning outcome achievement', 'usefulness of competence gap nodes' and 'learner motivation with competence gap nodes').

7. Repeated Two-Way ANOVA

A two-way test simply means that two independent variables have been manipulated in the experiment (Field, 2000). Hence, the test 'Repeated Two-Way ANOVA' is used when there are two repeated-measures independent variables: each participant undertakes all of the conditions in the experiment, and provides a score for each permutation of the two variables. This test was considered to provide an answer to Experiment III. Within a particular experiment, the two considered variables were types of tests and types of learning modes. There were two types of tests: pre-test and post-test. There were two types of learning modes: a freely-browsing learning mode and a competence-based learning mode. All participants experienced one of the learning modes, and were required to take both pre-tests and post-tests. The results of the tests showed an interaction effect between types of learning modes and types of test, a significant difference between types of learning modes and a significant difference between types of test.

8. Two-way ANOVA

A two-way analysis of variance (ANOVA) measures the effects of two factors simultaneously (Zar, 1996). A two-way test normally generates three *p*-values, one for each parameter independently, and one measuring the interaction effects between the two parameters. This test was used to explore the significant differences between the types of search engines used and the types of keywords used. Two-Way ANOVA was conducted three times. The first time was to determine the significant differences in the means of weighted ratings of study material links based on GoogleAPI and Google normal search. The second was to determine the significant differences in the means of weighted ratings for study material links based on keywords CA+SM+CO (combination of capability, subject matter and context) and only SM (subject matter). The last was to determine the significant differences in the means of weighted ratings for study material links based on GoogleAPI and an educational search engine (iSEEK). By considering the results of these tests, if an interaction effect were found, then the simple main effects for each parameter would be considered. In contrast, if there was a non-interaction effect, Bonferroni multiple comparisons could be considered, to detect differences in each individual pair of variables.

9. One-way ANOVA

One-way ANOVA is used to determine the significant differences between the means of two or more independent variables. This test is considered when an interaction effect from a two-way ANOVA test is found. If the results from one-way ANOVA show significant differences between the mean of independent variables, Tukey's HSD *post-hoc* test would be needed to determine which groups or which pairs differ.

10. Profile Plots/Graphs
Profile plots are used to display the means of independent variables. The overlapped error bars within profile plots could be considered as non-significant differences in means.
11. Multivariate Tests
Multivariate tests table are used in SPSS when the repeated measures ANOVA and MANOVA are used. Multivariate tests are determined to detect significant differences between learning paths. There are four such test statistics: Pillai's trace, Wilks' *lamda*, Hotelling's trace and Roy's largest root. In this thesis, Pillar's trace test statistics were mainly considered.
12. Tests of Within-Subjects Contrasts
In a within-subject design, each participant is tested under each condition. Normally this design is examined in repeated measure analysis. Tests of Within-Subjects Contrasts show the main results of ANOVA when repeated measures are considered. If the value of p is less than 0.05, then the means of the groups are significantly different (Field, 2000).
13. Tests of Between-Subjects Effects
In a between-subjects design, each participant is tested under one condition only. Tests of Between-Subjects Effects show the main results of ANOVA when two-way ANOVA is considered.

8.12 Summary

Six experiments are presented in this chapter. The first two experiments were to investigate appropriate learning paths and user overall reaction to Kirkpatrick's level one 'reaction', respectively. Experiment III was used to investigate the significant differences in the learners' learning improvements when interacting between a freely-browsing learning mode and a competence-based learning mode. Experiments IV, V, and VI were explored the types of search engines and different kinds of keywords that could affect the search results in terms of learners' learning outcome achievement. Following the targeted experiments, the obtained results and explanations of statistical analyses are presented in the next chapter.

Chapter 9
Experimental Results

9.1 Introduction

The previous chapter (Chapter 8) describes the methodology for the conducted experiments. This chapter gives the statistical results from the data deriving from those experiments, of which there were six. The statistical analysis for each experiment is presented separately.

9.2 Experiment I

Experiment I sought to compare three different learning paths. The three learning paths were:

- Learning path 1: ‘Ignore All Gap Nodes’
- Learning path 2: ‘Consider Some Gap Nodes’
- Learning path 3: ‘Consider All Gap Nodes’

The experiment was carried out in two parts. Each part compared learning paths for each knowledge domain. Part A was based on a mathematical HCF knowledge domain. Part B was based on a photosynthesis domain for Key Stage 4 learners. There were 9 participants for each experimental part ($n = 9$). Dependent variables for each part were:

- V1: ‘Learning outcome achievement’
- V2: ‘Usefulness of competence gap nodes to help achieve an intended learning outcome’
- V3: ‘Usefulness of competence gap nodes to improve learner’s motivation’

9.2.1 Experiment I Part A: Mathematical HCF

Repeated measures ANOVA and MANOVA were used to analyze the data obtained. For ‘learning outcome achievement’ over the three learning paths, repeated measures ANOVA was carried out. The overview of the experimental design is illustrated in Figure 9-1.

	LP1	LP2	LP3
Participant1	**LOA1**	**LOA2**	**LOA3**
Participant2	**LOA4**	**LOA5**	**LOA6**
•			
•			
•			
•			
Participant9	**LOA25**	**LOA26**	**LOA27**

LP1: Learning Path 1 “Ignore All Gap Nodes”
LP2: Learning Path 2 “Consider Some Gap Nodes”
LP3: Learning Path 3 “Consider All Gap Nodes”
LAO: Learning Outcome Achievement Rating

Figure 9-1: *Experimental Design of LP1 vs LP2 vs LP3 for ‘Learning Outcome Achievement’*

For all three dependent variables over learning path 2 and learning path 3, repeated measures MANOVA was carried out. The overview of the experimental design is illustrated in Figure 9-2. The variables ‘usefulness of competence gap nodes to help achieve an intended learning outcome’ and ‘usefulness of competence gap nodes to improve learner’s motivation’ were not considered for learning path 1 (‘ignore all gap nodes’) since competence gap nodes were not an element in this learning path.

	LP2	LP3
Participant1	**LOA1, UCG1, MCG1**	**LOA2, UCG2, MCG2**
Participant2	**LOA3, UCG3, MCG3**	**LOA4, UCG4, MCG4**
•		
•		
•		
•		
Participant9	**LOA17, UCG17, MCG17**	**LOA18, UCG18, MCG18**

LP2: Learning Path 2 “Consider Some Gap Nodes”
LP3: Learning Path 3 “Consider All Gap Nodes”
LAO: Learning Outcome Achievement Rating
UCG: Usefulness of Competence Gap Nodes For Achieving ILO Rating
MCG: Motivation with Competence Gap Nodes Rating

Figure 9-2: *Experimental Design of LP2 vs LP3 for All Three Variables*

Table 9-1 and Table 9-2 present descriptive statistics. Figure 9-3, Figure 9-4, Figure 9-5 and Figure 9-6 show profile graphs. Table 9-3 shows the results when comparing the three learning paths based on one dependent variable: ‘learning outcome achievement’. Table 9-4 shows the results when comparing learning path 2 and learning path 3 based on all three dependent variables.

Table 9-5 shows the F-test of significant difference for each pair of mean ratings for two of the learning paths.

Table 9-1*: Mean and Standard Deviation of Ratings of Learning Outcome Achievement for Three Learning Paths*

	Mean	Std. Deviation	N
LearningPath1_LearningOutComeAchievement	3.4	0.73	9
LearningPath2_LearningOutComeAchievement	3.4	0.73	9
LearningPath3_LearningOutComeAchievement	4.2	0.67	9

Table 9-2: *Mean and Standard Deviation of Ratings of All Dependent Variables for Learning Path 2 and 3*

	Mean	Std. Deviation	N
LearningPath2_LearningOutComeAchievement	3.4	0.73	9
LearningPath3_LearningOutComeAchievement	4.2	0.67	9
LearningPath2_UsefulnessOfCompetenceGaps	3.9	0.33	9
LearningPath3_UsefulnessOfCompetenceGaps	4.1	0.60	9
LearningPath2_LearnerMotivationWithCompetenceGaps	4.1	0.78	9
LearningPath3_LearnerMotivationWithCompetenceGaps	4.1	1.05	9

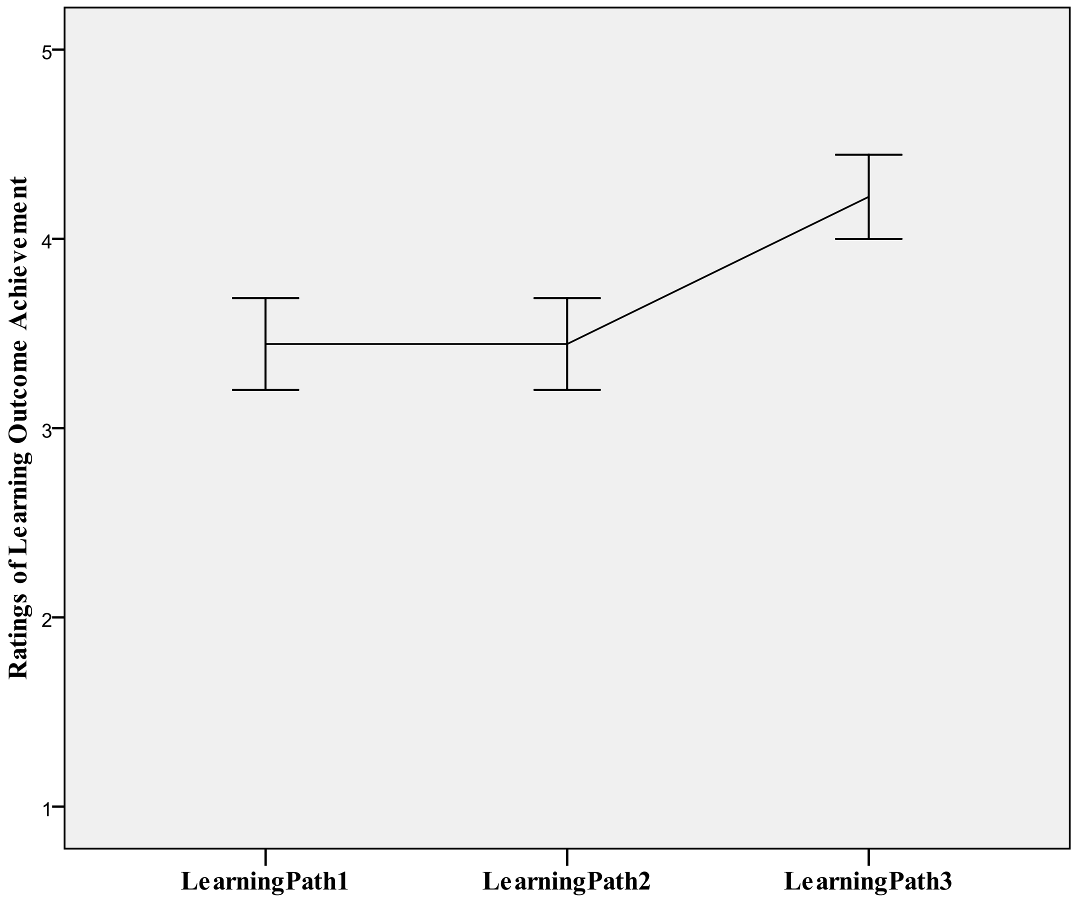


Figure 9-3: *Profile Graph of Mean Ratings of Learning Outcome Achievement for Three Learning Paths (Error Bars Show +- 1SE)*

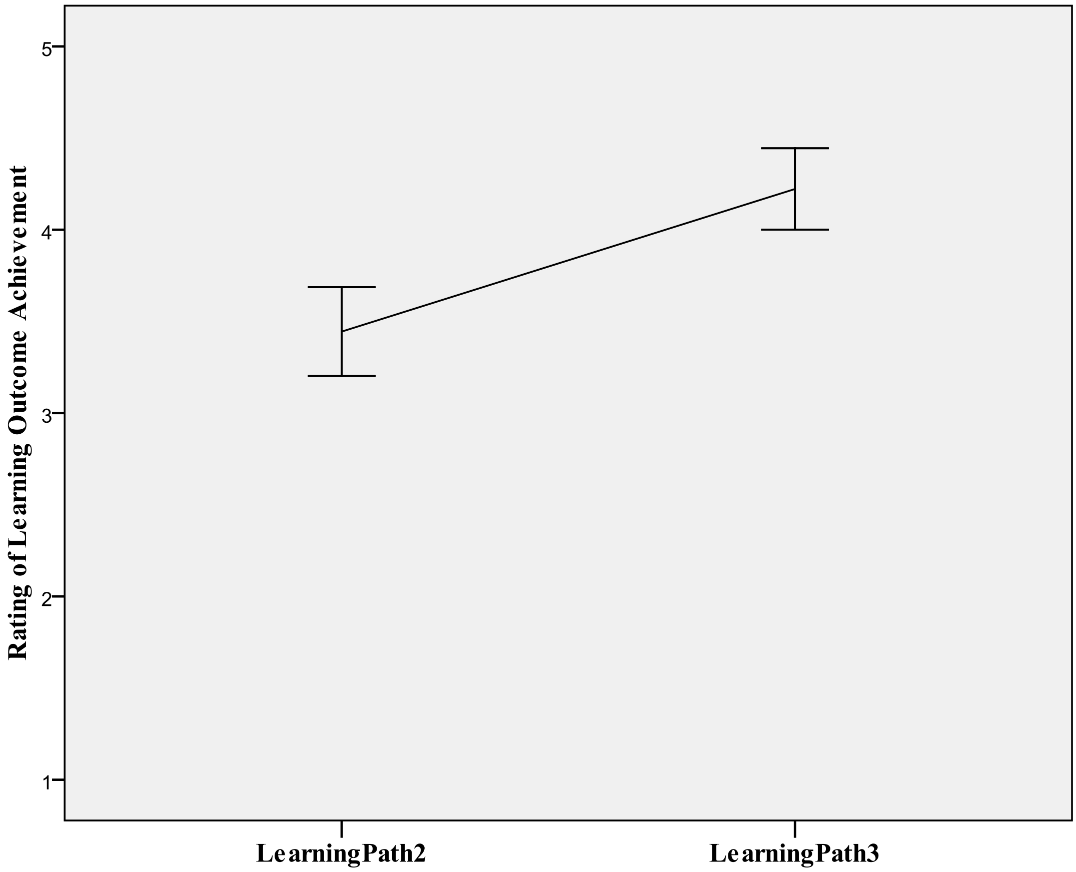


Figure 9-4: *Profile Graph of Mean Ratings of Learning Outcome Achievement for Learning Path 2 and 3*
(Error Bars Show +- 1SE and This Graph Also Shown in Figure 9-3)

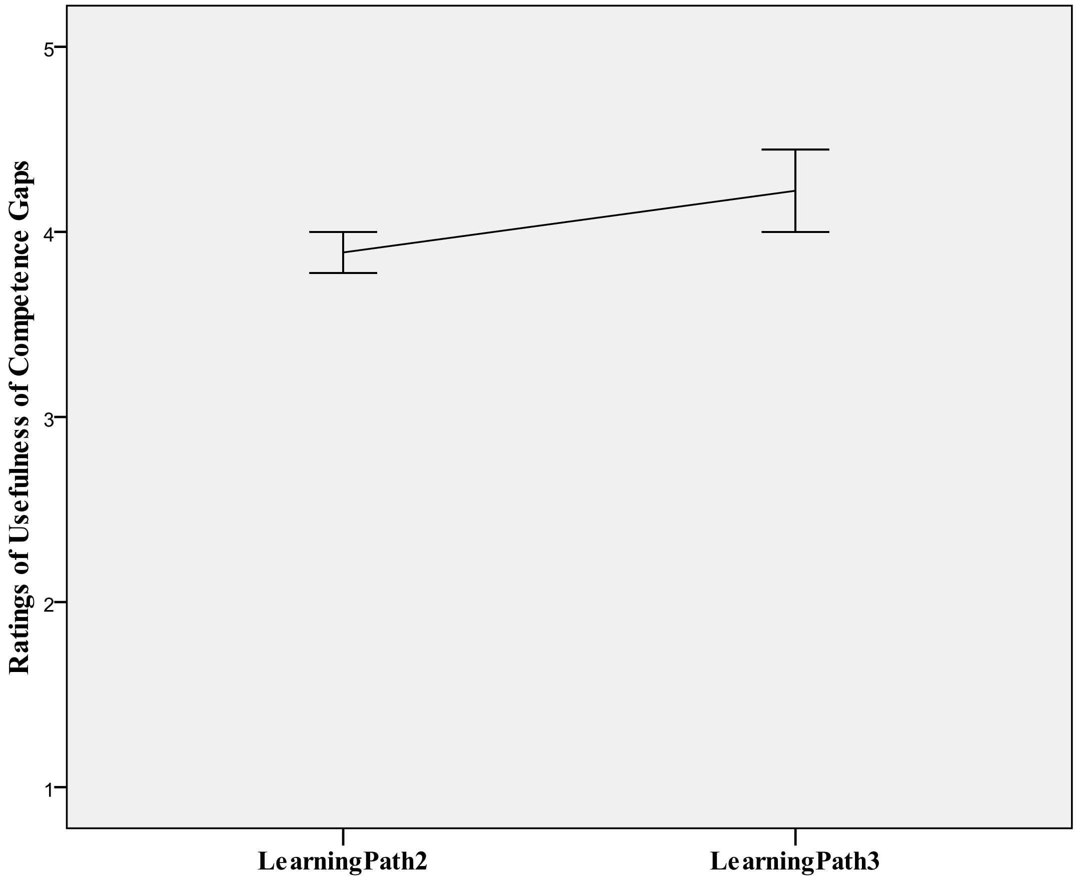


Figure 9-5: *Profile Graph of Mean Ratings of Usefulness of Competence Gap Nodes for Learning Path 2 and 3 (Error Bars Show +- 1SE)*

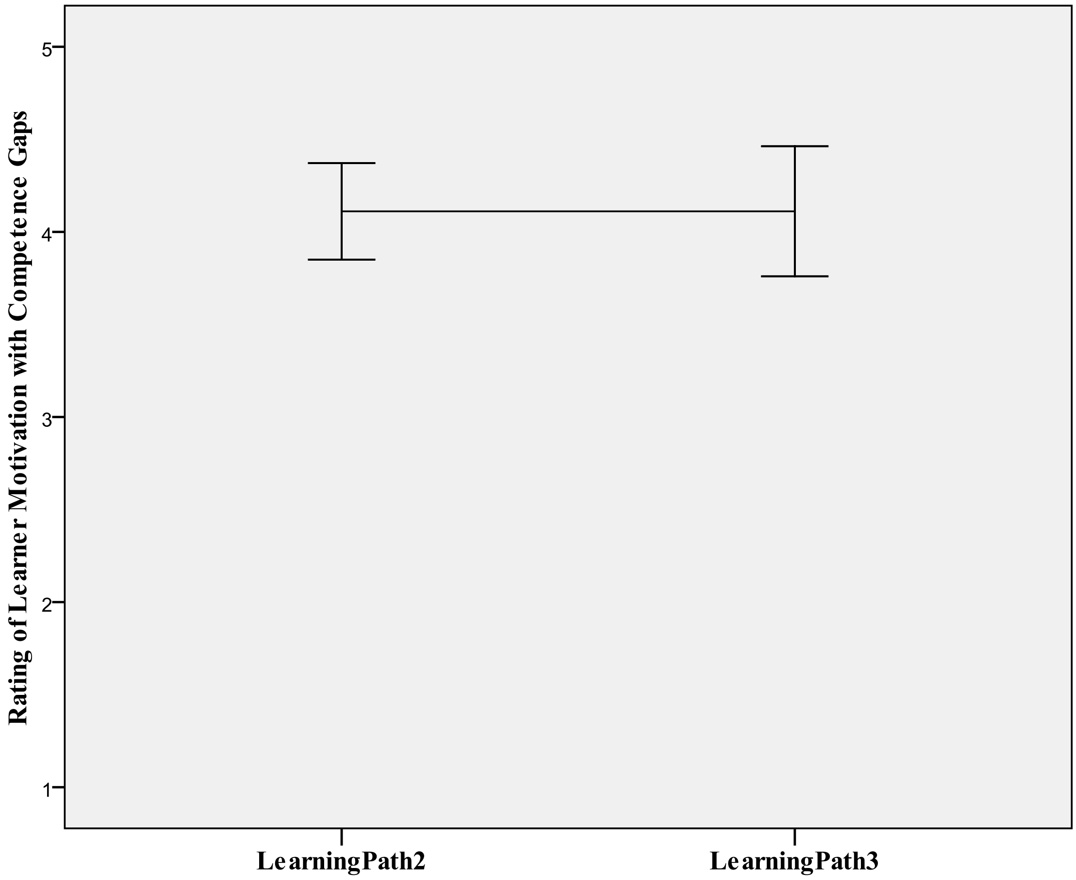


Figure 9-6: *Profile Graphs of Mean Ratings of Learner Motivation with Competence Gap Nodes for Learning Path 2 and 3 (Error Bar Show +- 1SE)*

Table 9-3: *Repeated Measure ANOVA - Multivariate Tests*

Effect		Value	F	Hypothesis df	Error df	Sig.
LearningPath (LP1 vs LP2 vs LP3)	Pillai's Trace	0.51	3.60	2	7	0.084
	Wilks' Lambda	0.50	3.60	2	7	0.084
	Hotelling's Trace	1.03	3.60	2	7	0.084
	Roy's Largest Root	1.03	3.60	2	7	0.084

Variable: 'learning outcome achievement'

Table 9-4: *Repeated Measure MANOVA – Multivariate Tests*

Within Subjects Effect		Value	F	Hypothesis df	Error df	Sig.
LearningPath (LP2 vs LP3)	Pillai's Trace	0.53	2.27	3	6	0.180
	Wilks' Lambda	0.47	2.27	3	6	0.180
	Hotelling's Trace	1.14	2.27	3	6	0.180
	Roy's Largest Root	1.14	2.27	3	6	0.180

Variables: 'learning outcome achievement'
'usefulness of competence gap nodes to help achieve an intended learning outcome'
'usefulness of competence gap nodes to improve learner's motivation'

Table 9-5: *Tests of Within-Subjects Contrasts*

Source	LearningPath	Type III Sum of Squares	df	Mean Square	F	Sig.
LearningPath (LP1 vs LP2 vs LP3)	Level 1 vs Level 2	0.00	1	0.00	0.00	1.000
	Level 2 vs Level 3	5.44	1	5.44	7.84	0.023
Error(LearningPath)	Level 1 vs Level 2	4.00	8	0.50		
	Level 2 vs Level 3	5.56	8	0.69		

Variable: 'learning outcome achievement'

Table 9-1 shows that the mean rating for 'learning outcome achievement' for learning path 3 was higher than for the other two learning paths, as illustrated in Figure 9-3. Table 9-3 shows the multivariate tests for significant difference between the mean ratings for 'learning outcome achievement'. Pillai's Trace ($0.05 < p = 0.084 < 0.10$) suggests that there is a significant difference in the mean ratings for 'learning outcome achievement' for the three learning paths.

Table 9-5 shows the F-test of significant difference for each pair of mean ratings for the two learning paths. There was a significant difference between the mean ratings for 'learning outcome achievement' for learning paths 2 and 3 ($p = 0.023 < 0.05$). Because the mean ratings for 'learning outcome achievement' for learning paths 1 and 2 were the same, there was a significant difference between the mean ratings for 'learning outcome achievement' for learning paths 1 and 3.

Table 9-2 shows that the mean ratings for 'learning outcome achievement' and 'usefulness of competence gap nodes to help achieve an intended learning outcome' for learning path 3 were higher than for learning path 2. These differences are illustrated in Figure 9-4 and Figure 9-5. The mean rating for 'usefulness of competence gap nodes to improve learner's motivation' for each learning path was the same. Table 9-4 shows the results of multivariate tests for significant difference between the mean ratings for the three variables ('learning outcome achievement', 'usefulness of competence gap nodes', and 'learner motivation with competence gap nodes') for learning paths 2 and 3. Pillai's Trace ($0.10 < p = 0.180$) suggests that there was no significant difference in the mean ratings between learning paths 2 and 3 in respect of all three variables.

9.2.2 Experiment I Part B: Photosynthesis for Key Stage 4 Learners

As in part A, repeated measures ANOVA and MANOVA were used to analyze the data obtained. The experimental designs for part B were the same as for part A (as shown in Figure 9-1 and Figure 9-2).

Table 9-6 and Table 9-7 display descriptive statistics. Figure 9-7, Figure 9-8, Figure 9-9 and Figure 9-10 display the profile graphs. Table 9-8 shows the repeated measure ANOVA result of comparing the three learning paths based on one dependent variable ('learning outcome achievement'). Table 9-9 shows the repeated measure MANOVA result of comparing learning path 2 and learning path 3 based on all three dependent variables. Table 9-10 shows the F-test of significant difference for each pair of mean ratings for two of the learning paths.

Table 9-6: Mean and Standard Deviation of Ratings of Learning Outcome Achievement for Three Learning Paths

	Mean	Std. Deviation	N
LearningPath1_LearningOutComeAchievement	2.7	1.23	9
LearningPath2_LearningOutComeAchievement	3.4	0.88	9
LearningPath3_LearningOutComeAchievement	4.0	0.71	9

Table 9-7: *Mean and Standard Deviation of Ratings of All Dependent Variables for Learning Path 2 and 3*

	Mean	Std. Deviation	N
LearningPath2_LearningOutComeAchievement	3.4	0.88	9
LearningPath3_LearningOutComeAchievement	4.0	0.71	9
LearningPath2_UsefulnessOfCompetenceGaps	3.4	1.13	9
LearningPath3_UsefulnessOfCompetenceGaps	4.3	0.50	9
LearningPath2_LearnerMotivationWithCompetenceGaps	3.9	0.78	9
LearningPath3_LearnerMotivationWithCompetenceGaps	4.4	0.73	9

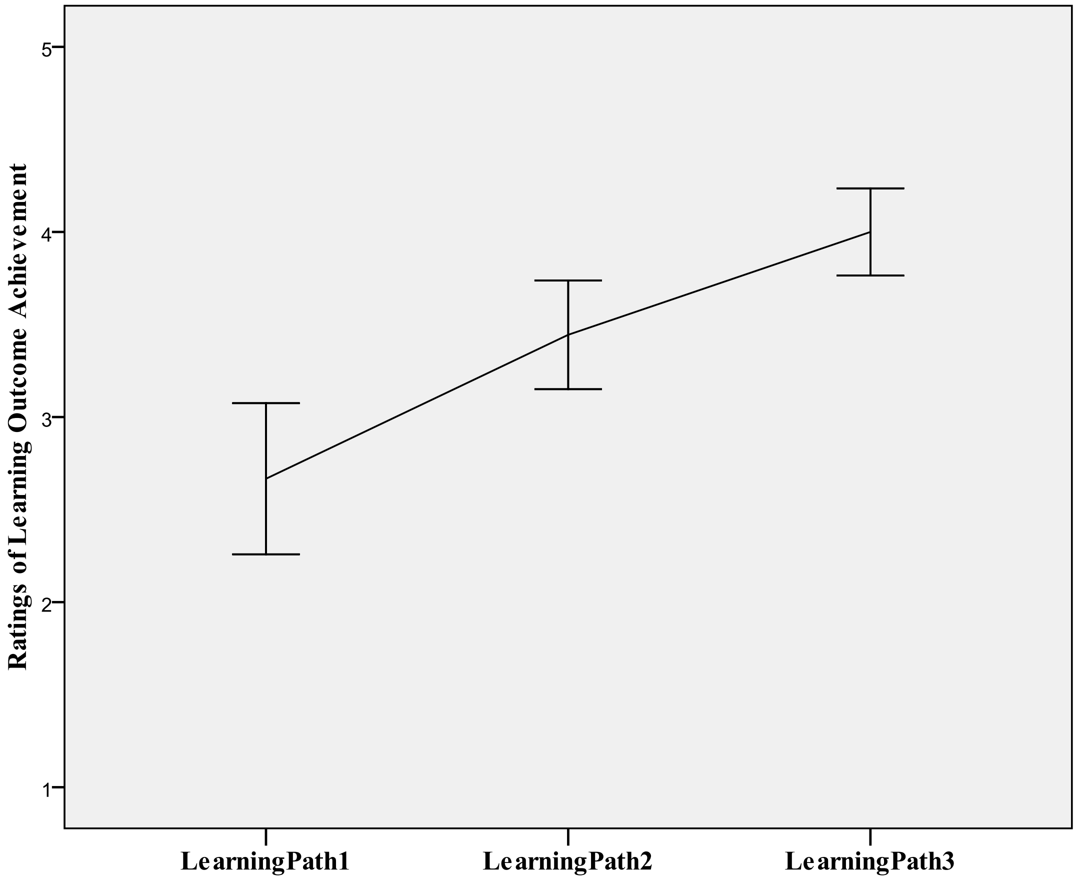


Figure 9-7: *Profile Graph of Mean Ratings of Learning Outcome Achievement for Three Learning Paths (Error Bars Show +- 1SE)*

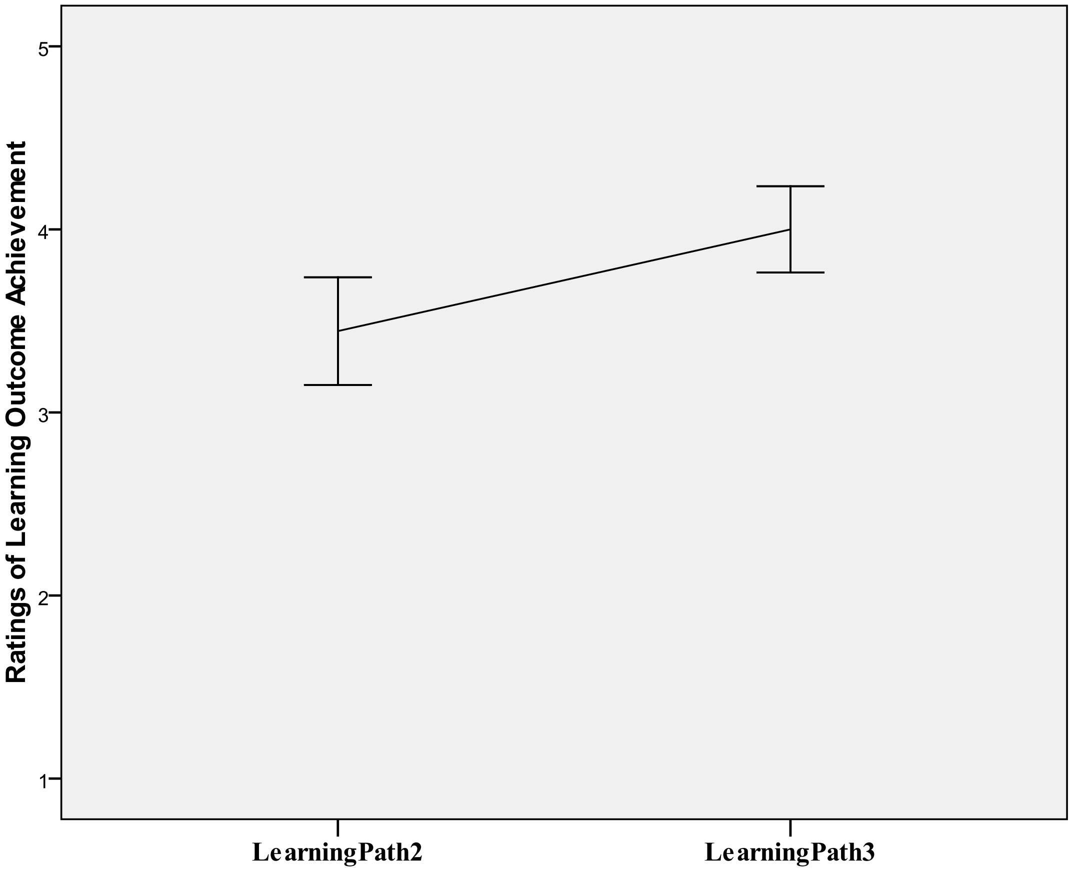


Figure 9-8: *Profile Graph of Mean Ratings of Learning Outcome Achievement for Learning Path 2 and 3*

(Error Bars Show +- 1SE and This Graph Also Shown in Figure 9-7)

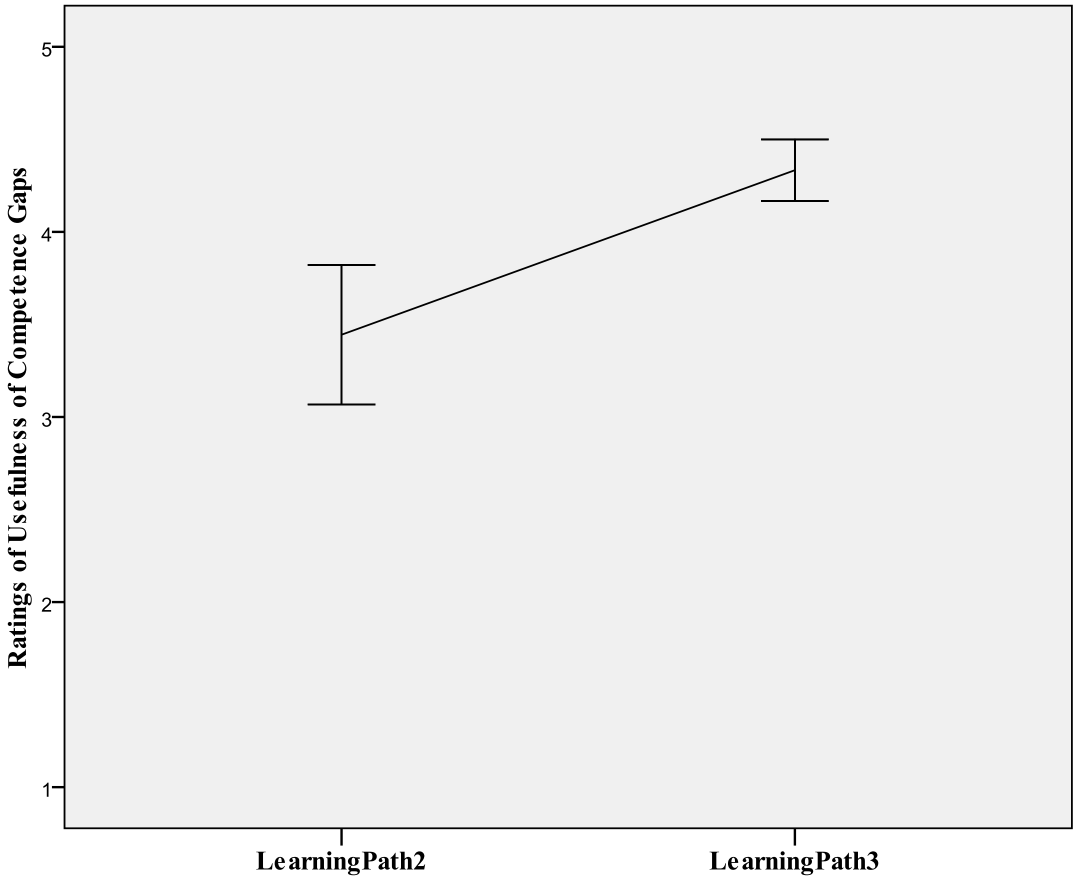


Figure 9-9: *Profile Graph of Mean Ratings of Usefulness of Competence Gap Nodes for Learning Path 2 and 3 (Error Bars Show +- 1SE)*

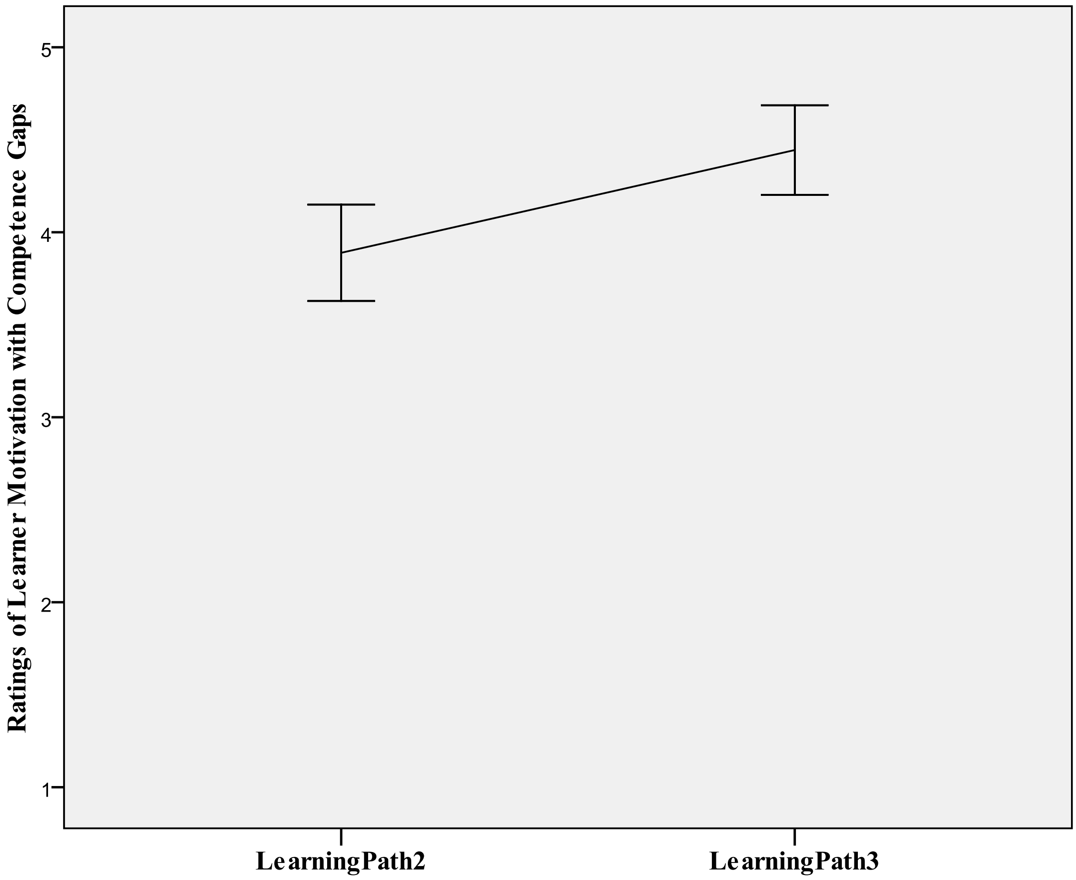


Figure 9-10: *Profile Graphs of Mean Ratings of Learner Motivation with Competence Gap Nodes for Learning Path 2 and 3 (Error Bar Show +- 1SE)*

Table 9-8: *Repeated Measure ANOVA - Multivariate Tests*

Effect		Value	F	Hypothesis df	Error df	Sig.
LearningPath (LP1 vs LP2 vs LP3)	Pillai's Trace	0.49	3.35	2	7	0.095
	Wilks' Lambda	0.51	3.35	2	7	0.095
	Hotelling's Trace	0.96	3.35	2	7	0.095
	Roy's Largest Root	0.96	3.35	2	7	0.095

Variable: 'learning outcome achievement'

Table 9-9: *Repeated Measure MANOVA – Multivariate Tests*

Within Subjects Effect		Value	F	Hypothesis df	Error df	Sig.
LearningPath (LP2 vs LP3)	Pillai's Trace	0.56	2.50	3	6	0.156
	Wilks' Lambda	0.44	2.50	3	6	0.156
	Hotelling's Trace	1.25	2.50	3	6	0.156
	Roy's Largest Root	1.25	2.50	3	6	0.156

Variables: 'learning outcome achievement'

'usefulness of competence gap nodes to help achieve an intended learning outcome'

'Usefulness of competence gap nodes to improve learner's motivation'

Table 9-10: *Tests of Within-Subjects Contrasts*

Source	LearningPath	Type III Sum of Squares	df	Mean Square	F	Sig.
LearningPath (LP1 vs LP2 vs LP3)	Level 1 vs Level 3	16.00	1	16.00	5.82	0.042
	Level 2 vs Level 3	2.78	1	2.78	5.26	0.051
Error(LearningPath)	Level 1 vs Level 3	22.00	8	2.75		
	Level 2 vs Level 3	4.22	8	0.53		

Variable: 'learning outcome achievement'

Table 9-6 shows that the mean rating for 'learning outcome achievement' for learning path 3 was higher than for the other two learning paths, as illustrated in Figure 9-7. Table 9-8 shows the results of multivariate tests of significant difference between the mean ratings for 'learning outcome achievement'. Pillai's Trace ($0.05 < p = 0.095 < 0.10$) suggests that there was a significant difference in the mean ratings of 'learning outcome achievement' for the three learning paths. Table 9-10 shows the result of the F-test of significant difference for each pair of mean ratings for two learning paths. There was a significant difference between the mean ratings for 'learning outcome achievement' for learning paths 1 and 2 ($p = 0.042 < 0.05$). The results also showed that there was no significant difference between the mean ratings for learning paths 2 and 3 ($0.05 < p = 0.051$).

Table 9-7 shows that the mean ratings for all three variables ('learning outcome achievement', 'usefulness of competence gap nodes to help achieve an intended learning outcome', and 'usefulness of competence gap nodes to improve learner's motivation') for learning path 3 were higher than for learning path 2. These differences are illustrated in Figure 9-8, Figure 9-9 and Figure 9-10. Figure 9-9 shows the results of multivariate tests of significant difference between the mean ratings for three variables for learning paths 2 and 3. Pillai's Trace ($0.10 < p = 0.156$) suggests that there was no significant difference in the mean ratings for all three variables for the three learning paths.

9.3 Experiment II

Experiment II was to determine users' overall reaction to Kirkpatrick's level one 'reaction' (Kirkpatrick, 2007). The analysis was to determine the significant differences between the mean ratings for each dependent variable and the particular value '3' on the Likert scale. There were two parts based on two knowledge domains. Part A was based on a mathematical HCF knowledge domain. Part B was based on a photosynthesis domain for Key Stage 4 learners. There were 9 participants in each part ($n = 9$). Dependent variables for the two parts were:

1. Clarity of learner's intended learning outcome
2. Clarity of learner's existing competence
3. Clarity of competence gap nodes
4. Quality of study materials
5. Ease to access information
6. Requirement of teacher
7. Wide range of types of study materials
8. Suggestion for future use

A one-sample t-test was used to analyze the data obtained for each variable in the experiment. For this experiment the number of tests of significance m equals 8.

Bonferroni correction provides an α level of 0.05/m = 0.0063. Our criterion for significance was thus 0.0063.

9.3.1 Experiment II Part A: Mathematical HCF

Table 9-11 presents the descriptive statistics. Table 9-12 shows the result of comparing the mean rating for each dependent variable against a value '3' in a competence-based system for the HCF knowledge domain.

Table 9-11: *Mean, Standard Deviation, STD. Error of Mean of Ratings of All Variables (HCF Knowledge Domain)*

	N	Mean	Std. Deviation	Std. Error Mean
1.Clarity of learner's intended learning outcome	9	4.0	0.50	0.17
2. Clarity of learner's existing competence	9	4.0	0.50	0.17
3. Clarity of competence gap nodes	9	4.1	0.60	0.20
4. Quality of study materials	9	3.8	1.20	0.40
5. Ease to access information	9	3.1	0.93	0.31
6. Requirement of teacher	9	3.6	0.88	0.30
7. Wide range of types of study materials	9	4.3	0.50	0.17
8. Suggestion for future use	9	4.0	0.50	0.17

Table 9-12: *One-sample t-test (HCF Knowledge Domain)*

	Test Value = 3					
					95% CI	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
1. Clarity of learner's intended learning outcome	6.00	8	< 0.001	1.0	0.6	1.4
2. Clarity of learner's existing competence	6.00	8	< 0.001	1.0	0.6	1.4
3. Clarity of competence gap nodes	5.55	8	< 0.001	1.1	0.7	1.6
4. Quality of study materials	1.94	8	0.09	0.8	-0.2	1.7
5. Ease to access information	0.36	8	0.73	0.1	-0.6	0.8
6. Requirement of teacher	1.89	8	0.10	0.6	-0.1	1.2
7. Wide range of types of study materials	8.00	8	< 0.001	1.3	1.0	1.7
8. Suggestion for future use	6.00	8	< 0.001	1.0	0.6	1.4

The results from Table 9-11 and Table 9-12 were as follows:

1. Dependent Variable: ‘Clarity of learner's intended learning outcome’

As $p < 0.0063$, the mean rating of ‘Clarity of learner’s intended learning outcome’ for a competence-based system was significantly higher than 3.

2. Dependent Variable: ‘Clarity of learner’s existing competence’

As $p < 0.0063$, the mean rating of ‘Clarity of learner’s existing competence’ for a competence-based system was significantly higher than 3.

3. Dependent Variable: ‘Clarity of competence gap nodes’

As $p < 0.0063$, the mean rating of ‘Clarity of competence gap nodes’ for a competence-based system was significantly higher than 3.

4. Dependent Variable: ‘Quality of study materials’

As $p > 0.0063$, the mean rating of ‘Quality of study materials’ for a competence-based system was not significantly different from 3.

5. Dependent Variable: ‘Ease to access information’

As $p > 0.0063$, the mean rating of ‘Ease to access information’ for a competence-based system was not significantly different from 3.

6. Dependent Variable: ‘Requirement of teacher’

As $p > 0.0063$, the mean rating of ‘Requirement of teacher’ for a competence-based system was not significantly different from 3.

7. Dependent Variable: ‘Wide range of types of study materials’

As $p < 0.0063$, the mean rating of ‘Wide range of types of study materials’ for a competence-based system was significantly higher than 3.

8. Dependent Variable: ‘Suggestion for future use’

As $p < 0.0063$, the mean rating of ‘Suggestion for future use’ for a competence-based system was significantly higher than 3.

9.3.2 Experiment II Part B: Photosynthesis for Key Stage 4 Learners

Table 9-13 shows descriptive statistics. Table 9-14 shows the result of comparing the mean rating for each dependent variable against a value ‘3’ of a competence-based system for the photosynthesis domain at Key Stage 4.

Table 9-13: *Mean, Standard Deviation, STD. Error of Mean of Ratings of All Variables (Photosynthesis at Key Stage 4)*

	N	Mean	Std. Deviation	Std. Error Mean
1. Clarity of learner's intended learning outcome	9	4.1	0.78	0.26
2. Clarity of learner's existing competence	9	4.2	0.67	0.22
3. Clarity of competence gap nodes	9	4.3	0.71	0.24
4. Quality of study materials	9	3.8	0.67	0.22
5. Ease to access information	9	3.1	0.93	0.31
6. Requirement of teacher	9	3.4	0.73	0.24
7. Wide range of types of study materials	9	4.4	1.01	0.34
8. Suggestion for future use	9	4.1	0.78	0.26

Table 9-14: *One-sample t-test Results (Photosynthesis at Key Stage 4)*

	Test Value = 3					
					95% CI	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
1. Clarity of learner's intended learning outcome	4.26	8	0.003	1.1	0.5	1.7
2. Clarity of learner's existing competence	5.50	8	0.001	1.2	0.7	1.7
3. Clarity of competence gap nodes	5.66	8	< 0.001	1.3	0.8	1.9
4. Quality of study materials	3.50	8	0.008	0.8	0.3	1.3
5. Ease to access information	0.36	8	0.729	0.1	-0.6	0.8
6. Requirement of teacher	1.84	8	0.104	0.4	-0.1	1.0
7. Wide range of types of study materials	4.27	8	0.003	1.4	0.7	2.2
8. Suggestion for future use	4.26	8	0.003	1.1	0.5	1.7

The results from Table 9-13 and Table 9-14 are as follows:

1. Dependent Variable: 'Clarity of learner's intended learning outcome'

As $p < 0.0063$, the mean rating of 'Clarity of learner's intended learning outcome' for a competence-based system was significantly higher than 3.

2. Dependent Variable: 'Clarity of learner's existing competence'

As $p < 0.0063$, the mean rating of 'Clarity of learner's existing competence' for a competence-based system was significantly higher than 3.

3. Dependent Variable: 'Clarity of competence gap nodes'

As $p < 0.0063$, the mean rating of 'Clarity of competence gap nodes' for a competence-based system was significantly higher than 3.

4. Dependent Variable: 'Quality of study materials'

As $p < 0.0063$, the mean rating of 'Quality of study materials' for a competence-based system was significantly higher than 3.

5. Dependent Variable: 'Ease to access information'

As $p > 0.0063$, the mean rating of 'Ease to access information' for a competence-based system was not significantly different from 3.

6. Dependent Variable: 'Requirement of teacher'

As $p > 0.0063$, the mean rating of 'Requirement of teacher' for a competence-based system was not significantly different from 3.

7. Dependent Variable: 'Wide range of types of study materials'

As $p < 0.0063$, the mean rating of 'Wide range of types of study materials' for a competence-based system was significantly higher than 3.

8. Dependent Variable: 'Suggestion for future use'

As $p < 0.0063$, the mean rating of 'Suggestion for future use' for a competence-based system was significantly higher than 3.

9.4 Experiment III

Experiment III explored whether a competence-based learning mode was better than a freely-browsing learning mode. The experimental subjects were divided into two groups: one group experienced a competence-based learning mode and the other group experienced a freely-browsing learning mode. All participants were required to take a pre-test and a post-test before and after experiencing the learning mode. There was a total of 8 participants: 4 participants experienced a freely-browsing learning mode and the other 4 experienced a competence-based learning mode.

Two-way repeated measures ANOVA was used to analyze the obtained test scores, in order to determine the better learning mode. Table 9-15, Table 9-16 and Table 9-17 show the descriptive statistics, the tests of within-subjects effects and the tests of between-subjects effects.

‘Learning mode’ comprised two levels, freely-browsing and competence-based. ‘Test type’ comprised two levels, pre-test and post-test.

Table 9-15: *Mean and Standard Deviation of Test Scores*

Test_Type	Learning_Mode	Mean	Std. Deviation	N
Pre_Test	Freely_Browsing	7.0	1.41	4
	Competence_Based	4.5	1.29	4
	Total	5.8	1.83	8
Post_Test	Freely_Browsing	7.8	1.89	4
	Competence_Based	6.3	1.26	4
	Total	7.0	1.69	8
Total	Freely_Browsing	7.4	1.50	8
	Competence_Based	5.4	1.41	8
	Total	6.4	1.76	16

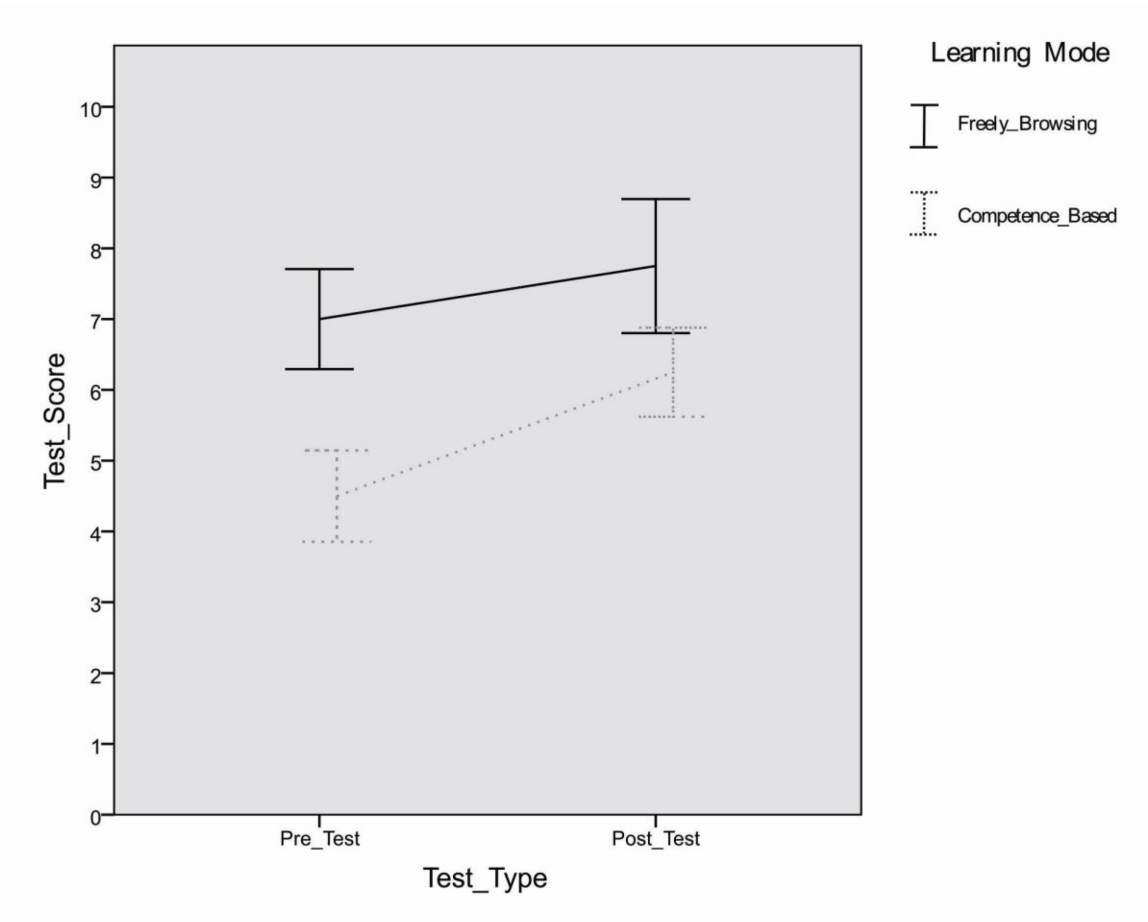


Figure 9-11: *Profile Graph of Mean Ratings of Test Scores of Pre-Test and Post-Test for Two Learning Modes (Error Bars Show +- 1SE)*

Table 9-16: *Tests of Within-Subjects Effects*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Test_Type	6.25	1	6.25	4.84	0.07
Test_Type * Learning_Mode	1.00	1	1.00	0.77	0.41

Table 9-17: *Tests of Between-Subjects Effects*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Learning_Mode	16.00	1	16.00	5.12	0.06
Error	18.75	6	3.13		

The results from the statistical data obtained (as shown in Table 9-15, Table 9-16, and Table 9-17) were as follows.

1. There was no interaction effect between test type and learning mode ($0.10 < p = 0.41$).
2. There was a significant test type effect. The result suggested that there was a significant difference between the mean test scores between pre-test and post-test at a significance level of 0.10 ($0.05 < p = 0.07 < 0.10$). Inspection of the means in Table 9-15 shows that the post-test mean was significantly higher than the pre-test mean.
3. There was a significant learning mode effect. The result suggested that there was a significant difference between the mean test scores between a freely-browsing learning mode and a competence-based learning mode ($0.05 < p = 0.06 < 0.10$). Inspection of the means in Table 9-15 shows that the mean of the freely-browsing learning mode was significantly higher than the mean of the competence-based learning mode.

The profile plot illustrates the interaction (Figure 9-11). The profile lines are apparently not parallel, visually suggesting an interaction, but not a statistically significant effect.

9.5 Experiment IV

Experiment IV explored the question: 'Are search results given by Google browser (www.google.com) better than those given by GoogleAPI in terms of relating to the achievement of competence nodes?'

Two-way ANOVA was used to analyze the data obtained in order to find any significant differences between the means for 'helpfulness to achieve learning outcome' rating for the search engine types and competence nodes types.

Table 9-18, Table 9-19 and Table 9-20 show the descriptive statistics, tests of between-subjects effects and multiple comparisons of the data obtained. Figure 9-12 and Figure 9-13 show the profile plots of means for weighted ratings of search engine types and competence nodes types, respectively.

'SearchEngine_Type' comprised two levels: GoogleSE and GoogleAPI. 'Competence_Node' comprised five levels: 'Recall a photosynthesis equation', 'Recall a photosynthesis definition', 'Demonstrate a daytime photosynthesis procedure', 'Predict a photosynthesis rate' and 'Define chlorophyll'.

Table 9-18: *Means and Standard Deviations of Weighted Ratings of Links (Google Search Engine vs Google API)*

SearchEngine_Type	Competence_Node	Mean	Std. Dev	N
GoogleSE	Recall a photosynthesis equation	20.7	11.37	3
	Recall a photosynthesis definition	13.3	4.16	3
	Demonstrate a day time photosynthesis procedure	11.3	1.16	3
	Predict a photosynthesis rate	5.0	1.00	3
	Define chlorophyll	6.7	3.06	3
	Total	11.4	7.44	15
GoogleAPI	Recall a photosynthesis equation	21.3	7.57	3
	Recall a photosynthesis definition	14.0	8.72	3
	Demonstrate a day time photosynthesis procedure	12.0	5.29	3
	Predict a photosynthesis rate	5.0	1.00	3
	Define chlorophyll	6.7	3.06	3
	Total	11.8	7.79	15
Total	Recall a photosynthesis equation	21.0	8.65	6
	Recall a photosynthesis definition	13.7	6.12	6
	Demonstrate a day time photosynthesis procedure	11.7	3.45	6
	Predict a photosynthesis rate	5.0	0.89	6
	Define chlorophyll	6.7	2.73	6
	Total	11.6	7.49	30

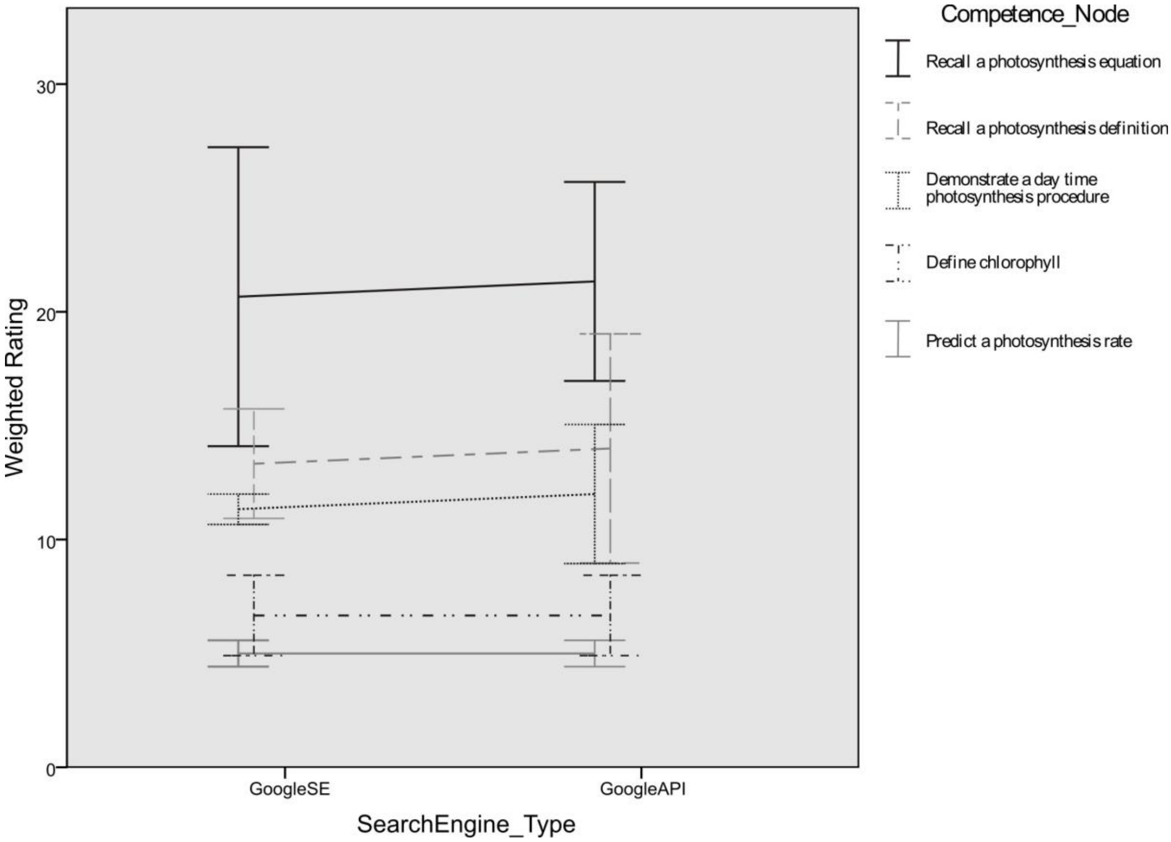


Figure 9-12: *Profile Graph of Mean of Weighted Ratings of Links of Each Competence Nodes for Two Search Engine Types (Error Bars Show +- 1SE)*

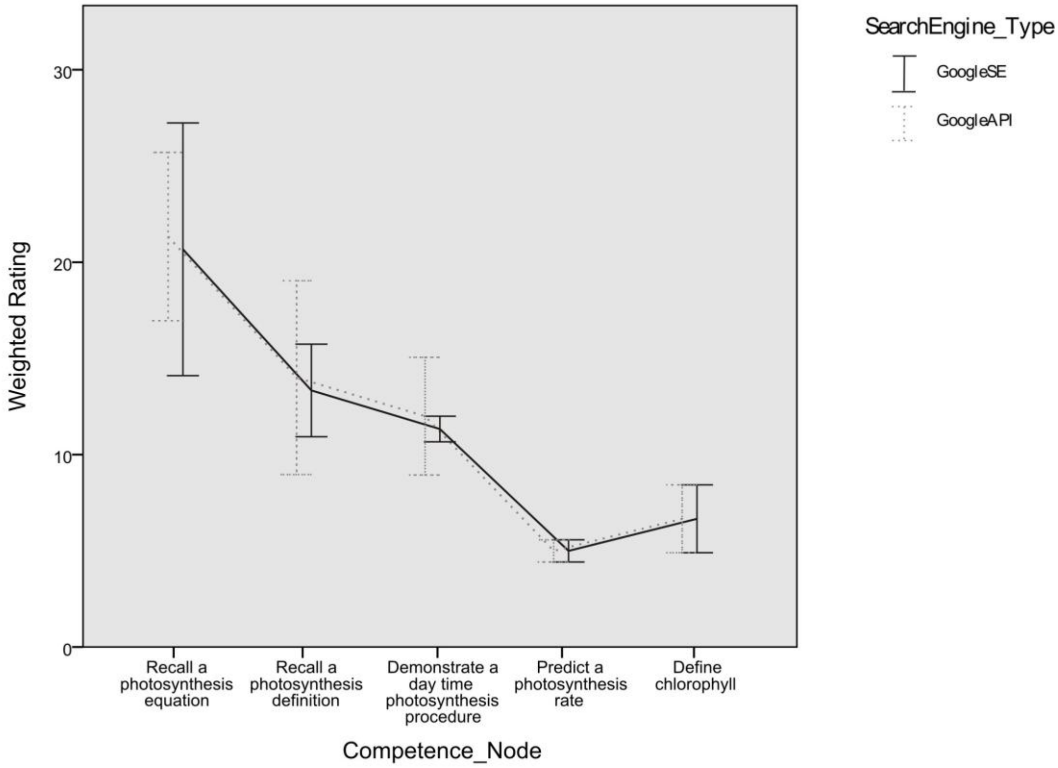


Figure 9-13: *Profile Graph of Mean of Weighted Ratings of Links of Each Search Engine for Five Types of Competence Node (Error Bars Show +- 1SE)*

Table 9-19: *Tests of Between-Subjects Effects (Google Browser vs Google API)*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SearchEngine_Type	1.20	1	1.20	0.04	0.851
Competence_Node	963.20	4	240.80	7.30	0.001
SearchEngine_Type * Competence_Node	0.80	4	0.20	0.01	1.000
Error	660.00	20	33.00		
Total	1625.20	29			

Table 9-20: *Bonferroni Multiple Comparisons (Google Browser vs Google API)*

(I) Competence_Node	(J) Competence_Node	Mean Difference (I-J)	SE	Sig.	95% CI Lower Bound	95% CI Upper Bound
Recall a photosynthesis equation	Recall a photosynthesis definition	7.3	3.32	0.388	-3.1	17.8
	Demonstrate a day time photosynthesis procedure	9.3	3.32	0.107	-1.1	19.8
	Predict a photosynthesis rate	16.0	3.32	0.001	5.5	26.5
	Define chlorophyll	14.3	3.32	0.003	3.9	24.8
Recall a photosynthesis definition	Recall a photosynthesis equation	-7.3	3.32	0.388	-17.8	3.1
	Demonstrate a day time photosynthesis procedure	2.0	3.32	1.000	-8.5	12.5
	Predict a photosynthesis rate	8.7	3.32	0.166	-1.8	19.1
	Define chlorophyll	7.0	3.32	0.476	-3.5	17.5
Demonstrate a day time photosynthesis procedure	Recall a photosynthesis equation	-9.3	3.32	0.107	-19.8	1.1
	Recall a photosynthesis definition	-2.0	3.32	1.000	-12.5	8.5
	Predict a photosynthesis rate	6.7	3.32	0.581	-3.8	17.1
	Define chlorophyll	5.0	3.32	1.000	-5.5	15.5
Predict a photosynthesis rate	Recall a photosynthesis equation	-16.0	3.32	0.001	-26.5	-5.5
	Recall a photosynthesis definition	-8.7	3.32	0.166	-19.1	1.8
	Demonstrate a day time photosynthesis procedure	-6.7	3.32	0.581	-17.1	3.8
	Define chlorophyll	-1.7	3.32	1.000	-12.1	8.8
Define chlorophyll	Recall a photosynthesis equation	-14.3	3.32	0.003	-24.8	-3.9
	Recall a photosynthesis definition	-7.0	3.32	0.476	-17.5	3.5
	Demonstrate a day time photosynthesis procedure	-5.0	3.32	1.000	-15.5	5.5
	Predict a photosynthesis rate	1.7	3.32	1.000	-8.8	12.1

The results from the statistical data obtained (as shown in Table 9-18, Table 9-19, Table 9-20, Figure 9-12 and Figure 9-13) were as follows.

1. There was no significant interaction effect between types of search engine (Google & GoogleAPI) and types of competence node ($0.10 < p = 1.000$).
2. There was no significant main effect of types of search engine. This indicates that there was no significant difference between the means of weighted ratings for links generated from Google and GoogleAPI ($0.10 < p = 0.851$).
3. There was a significant main effect of types of competence node. This indicates that there were significant differences among the means of weighted ratings for links based on different types of competence node ($p = 0.001 < 0.05$).

In order to see which pairs of competence nodes were significantly different, Bonferroni multiple comparisons were undertaken (Field, 2000, pp. 339-341). Significant differences were seen between the following pairs of competence nodes:

- Recall a photosynthesis equation vs Predict a photosynthesis rate ($p = 0.001 < 0.05$)
- Recall a photosynthesis equation vs Define chlorophyll ($p = 0.003 < 0.05$))

9.6 Experiment V

Experiment V explored the question 'Are search results from capability, subject matter and context keywords better than those from subject matter content keywords alone in terms of relating to the achievement of competence nodes?'

Two-way ANOVA was used to analyze the data obtained in order to find any significant differences between means of 'helpfulness to achieve learning outcome' ratings for types of keyword and types of competence.

Table 9-21, Table 9-22 and Table 9-23 show descriptive statistics, tests of between-subjects effects and multiple comparisons of the data obtained, respectively. Figure 9-14 and Figure 9-15 show the profile plots of means of weighted ratings for keyword types and competence node types, respectively.

'Keyword_Type' comprised two levels: SM and CA+SM+CO. 'Competence_Node' comprised five levels: 'Recall a photosynthesis equation', 'Recall a photosynthesis definition', 'Demonstrate a daytime photosynthesis procedure', 'Predict a photosynthesis rate' and 'Define chlorophyll'.

Table 9-21: *Means and Standard Deviations of Weighted Ratings of Links (SM vs CA+SM+CO)*

Keyword_Type	Competence_Node	Mean	Std. Dev	N
SM	Recall a photosynthesis equation	25.0	5.00	3
	Recall a photosynthesis definition	20.3	8.39	3
	Demonstrate a day time photosynthesis procedure	11.3	1.16	3
	Predict a photosynthesis rate	23.3	5.77	3
	Define chlorophyll	23.7	7.10	3
	Total	20.7	7.21	15
CA+SM+CO	Recall a photosynthesis equation	23.3	5.77	3
	Recall a photosynthesis definition	12.0	5.29	3
	Demonstrate a day time photosynthesis procedure	8.3	3.51	3
	Predict a photosynthesis rate	25.0	5.00	3
	Define chlorophyll	25.0	5.00	3
	Total	18.7	8.48	15
Total	Recall a photosynthesis equation	24.2	4.92	6
	Recall a photosynthesis definition	16.2	7.76	6
	Demonstrate a day time photosynthesis procedure	9.8	2.86	6
	Predict a photosynthesis rate	24.2	4.92	6
	Define chlorophyll	24.3	5.54	6
	Total	19.7	7.80	30

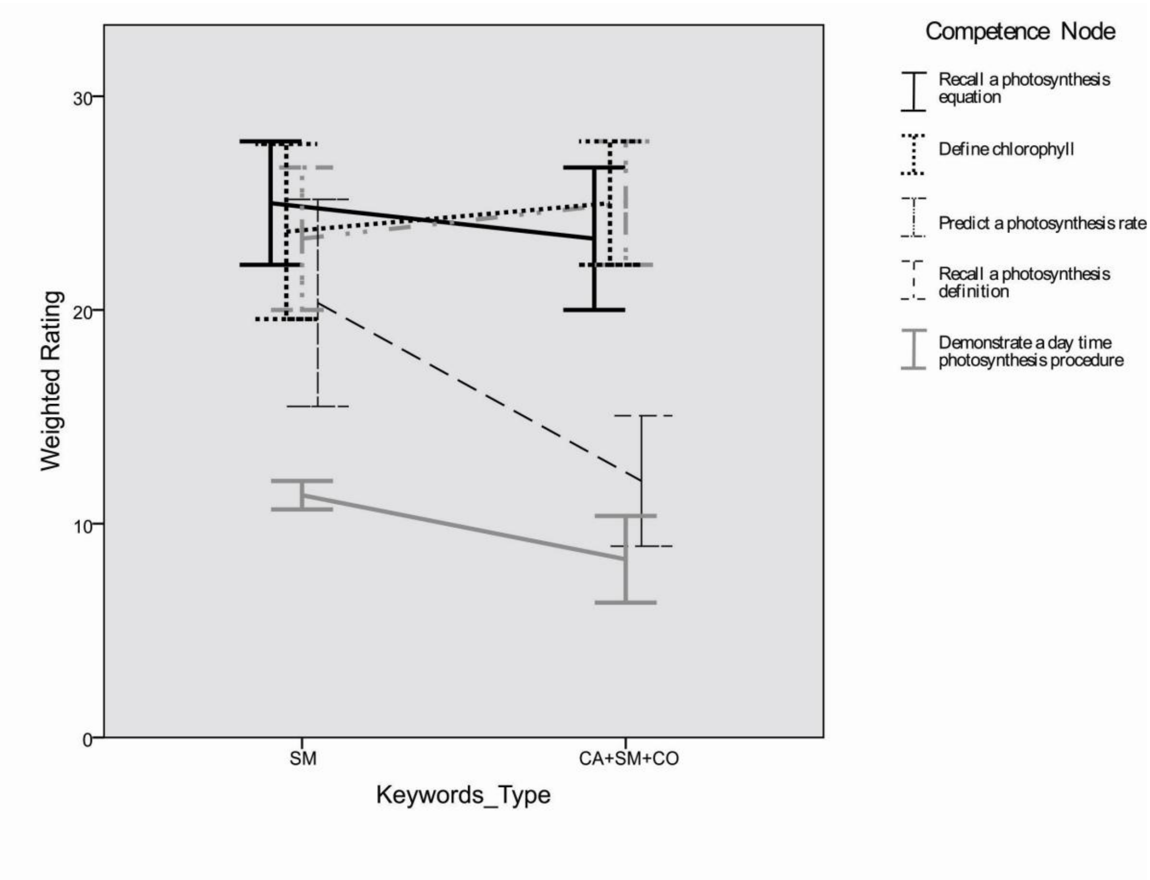


Figure 9-14: *Profile Graph of Mean of Weighted Ratings of Links of Each Competence Node for Two Types of Keywords (Error Bars Show +- 1SE)*

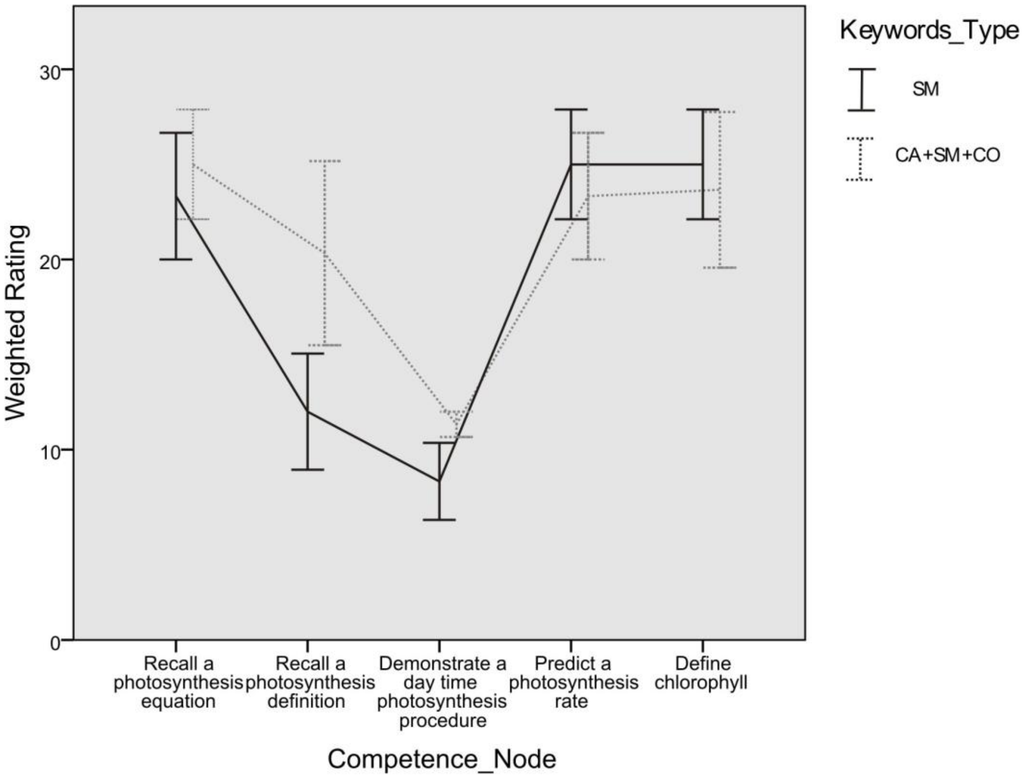


Figure 9-15: *Profile Graph of Mean of Weighted Ratings of Links of Each Keyword Type for Five Types of Competence Node (Error Bars Show +- 1SE)*

Table 9-22: *Tests of Between-Subjects Effects (SM vs CA+SM+CO)*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Keyword_Type	30.00	1	30.00	0.99	0.332
Competence_Node	1027.20	4	256.80	8.45	< 0.001
Keyword_Type * Competence_Node	98.67	4	24.68	0.81	0.533
Error	608.00	20	30.40		
Total	1763.87	29			

Table 9-23: *Bonferroni Multiple Comparisons (SM vs CA+SM+CO)*

(I) Competence_Node	(J) Competence_Node	Mean Difference (I-J)	SE	Sig.	95% CI Lower Bound	95% CI Upper Bound
Recall a photosynthesis equation	Recall a photosynthesis definition	8.0	3.18	0.206	-2.0	18.0
	Demonstrate a day time photosynthesis procedure	14.3	3.18	0.002	4.3	24.4
	Predict a photosynthesis rate	0.0	3.18	1.000	-10.0	10.0
	Define chlorophyll	-0.2	3.18	1.000	-10.2	9.9
Recall a photosynthesis definition	Recall a photosynthesis equation	-8.0	3.18	0.206	-18.0	2.0
	Demonstrate a day time photosynthesis procedure	6.3	3.18	0.605	-3.7	16.4
	Predict a photosynthesis rate	-8.0	3.18	0.206	-18.0	2.0
	Define chlorophyll	-8.2	3.18	0.185	-18.2	1.9
Demonstrate a day time photosynthesis procedure	Recall a photosynthesis equation	-14.3	3.18	0.002	-24.4	-4.3
	Recall a photosynthesis definition	-6.3	3.18	0.605	-16.4	3.7
	Predict a photosynthesis rate	-14.3	3.18	0.002	-24.4	-4.3
	Define chlorophyll	-14.5	3.18	0.002	-24.5	-4.5
Predict a photosynthesis rate	Recall a photosynthesis equation	0.0	3.18	1.000	-10.0	10.0
	Recall a photosynthesis definition	8.0	3.18	0.206	-2.0	18.0
	Demonstrate a day time photosynthesis procedure	14.3	3.18	0.002	4.3	24.4
	Define chlorophyll	-0.2	3.18	1.000	-10.2	9.9
Define chlorophyll	Recall a photosynthesis equation	0.2	3.18	1.000	-9.9	10.2
	Recall a photosynthesis definition	8.2	3.18	0.185	-1.9	18.2
	Demonstrate a day time photosynthesis procedure	14.5	3.18	0.002	4.5	24.5
	Predict a photosynthesis rate	0.2	3.18	1.000	-9.9	10.2

The results from the statistical data obtained (as shown in Table 9-21, Table 9-22, Table 9-23, Figure 9-14 and Figure 9-15) were as follows.

1. There was no significant interaction effect between types of keyword input (SM & CA+SM+CO) and types of competence node ($0.10 < p = 0.533$).
2. There was no significant main effect of types of keyword. This indicates that there was no significant difference between the means of weighted ratings for links generated from keywords SM and CA+SM+CO ($0.10 < p = 0.332$).
3. There was a significant main effect of types of competence. This indicates that there were significant differences among the means of weighted ratings for links based on different types of competence node ($p < 0.05$).

In order to determine which pairs of competence nodes were significantly different, Bonferroni multiple comparisons were undertaken. Significant differences were seen between the following pairs of competence nodes:

- Recall a photosynthesis equation vs Demonstrate a daytime photosynthesis procedure ($p = 0.002 < 0.05$)
- Predict a photosynthesis rate vs Demonstrate a daytime photosynthesis procedure ($p = 0.002 < 0.05$)
- Define chlorophyll vs Demonstrate a daytime photosynthesis procedure ($p = 0.002 < 0.05$)

9.7 Experiment VI

Experiment VI explored the question: 'Are search results given by GoogleAPI better than those given by iSEEK in terms of relating to the achievement of competence nodes?'

Two-way ANOVA was used to analyze the data obtained in order to find any significant differences between the means of 'helpfulness to achieve learning outcome' rating of the search engine types and competence node types.

Table 9-24, Table 9-25 and Table 9-26 show the descriptive statistics, tests of between-subjects effects and multiple comparisons of the data obtained, respectively. Figure 9-16 and Figure 9-17 show the profile plots of means for weighted ratings of search engine types and competence node types, respectively.

'SearchEngine_Type' comprised two levels: GoogleAPI and iSEEK. 'Competence_Node' comprised five levels: 'Recall a photosynthesis equation', 'Recall a photosynthesis definition', 'Demonstrate a daytime photosynthesis procedure', 'Predict a photosynthesis rate' and 'Define chlorophyll'.

Table 9-24: *Means and Standard Deviations of Weighted Ratings of Links (GoogleAPI vs iSEEK)*

SearchEngine_Type	**Competence_Node**	**Mean**	**Std. Dev**	**N**
GoogleAPI	Recall a photosynthesis equation	25.0	5.00	3
	Recall a photosynthesis definition	13.7	5.13	3
	Demonstrate a day time photosynthesis procedure	8.7	4.16	3
	Predict a photosynthesis rate	20.0	4.00	3
	Define chlorophyll	20.0	4.00	3
	Total	17.9	7.88	15
iSEEK	Recall a photosynthesis equation	22.7	12.70	3
	Recall a photosynthesis definition	13.0	1.73	3
	Demonstrate a day time photosynthesis procedure	6.3	1.53	3
	Predict a photosynthesis rate	13.7	5.13	3
	Define chlorophyll	14.0	8.72	3
	Total	14.3	9.14	15
Total	Recall a photosynthesis equation	23.8	8.73	6
	Recall a photosynthesis definition	13.3	3.44	6
	Demonstrate a day time photosynthesis procedure	7.5	3.08	6
	Predict a photosynthesis rate	16.8	5.38	6
	Define chlorophyll	17.0	6.90	6
	Total	16.1	8.58	30

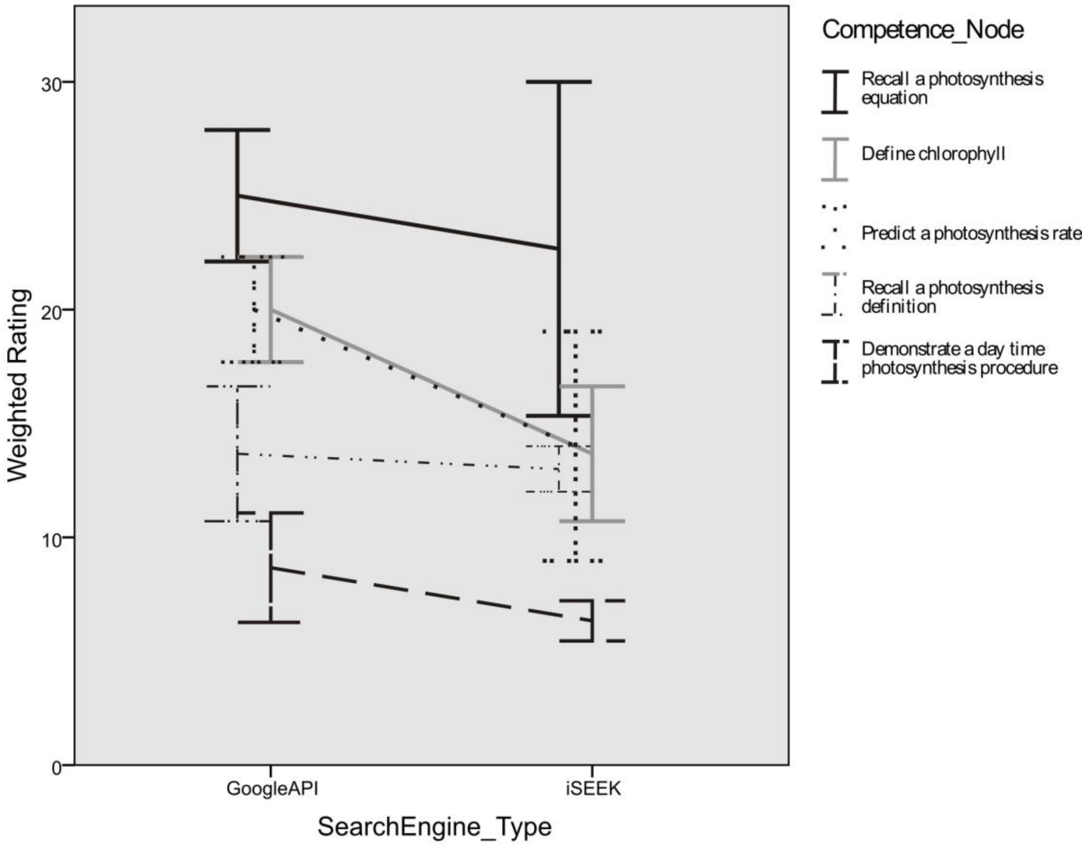


Figure 9-16: *Profile Graph of Mean of Weighted Ratings of Links of Each Competence Node for Two Types of Search Engines (Error Bars Show +- 1SE)*

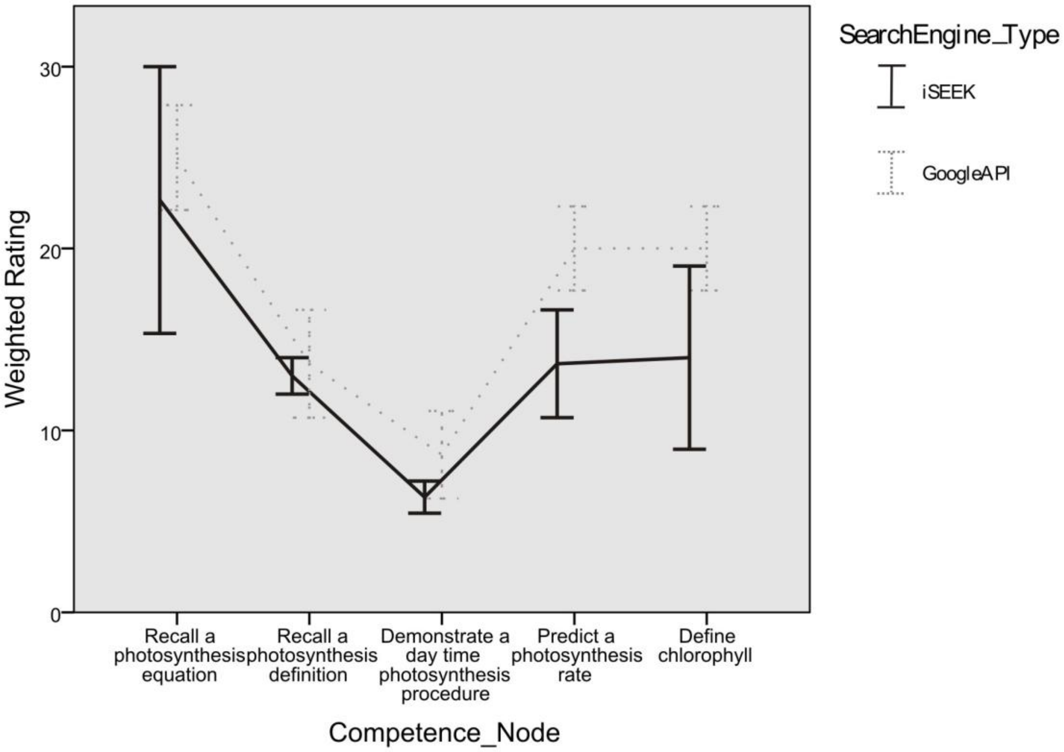


Figure 9-17: *Profile Graph of Mean of Weighted Ratings of Links of Each Type of Keyword for Five Types of Competence Node (Error Bars Show +- 1SE)*

Table 9-25: *Tests of Between-Subjects Effects (GoogleAPI vs iSEEK)*

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
SearchEngine_Type	93.63	1	93.63	2.53	0.127
Competence_Node	851.80	4	212.95	5.76	0.003
SearchEngine_Type * Competence_Node	37.53	4	9.38	0.25	0.904
Error	739.33	20	36.97		
Total	1722.30	29			

Table 9-26: *Bonferroni Multiple Comparison (Google vs iSEEK)*

(I) Competence_Node	**(J) Competence_Node**	**Mean Difference (I-J)**	**SE**	**Sig.**	**95% CI**	
					Lower Bound	**Upper Bound**
Recall a photosynthesis equation	Recall a photosynthesis definition	10.5	3.51	0.072	0.6	21.6
	Demonstrate a day time photosynthesis procedure	16.3	3.51	0.002	5.3	27.4
	Predict a photosynthesis rate	7.0	3.51	0.600	-4.1	18.1
	Define chlorophyll	6.83	3.51	0.685	-4.2	17.9
Recall a photosynthesis definition	Recall a photosynthesis equation	-10.5	3.51	0.072	-21.6	0.6
	Demonstrate a day time photosynthesis procedure	5.8	3.51	1.000	-5.2	16.9
	Predict a photosynthesis rate	-3.5	3.51	1.000	-14.6	7.6
	Define chlorophyll	-3.7	3.51	1.000	-14.7	7.4
Demonstrate a day time photosynthesis procedure	Recall a photosynthesis equation	-16.3	3.51	0.002	-27.4	-5.3
	Recall a photosynthesis definition	-5.8	3.51	1.000	-16.9	5.2
	Predict a photosynthesis rate	-9.3	3.51	0.151	-20.4	1.7
	Define chlorophyll	-9.5	3.51	0.136	-20.6	1.6
Predict a photosynthesis rate	Recall a photosynthesis equation	-7.0	3.51	0.600	-18.1	4.1
	Recall a photosynthesis definition	3.5	3.51	1.000	-7.6	14.6
	Demonstrate a day time photosynthesis procedure	9.3	3.51	0.151	-1.7	20.4
	Define chlorophyll	-0.2	3.51	1.000	-11.2	10.9
Define chlorophyll	Recall a photosynthesis equation	-6.8	3.51	0.658	-17.9	4.2
	Recall a photosynthesis definition	3.7	3.51	1.000	-7.4	14.7
	Demonstrate a day time photosynthesis procedure	9.5	3.51	0.136	-1.6	20.6
	Predict a photosynthesis rate	0.2	3.51	1.000	-10.9	11.2

From the statistical data obtained (as shown in Table 9-24 and Table 9-25), the results were as follows.

1. There was no significant interaction effect between types of search engine and types of competence node ($0.10 < p = 0.904$).
2. There was no significant main effect for types of search engine. This indicates that there was no significant difference between the means for weighted ratings for links generated from GoogleAPI and iSEEK ($0.10 < p = 0.127$)
3. There was a significant main effect for types of competence node. This indicates that there were significant differences among means for weighted ratings for links based on different types of competence node ($p = 0.003 < 0.05$).

In order to determine which pairs of competence nodes were significantly different, Bonferroni multiple comparisons were undertaken. A significant difference was seen in the following pair of competence nodes:

- Recall a photosynthesis equation vs Demonstrate a daytime photosynthesis procedure ($p = 0.002 < 0.05$)

9.8 Summary

This chapter has presented experimental results and statistical analyses. In the first experiment, the mean ratings for the two learning paths ‘learning path 2’ and ‘learning path 3’ did not significantly differ on all variables for both knowledge domains. The mean rating for learning path 3 was significantly higher than for the other two learning paths on ‘learning outcome achievement’ in the HCF domain. The mean rating for learning path 1 was significantly lower than for the other two learning paths (‘learning outcome achievement’ in the photosynthesis domain). In Experiment II, participants were, in general, significantly satisfied with the clarity of the system and the range of materials. In addition, they felt that they would recommend the system to other users in the future.

Freely-browsing and competence-based learning modes were compared in Experiment III. Both learning modes helped learners to improve their test scores equally. In Experiment IV, there were no differences between the weighted ratings for links generated by the Google search engine and GoogleAPI. In Experiment V, there were no differences between the weighted ratings for links generated by subject matter keywords alone or by subject matter augmented with capability and context keywords. In Experiment VI, there were no differences between the weighted ratings for links generated by GoogleAPI and iSEEK. The next chapter discusses all the obtained statistical results.

Chapter 10
Discussion

10.1 Introduction

This chapter discusses the results from the previous chapter. The discussions of possible reasons for obtaining the outcomes for each experiment are given. In addition, some approaches to further studies are suggested. A summary of the discussion is provided at the end of the chapter.

10.2 Experiment I

Experiment I compared three learning paths: 'ignore all gap nodes', 'consider some gap nodes', and 'consider all gap nodes'. This was to see if more competence nodes in a learning path would be more useful. The experiment explored two knowledge domains: the HCF mathematical domain (part A) and the photosynthesis domain for Key Stage 4 learners (part B). In part A, the mean ratings for 'learning outcome achievement' of links under learning path 3 were higher than those under learning paths 1 and 2. The mean ratings for learning paths 1 and 2 were not significantly different on the 'usefulness' rating, whereas in part B, the mean ratings for 'learning outcome achievement' of links under learning path 1 were lower than those under learning paths 2 and 3. In part B, the mean ratings for the two learning paths 'learning path 2' and 'learning path 3' did not significantly differ on the 'usefulness' rating.

In part A, learning path 3 was shown to be the most appropriate for learners to achieve their learning outcomes, while learning paths 1 and 2 equally did not help learners to achieve them. Consider the list of learning paths in part A that were provided to participants:

- Learning path 1: 'Define factor → Calculate highest common factor'
- Learning path 2: 'Define factor → Define common factor → Calculate highest common factor'
- Learning path 3: 'Define factor → Define common factor → Define highest common factor → Calculate highest common factor'

The difference in learning path 3 from learning paths 1 and 2 was one added competence gap node: 'Define highest common factor'. In fact, learners should be able to define a highest common factor (HCF) so that they can actually calculate an HCF. Only to define a factor and to define a common factor were not sufficient for learners to define an HCF. The links related with competence node 'Define common factor' were followed up and checked. The content within those links was generally the definitions of 'common factor'. The explanations of highest common factor were not found within these links. The lack of the competence gap 'Define highest common factor' reduces the effectiveness of achieving the learning outcome.

In part B, the mean rating for learning path 1 was significantly lower than for the other two learning paths on 'learning outcome achievement'. Consider the list of the learning paths in part B that was given to participants:

- Learning path 1: 'Recall a definition of energy → State a daytime photosynthesis procedure'
- Learning path 2: 'Recall a definition of energy → Define light → Rehearse the fact that chlorophyll absorbs light → State a daytime photosynthesis procedure'
- Learning path 3: 'Recall a definition of energy → Define light → Define chlorophyll → Rehearse the fact that chlorophyll absorbs light → State a daytime photosynthesis procedure'

The differences in learning paths 2 and 3 from learning path 1 were some added competence gap nodes, such as 'Define light 'and 'Rehearse the fact that chlorophyll absorbs light'. This suggests that these competence gap nodes helped learners to achieve competence in: 'State a daytime photosynthesis procedure'. The absence of the two competence gap nodes 'Define light' and 'Rehearse the fact that chlorophyll absorbs light' reduces the effectiveness of achieving the learning outcome.

Considering both parts, the lack of competence gap nodes seems to reduce the effectiveness of achieving the learning outcome. Learning paths with more complete gap nodes seem to achieve higher ratings. The theoretical expectation of Experiment I was that there would be significant differences between the three learning paths. In particular, we expected that learning path 3 ('Consider all gap nodes') was the most appropriate learning path for learners to achieve the learning outcome. This is shown in Figure 10-1 by the solid black line, as per the key. The mean rating for learning path 3 was expected to be the highest. Learning paths 2 and 1 were expected to be rated as the middle and lowest, respectively.

Expressing the results obtained as a conceptual overview (Figure 10-1), the actual results from part A and part B are shown by the dashed line and the grey line, as per key. In part A, learning path 1 was as good as learning path 2, but learning path 3 was better. Comparing the conceptual overview in part A with theoretical expectations, learning path 1 was rated as equal to learning path 2, whereas learning path 1 was expected to be rated lower than learning path 2.

In part B, learning path 1 was the worst and learning path 2 was as good as learning path 3. Comparing the conceptual overview in part B with theoretical expectations, learning path 2 was rated as equal to learning path 3, whereas learning path 2 was expected to be rated lower than learning path 3.

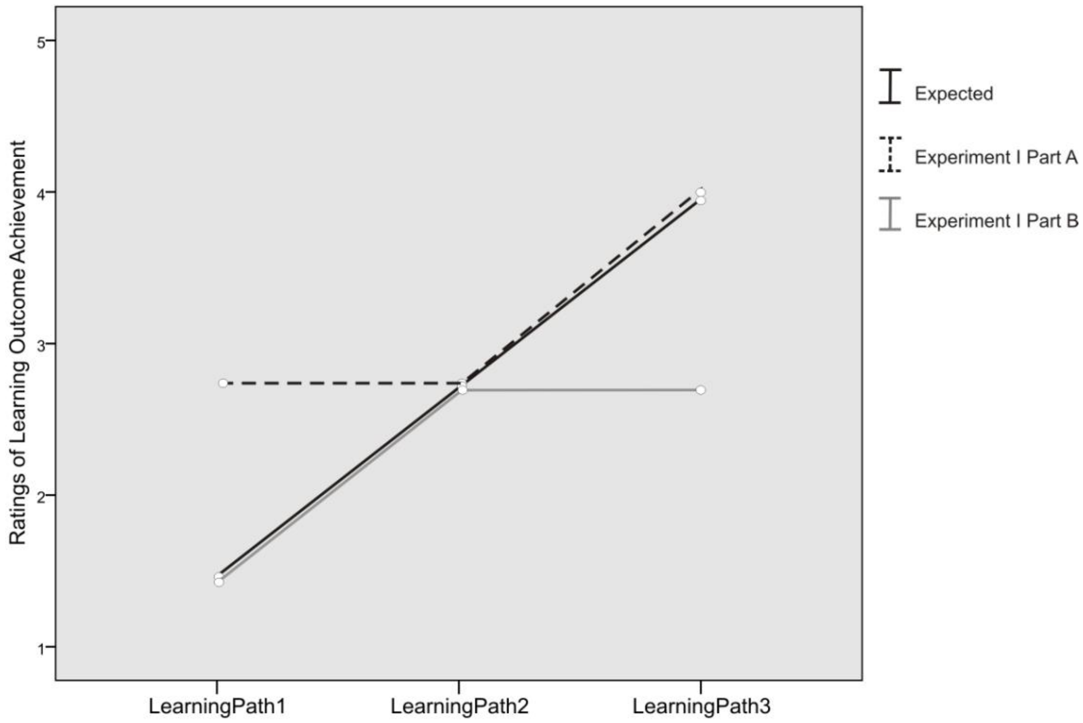


Figure 10-1: *Theoretical Comparison of Results might be Expected with the Obtained Results from Experiment I Part A and B*

Therefore, some parts of the results obtained were consistent with theoretical expectations, but some were not. These unexpected results may be due to certain different features of the parts. These are as follows.

- The photosynthesis knowledge domain in part B is more complex than the highest common factor domain in part A.
- Part B competence structure is also larger and more complex than part A competence structure.
- Numbers of competence gap nodes within learning paths for part A are fewer than those within learning paths for part B.

These different characteristics may explain the results obtained. Firstly, the length of the learning path could vary according to the desired and existing competence. Secondly, the size of the competence structures can be large, and there are several competence gap nodes between competences. In this experiment, the size of the photosynthesis competence structure is larger and more complex than the size of the HCF competence structure. Learners could skip some competence nodes in order to achieve their desired competences.

Thirdly, the extent of a competence structure relies on the developers of that structure. One competence node may be decomposed into more than one small node. A developer could locate the small competence nodes within the structure instead of representing one competence as a whole. This is illustrated in Figure 10-2, where competence node A can be decomposed into competence nodes B and C. Competence node B can be decomposed into competence nodes D and E. Competence node C can also be decomposed into competence nodes F and G. This process can in principle be considered to infinity.

Lastly, learners may have felt more satisfied in achieving a desired competence when the competence gap nodes were considered within learning paths 2 and 3, rather than when none of them were added within learning path 1.

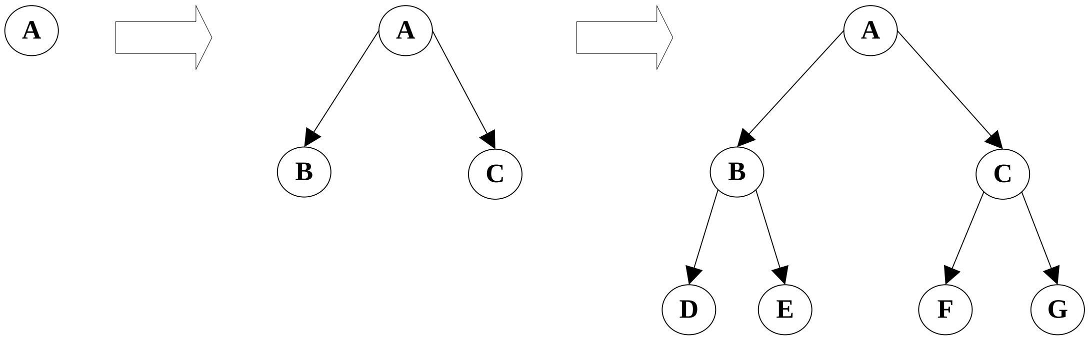


Figure 10-2: *One Competence can be Decomposed into Some Sub Competences*

A further study on the size of acceptable competence structures and competence gap nodes can be carried out in future work. Further studies can also explore different knowledge domains and different competence structures. In addition, assessment and feedback processes can be considered to ensure the learners' achievement of desired competences. Further details of this future work are explained later, in Section 11.4.

To summarise, appropriate learning paths may vary according to the size of the competence structure and the chosen (desired/existing) competences.

10.3 Experiment II

Experiment II was to determine users' overall reaction ratings to Kirkpatrick's level one 'reaction' (Kirkpatrick, 2007) and whether the mean reaction ratings were significantly different from the middle, 'neutral', option. Two parts to this experiment were conducted, based on the HCF mathematical domain (part A) and on the photosynthesis knowledge domain for Key Stage 4 learners (part B). Participants were in general significantly satisfied with the clarity of the system and the range of materials. They thought that the approach helped them to identify their competences (desired competence, actual or existing competences, and gap competences) and there was a wide range of types of study materials (for example, text explanation, figures, pictures, videos, and etc). In addition, the participants felt that they could recommend the system to other users in the future. This finding holds for both parts (A and B).

There was, however, one difference between the two parts. In part A, the participants felt that they could find sufficient information on the topic for each learning outcome. However, this was not true for part B. In part B, context terms were considered within the learning paths; for example, context ‘daytime’ was added within the competence ‘State a daytime photosynthesis procedure’. This explains why learners felt more satisfied in achieving the desired competence when contexts were not considered within competences.

In general, there were two issues about which participants were neutral; the first was the requirement of help from teachers and the second was ease of access to information.

Participants in parts A and B were neutral on the question of whether teachers would be required to help learners to obtain study materials. In both parts, participants accessed only the first three links, and the first page within those three links related to one competence. Google normally ranks webpages according to the Web’s rank of popularity, and sometimes these pages may not apply for educational purposes. Other links apart from the first three links for each competence node may be relevant, so that learners can achieve particular ones. In addition, there were various types of study materials found within a page link, such as text explanation, power point slides, video explanations and picture illustrations. Some of these types of study materials are actually useful for learning but not really related to a particular competence. Hence participants in both parts were unsure about the issue of teacher requirements to give explanations. Improvement in the relevance and appropriateness of links will be considered in future work.

They were also neutral on the subject of ease of access to information. It could be that GoogleAPI is considered within the approach, and the links are accessed in different browser windows or tabs from the competence-based system page. When learners clicked to access each link, the link was accessed in a different window. They were required to close particular windows before returning to the competence-based system. Perhaps this could be because the system was constructed with insufficient consideration to the user interface. Improvement in the usability of the user interface will be considered in future studies.

The feedback obtained was useful for improving the research approach, and will be considered in future study. However, five out of the eight questions asked obtained positive feedback. Hence, the participants still felt satisfied with the approach in general. For future study, the control of search results and search patterns can be considered; for example, the ratings of links (relating to achieving learning outcome) by users can be gathered. High rating links will be recommended to users. In addition, users can be classified according to type, for example experts or learners. Ratings will be obtained from both types of users and presented to them for consideration. In addition, the domain of study material links can be filtered and recommended to learners from trusted sources, for example .gov, .edu, .ac.uk, and so on.

10.4 Experiment III

Experiment III explored whether a competence-based learning mode was better than a freely-browsing learning mode. In this experiment, further improvement in the learning of participants was expected, as illustrated in Figure 10-3. The pre-test scores for the two groups should be equal; in other words, the participants in the two groups should have equal initial knowledge. The expected results were that the increment in the learning improvement of the participants in the competence-based learning mode would be significantly higher than the increment in the learning improvement of the participants in the freely-browsing learning mode.

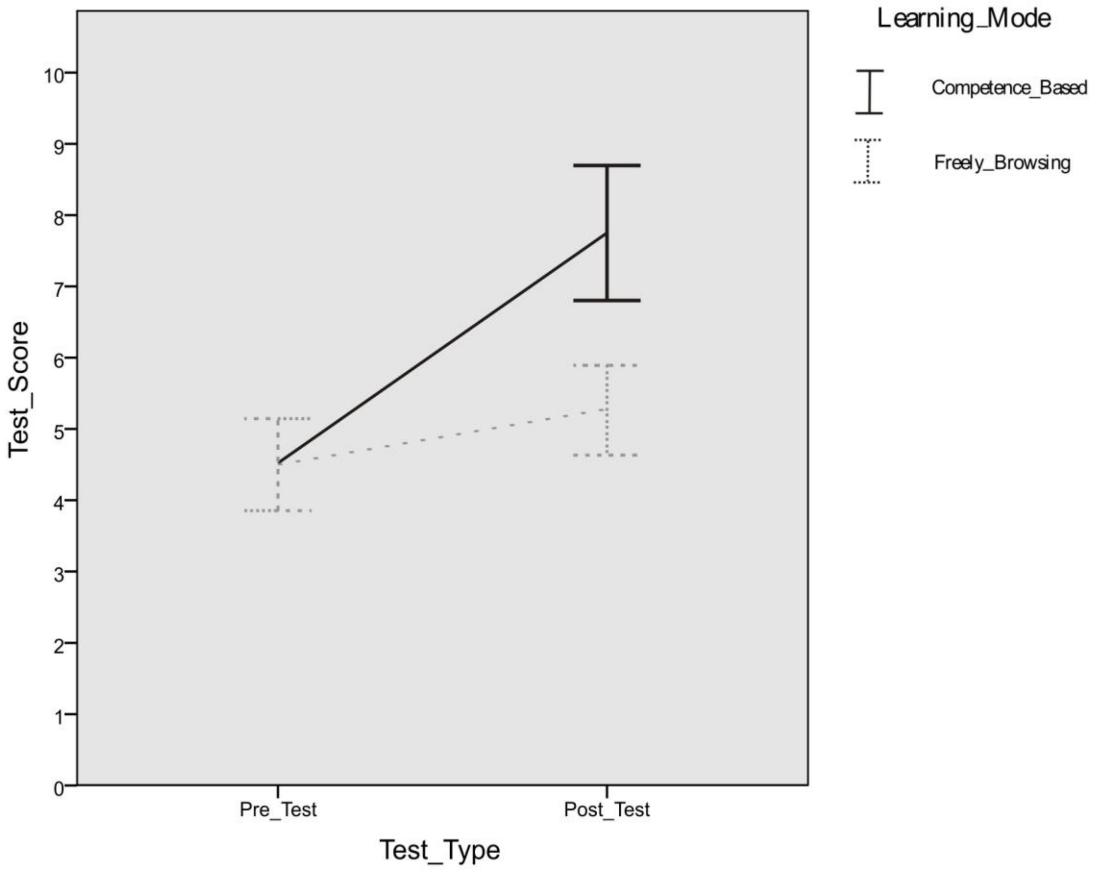


Figure 10-3: *Expected Results of Profile Graph of Mean Ratings of Test Scores of Pre-Test and Post-Test for Two Learning Modes (Error Bars Show +- 1SE)*

Equal learning improvements were shown in the two modes of learning. There are three possible reasons indicating why the expected result was not obtained. Firstly, participants in the freely-browsing learning mode group were more knowledgeable than those in the other group. It could be that learners' existing knowledge helped them to improve their learning. Secondly, the type of search engine used was Google browser (www.google.com) in a freely-browsing learning mode, while in the competence-based learning mode, the study material links were generated from the

GoogleAPI embedded within the system. Thirdly, it may have been as a result of the keywords. At the beginning of the experiment, participants in the two modes of learning were given the same set of subject matter to be learnt. However, participants in the freely-browsing learning mode decided the keywords to input by themselves, and most of them used subject matter content as keywords. This was observed during the experiment conducted. In the competence-based learning mode, participants were required to choose targeted subject matter content and (later) corresponding competences. The keywords generated by the competence-based system contained a choice of words from capability, subject matter content and context. Experiments IV and V were subsequently considered to further explore these issues of significant differences among the types of search engine used and the types of keyword.

To summarise, learners' improvements were equal in both modes of learning (freely-browsing and competence-based), regardless of the fact that participants with different knowledge backgrounds were experiencing each learning mode.

10.5 Experiment IV

Experiment IV sought to determine whether the search results given by Google browser (www.google.com) were significantly better than those given by GoogleAPI in terms of relating to achievement of competences.

The means for the weighted ratings of links between the two types of search engine did not differ according to type of competence node; the two types of search engine gave similar results. However, a significant difference between the means for weighted ratings of links was found between the types of competence node. There were two pairs of competence nodes in which a significant difference was found (the other eight pairs showed no significant difference):

- Recall a photosynthesis equation vs Predict a photosynthesis rate
- Recall a photosynthesis equation vs Define chlorophyll

It is more difficult to find good webpages to deal with competence nodes at the high levels of Bloom's taxonomy (Bloom, 1956). Surprisingly, the links related to 'Define chlorophyll' were rated significantly less helpful than 'Recall a photosynthesis equation'. It may be noted that the links related to 'Define chlorophyll' simply reference dictionary definitions.

In summary, even though there were significant differences in the means of weighted ratings of links between some competences, there was no significant difference between the search results generated by Google and GoogleAPI in terms of learning outcome achievement.

10.6 Experiment V

This experiment sought to determine whether the search results relating to capability, subject matter and context keywords were significantly better than those from subject matter keywords in terms of achievement of competences. The means of weighted ratings for links between the two types of keyword showed no difference according to type of competence nodes. The means of weighted ratings for links were similar for the two types of keyword. However, a significant difference among the means for weighted ratings of links was found between types of competence node. There were three pairs of competence nodes in which a significant difference was found (the other seven pairs showed no significant difference):

- Recall a photosynthesis equation vs Demonstrate a daytime photosynthesis procedure
- Predict a photosynthesis rate vs Demonstrate a daytime photosynthesis procedure
- Define chlorophyll vs Demonstrate a daytime photosynthesis procedure

The means of weighted ratings for links related to the competences 'Recall a photosynthesis equation', 'Predict a photosynthesis rate' and 'Define chlorophyll' were significantly higher than the means of weighted ratings for links related to the competence 'Demonstrate a daytime photosynthesis'. The reason for this could be that the information within the links of the competence 'Demonstrate a daytime photosynthesis' did not contain sufficient information for learners to achieve this competence, and this competence node capability is at a high level in Bloom's taxonomy. As per the discussion in Experiment IV, the links related to competence nodes at a high level in Bloom's taxonomy are difficult to implement sufficiently well in webpages, in order that they help learners achieve competences. This can be explained for the pairs of competences 'Recall a photosynthesis equation' and 'Define chlorophyll' with the competence 'Demonstrate a daytime photosynthesis procedure'. However, there was no obvious explanation for the pair of competences 'Predict a photosynthesis rate' and 'Demonstrate a daytime photosynthesis procedure'. Still, overall, the means of weighted ratings for different types of keywords (SM and CA+SM+CO) did not significantly differ.

In summary, even though there were significant differences in the means of weighted ratings for links between some competences, there was no significant difference in search results from subject matter alone keywords and subject matter with capability and context keywords in terms of learning outcome achievement.

Reflecting on Experiment III, there were no significant differences between the two types of search engine (Google and GoogleAPI), and neither between the two types of keyword. Hence, differences did not occur between the two learning modes in experiment III because of the learners' initial knowledge helping learners to improve their learning when they were experiencing the freely-browsing learning mode.

10.7 Experiment VI

This experiment was to determine whether the search results given by GoogleAPI were significantly better than those given by iSEEK, which is an educational search tool, in terms of achievement of competence. The means of weighted ratings of links between the two types of search engine showed no difference according to types of competence node. The means of weighted ratings of links were similar for both types of search engine. However, a significant difference between the means of weighted ratings of links was found between types of competence node. In one pair of competence nodes, a significant difference was found (the other nine pairs showed no significant differences):

- Recall a photosynthesis equation vs Demonstrate a daytime photosynthesis procedure

As in the previous two experiments (IV and V), links related to a competence node with a high level in Bloom's taxonomy are difficult to find on the Web; they could have helped learners to achieve their desired competences. The findings from Experiments IV, V and VI are illustrated in Figure 10-4.

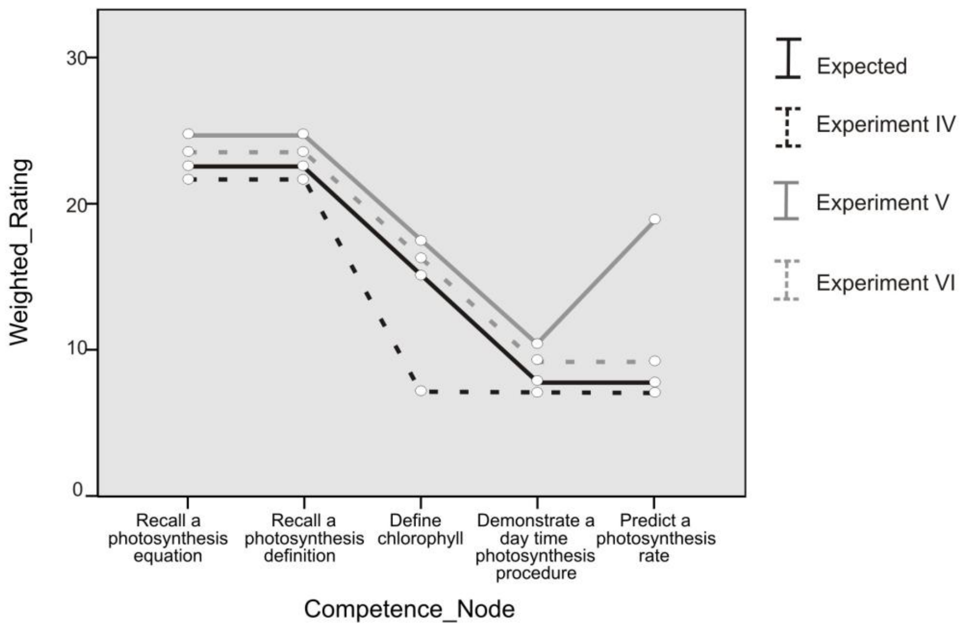


Figure 10-4: *Theoretical Comparison of Results might be Expected with the Obtained Results from Experiment IV, V, and VI*

Figure 10-4 shows the theoretical expectations guided by the overall actual results. One theoretical expectation was that the ratings for the links in competence gap nodes with the higher level in Bloom's taxonomy were lower than the ratings for the links of competence gap nodes with the lower level of Bloom's taxonomy. This is shown by the solid black line, as per the key.

Figure 10-4 also shows a conceptual overview of the results obtained in the experiment: the ratings for the links for each competence node 'Recall a photosynthesis equation', 'Recall a photosynthesis definition' and 'Demonstrate a daytime photosynthesis procedure' in all three experiments were equal. These conceptual overviews are consistent with theoretical expectations.

However, there were some unexpected results. In Experiment IV, the links for competence node 'Define chlorophyll' (low level in Bloom's taxonomy) were rated lower than theoretical expectations. In Experiment V, the links for competence node 'Predict a photosynthesis rate' (high level in Bloom's taxonomy) were rated higher than theoretical expectations. Nevertheless, some unexpected results were found: the overall trends for all three experiments (IV, V, and V) were still seen to be similar to theoretical expectations.

To summarise, even though there were significant differences in the means for the weighted ratings of links between some competences, there was no significant difference between the search results generated by GoogleAPI and iSEEK in terms of learning outcome achievement.

10.8 Summary

The overall experimental studies were conducted to validate how effectively and successfully the system provides learners with study material links based on their competences. The findings of Experiments I, II and III answer research questions 1, 2 and 3, which are noted in Chapter 1. Experiments IV and V were further investigations following on from Experiment III. Experiment VI was a further study of significant differences between the search engine (GoogleAPI) and an educational search engine (iSEEK).

Experiment I was conducted to answer research question 1 (What learning path is most appropriate for helping learners achieve their desired competences?). The findings were that appropriate learning path(s) may vary according to learners' competences and the size of the competence structure. Experiment II was conducted to answer research question 2 (Do learners accept a system at reaction level?). In Experiment II, participants were in general significantly satisfied with the clarity of the system and the range of materials; however they were neutral on the issues of: sufficient information within one page, help requirements from teachers, and contents related to educational purposes. These findings suggest that learners could use a competence-based system and achieve their desired competences.

Experiment III was conducted to answer research question 3 (When a system is compared to other approaches to learning, which approach provides learners with a better way of improving their learning?). Experiment III explored the real learning improvement of learners after interacting with a competence-based system. The comparison between the learning mode using a competence-based system and the freely-browsing system showed equal improvement (both modes). It was expected that there would be better improvement in learning when experiencing a competence-based system, and possible reasons for the results were explored further. In Experiment IV, there were no significant differences demonstrated between Google and GoogleAPI to help learners achieve ILOs. Experiment V showed no significant differences between the means for weighted ratings of links from keywords SM (only subject matter) and CA+SM+CO (combination of capability, subject matter and context). These outcomes suggest that the quality of the freely-browsing mode was due to the higher initial knowledge of the participants.

Finally, Experiment VI showed that there was no significant difference between the search results generated by GoogleAPI and iSEEK in terms of learning outcome achievement. Considering the results from Experiments IV, V, and VI, it seems that the links related to competence nodes with high levels in Bloom's taxonomy were less useful to learners. Perhaps, this is because it is more difficult for learners to achieve these competences using webpages dealing with the higher levels of Bloom's taxonomy. The next chapter presents the contribution of the present study and suggests the direction for future work.

Chapter 11
Contributions and Future Work

11.1 Introduction

This chapter starts by presenting the contributions made by this work. Some limitations of this study are then discussed. The chapter also proceeds to highlight the directions for further studies to address the drawbacks. It ends with a number of concluding remarks.

11.2 Contributions

A competence-based system for suggesting study material links from the Web has been proposed in this research. The aim of the approach is to assist learners to achieve their learning outcomes. A competence-based system suggests appropriate study materials as links from the Web for learners based on their competences which are 'existing competence' and 'desired competence'. A competence structure is viewed to identify the range and relationship of competence elements/nodes for a particular knowledge domain. The system uses the learner's competences to generate different learning paths and, from the chosen learning path, it produces appropriate keywords to be used by a search engine in order to suggest appropriate study materials from the Web. Experimental studies were conducted, which explored:

- User reaction ratings against learning paths and approach
- Comparison between two learning modes (freely-browsing and competence-based) on the learning level
- Significant differences in types of keywords and types of search engine

From the work conducted (approach and experiments), the main findings or contributions are as follows.

1. Competence structures may be effectively designed by following the instruction developed.
2. Competence structures may be effectively represented as XML schema.
3. Learning paths with more competence gap nodes are more helpful.
4. A competence-based system is acceptable for learners.
5. Web links of a competence node with a lower level of Bloom's taxonomy showed higher ratings than those with a higher level of Bloom's taxonomy

11.2.1 Instruction for Designing a Competence Structure

A competence structure is a major component of the competence-based system. The elements within this structure are competence nodes. Each node is composed of capability, subject matter, and context. A combination of capability and subject matter is an intended learning outcome. In order to design a competence structure, the intended learning outcomes for specific subject matter content of a course are then required.

This thesis contains instructions for designing a competence structure. Briefly explained, the steps in designing a competence structure are as follows:

1. Choose the knowledge domain and its set of intended learning outcomes.
2. Construct a task analysis of all subject matters.
3. Identify the decomposition levels and relationships of the designed task analysis.
4. Structure the subject matter into parent-child relationships.
5. Tag each node of subject matter with corresponding capability and context.

Understanding the process of designing a competence structure helps developers to construct a competence structure from the intended learning outcomes of an available course.

11.2.2 XML-Schema of a Competence Structure

The designed XML-schema of a competence structure has been proposed in this research. There are some key points in representing a competence structure in an XML format. For example, XML enables us to focus on the definition of shared vocabularies for exchanging information and it easily reuses the content in other applications. Initially, it is used to represent – in ER diagram – all the main objectives of a competence structure. These objectives include: the intended learning outcomes, different types of subject matter content (including its task analysis) and representations of competence. From the built ER diagram, all entities and identified keys are mapped as elements and keys of the XML-schema. The designed XML-schema represents a common framework for abstracting information from the competence structure. It can be reused for any knowledge domains of subject matter content.

11.2.3 Learning Paths with More Competence Gap Nodes More Helpful

The possibilities for traversing the competence structure are considered as possible cases of learning paths. In this research, a learning path represents the route of competence nodes visited by learners in order to achieve a desired competence. There are three possible cases of learning paths: ‘Ignore all gap nodes’, ‘Consider some gap nodes’, and ‘Consider all gap nodes’. The numbers of visited competence gap nodes in the three learning paths are different. Consequently, an experiment (experiment I) was conducted to explore the appropriate learning path(s), and the rating of users’ reactions against each learning path was obtained. Appropriate learning path(s) were still not conclusive. The findings showed that appropriate learning path(s) may vary, depending on learners' competences and the size of the competence structure. The lack of competence gap nodes seems to reduce the effectiveness of achieving learning outcomes. Learning paths with more complete gap nodes seem to achieve higher ratings.

11.2.4 Competence-based System Acceptable to Learner

In the last stage of this research, the evaluations of users' reactions to the approach were conducted. At the reaction level, participants were significantly satisfied with the approach, for example, the clarity of the system, and the range of materials. They felt that the system helped them to identify their competences (desired competence, actual or existing competence, and gap competences) and there was a wide range of types of study materials (for example, text explanation, figures, picture, and video). In addition, the participants felt they would suggest the system to other people for future use.

11.2.5 Web Links of the Competence Node with Lower Level of Bloom's Taxonomy Showed Higher Ratings Than Those with Higher Level of Bloom's Taxonomy

Experiments IV, V, and VI explored the significant differences in types of keywords and types of search engines. Links generated were based on five competence nodes:

- Recall a photosynthesis equation
- Recall a photosynthesis definition
- Demonstrate a day-time photosynthesis procedure
- Predict a photosynthesis rate
- Define chlorophyll

These links were rated on the variable 'helpfulness to achieve learning outcome'. The findings suggest that it is more difficult to find good webpages to deal with a competence node at a high level of Bloom's taxonomy (Bloom, 1956). It seems that the links related to a competence node with a high level of Bloom's taxonomy were less useful to learners.

11.3 Limitations of the Present Study

There are some limitations to this study that need to be addressed. Each limitation is explained as follows.

11.3.1 Context Classification

There are established categorizations of capability and subject matter but none for context. Merrill's analysis (Merrill, 1994) was used for classifying subject matter contents into four fields: fact, concept, procedure, and principle. The classification of capability is undertaken by considering Bloom's taxonomy (Bloom, 1956) as recall, comprehend, apply, analyze, synthesize, and evaluate. Both classifications are well defined. However, in this research, context classification referred to tools and situation. The classification of context is still not well defined. Further studies on this issue should be conducted.

11.3.2 Competence Structure

Two competence structures were considered in this study. One was based on the highest common factor domain and the other was based on the photosynthesis domain for Key Stage 4 learners. These two competence structures differed significantly in terms of the following most important characteristics: size, complexity of structure, and types of data structure used. However, both may be smaller and less complex when compared to other larger domains, such as the whole biology subject for A-level learners. The findings of this study have been limited to small or medium-sized competence structures and not all levels of capability within Bloom's taxonomy were explored. In addition, the design of competence structure may require persons who are familiar with knowledge representation and data structure. Teachers for particular subjects will need to consult these experts in order to construct the competence structure.

Another limitation is the availability of existing competence structures. It seems that more knowledge (or conceptual) structures are available than competence structures. The idea of a knowledge structure (or conceptual structure) is a subarea of knowledge representation which was noted by Sowa (2000). This study endeavours to analyze knowledge of the real world into a computable representation. Knowledge representations are applied to various fields, such as artificial intelligence, semantic networks, object-oriented languages and the Knowledge Interchange Format (KIF). Normally the focus is exclusively on each node within a structure as either subject matter or capability or context.

11.3.3 Chosen Existing Competence

After a learner chooses a desired competence, the competence-based system provides a list of competences which are all child nodes of desired competence. Learners can choose only one competence from this list, as an existing competence. At this stage, more than one existing competence is not allowed. In fact, learners may already have achieved more than one existing competence. However, the current competence-based system does not deal with complex existing competences.

11.3.4 Learning Paths

In this study, three learning paths are considered: 'Ignore all gap nodes.', 'consider some gap nodes' and 'consider all gap nodes' For any competence structures, learning paths 'ignore all gap nodes' and 'consider all gap nodes' are clearly identified. There is normally one path per type of these two learning paths. The learning path 'considers some gap nodes' can be considered in more than one path. Each path can have a different number of competence gap nodes. This number of competence gap nodes for learning path 2 'Consider some gap nodes.' is still unclear. This is due to the structure of the competence itself. The different numbers of competence gap nodes with learning path 2 may affect the results of experiments conducted.

11.3.5 Application (Competence-based System)

A competence-based system is a Web-based tool for suggesting study material links based on the learner's competences. GoogleAPI was embedded within a system for searching links from the Web. The coding function within GoogleAPI tends to be changed regularly, which may affect the usability of the application. The application development is required to check the API regularly.

At this stage, the competence-based system has been implemented as a prototype. The designs and implementation did not particularly address usability and accessibility. Users may have felt uncomfortable when interacting with the system and therefore did not rate the system as highly as they could have.

11.3.6 Limited Domains

There were six experiments conducted in total. Experiments I and II explored two different knowledge domains. In order to partially address possible results, we found the effects in experiments I and II were similar. While other experiments (III, IV, V and VI) explored one knowledge domain (photosynthesis domain), the results of these experiments should also be similar to another domain. However, the findings from experiments I and II may be limited to two domains. Other different domains have not yet been explored.

Another limitation found within experiment III is that the participants' reactions against a freely-browsing learning mode were not considered. The comparison was made between two learning modes: competence-based and freely-browsing. The participants' evaluation, that is their reactions against a competence-based mode, was considered in experiments I and II. However, the participants' reactions against a freely-browsing learning mode have not yet been considered. It is unclear how participants would register their reaction ratings against a freely-browsing learning mode.

11.4 Future Work

Some limitations are acknowledged in section 11.3. To address these drawbacks, directions for future research are then suggested.

11.4.1 Context Classification

The literature features various aspects of context yet this concept is still not well defined. De Jong (2007) specifies the idea of context as identity, location, time, environment, and relation. Sampson and Fytros (2008) define context as job, occupations, function, life outcome, situation and task. There is one study conducted by Zimmermann, Lorenz and Oppermann (2007), in which they classify the context information into five categories: individuality, activity, location, time, and relations.

Individuality context refers to information about the entity which can be considered as natural, human, artificial, and group. Activity context can be described as a means of describing goals, task, and actions which extend the current needs. Location context is represented as the physical or virtual state of an entity or the exact location of something. Time information about situations is expressed as time context. Relations context refers to the relations established between an entity and other entities.

Reflecting on the context definitions which are applied within the competency model (see Figure 3-2), Zimmermann et al. refer to tools and situations. Tools can be placed within the category 'activity' of the five categories. The categories 'location' and 'time' of the five categories can also relate to situations, while the categories 'individuality' and 'relations' focus on persons or humans. The classification of contexts remains vague. In addition, this suggested classification currently applies to context-aware applications only. A well-defined and standard definition of context is still needed for future consideration.

11.4.2 Competence Structure

In this research, only two competence structures were considered. Their sizes are small to medium. The competence structure of the HCF domain contains 9 competence nodes and the other competence structure (photosynthesis for Key Stage 4) contains 32 competence nodes. Larger competence structures which contain more than 100 nodes should be explored in the future. In addition, experiments similar to experiments I, II, III, IV, V, and VI could be conducted, based on these larger-sized competence structures.

Another limitation of competence structures (section 11.3.2) is the lack of availability of existing competence structures. However, the existing knowledge structures can be extended to competence structures by tagging each node with capability and context.

In addition to this, a competence structure repository should be considered so that the structures can be stored and searched for future use.

11.4.3 Chosen Existing Competence

A learner can choose only one existing competence. In fact, the learner may have more than one existing competence. Further study on complex existing competences can be explored. This issue also deals with the generated learning path. When more than one existing competence is allowed, numbers of competence gap nodes within learning paths 2 and 3 can be less. A learner may already have achieved some competence gap nodes apart from one existing competence. When there are fewer competence gap nodes within learning paths, a learner may use less time to reach a desired competence. Future work could involve the development of a better algorithm for structuring the learning paths when multiple existing competences are chosen.

11.4.4 Learning Paths

The number of competence gap nodes varies, depending upon the size of the competence structure. When the size of the competence structure is small or medium (1 to 100 competence gap nodes), the competence gap nodes between learning path 2 'Consider some gap nodes' and learning path 3 'Consider all gap nodes' do not differ greatly in number. This would affect the experiment results in that sometimes the effectiveness of learning paths 2 and 3 could be similar for learners to achieve the learning outcome. Learning path 2 can sometimes be ignored when the size of the competence structure is small to medium.

When the size of the competence structure is large (more than 100 competence gap nodes), learning path 2 'Consider some gap nodes.' can be considered for several paths. The competence gap nodes of some paths do not differ much in number from the number of competence gap nodes in learning path 3. But there may be differences in some paths. The study of the appropriate number of competence gap nodes for learning path 2 in different sizes of competence structures is suggested as future work.

11.4.5 Application (Competence-Based System)

In this research a competence-based system was implemented as a prototype. The designs and implementation did not particularly address usability and accessibility. One important issue is that the competence-based system still relies on GoogleAPI. A future plan is to include a self-search engine within an application and improve the application's usability/accessibility.

11.4.6 Knowledge Impact on Learner's Learning When Interacting with Freely-Browsing Learning Mode

In experiment III, the outcomes suggested that the learning improvement of learners in the freely-browsing mode was due to the higher initial knowledge of participants. In order to validate this suggestion, future work could include the study of the impact of knowledge on learners' learning when interacting with a freely-browsing learning mode. This is to explore the significant differences between the learning of knowledgeable learners and that of non-knowledgeable learners when interacting with a freely-browsing learning mode.

11.4.7 Self-Assessment and Feedbacks

The current process within a competence-based system is to suggest study materials from the Web to learners, based on their competences. Once learners study the recommended materials from the Web, the system assumes that they have achieved their desired competence. In an e-learning transaction (Figure 2-1), the 'ask' part checks or confirms with students to help or support their understanding. This could be considered with a view to enhancing the competence-based system in two ways. One way is to generate an assessment question based on the current visited competence. For example, an existing competence might be 'Define factor' and the current visited node might be 'Calculate factor'. The learner could be asked the question: 'Please calculate the factors of 20.' This question is constructed from the current node: 'Calculate factor'. In general terms, if the competence is 'X', the assessment question is simply 'Please X', where any general variable in X is instantiated as a specific value. Another way could be that a competence-based system could be enhanced by searching for an online quiz and test from the Web.

The 'feedback' part can be considered after the assessment process. The feedback could arise from the answers a learner gives to the assessment questions. If the learner gives the correct answer, then the system would suggest he/she obtains study material links based on the next competence node. But if the learner fails to answer the question, the system would suggest obtaining study material links based on the child node of the currently visited competence. The learner may need to obtain study material links connected to an existing competence if he/she fails to answer the question based on the competence node next to the existing competence within a chosen learning path. In this case, the learner may be required to re-answer the question based on the competence node that he/she has already visited. A process of self-assessment and feedback will be needed for further investigation.

11.5 Concluding Remarks

A competence-based system for suggesting study material links is proposed in this thesis. There is a system process which considers the method for deriving the recommended links with study materials from learners' competences. The choices of competence elements are listed, based on a competence structure which identifies the relationship with competences. Investigating this research provides contributions such as: an instruction for designing a competence structure, the mapped XML-schema of a competence structure, and the finding that learning paths with more competence gap nodes are more helpful. By evaluating the approach via experimental studies, a competence-based system can be accepted by learners at the reaction level. Equal improvements in learners' learning were found between a freely-browsing and a competence-based system. However, this is due to the initial knowledge of learners within a freely-browsing learning mode.

The idea behind the proposed competence-based system is the desire to reduce the problems of high development costs and the requirement of content of knowledge within Web-based educational systems. All that will be required is a competence structure which will gather the existing study material links and recommend them to learners based on their competences. The intention behind developing a competence-based system is to allow the developers and researchers to conduct further studies on various structures of competence in other domains and different aspects of recommending existing study material links to learners.

Appendix A

The details of all intended learning outcomes of photosynthesis domain at a Key Stage 4 from AQA – revised version

Table AA-0-1: *Intended Learning Outcomes of Photosynthesis Domain at Key Stage 4 from AQA (Revised Version)*

<table>
<tr><td colspan="2">B2.3 Photosynthesis</td></tr>
<tr><td colspan="2">Green plants and algae use light energy to make their own food. They obtain the raw materials they need to make this food from the air and the soil. The conditions in which plants are grown can be changed to promote growth.</td></tr>
<tr><td colspan="2">Candidates should use their skills, knowledge and understanding to:</td></tr>
<tr><td> interpret data showing how factors affect the rate of photosynthesis
 evaluate the benefits of artificially manipulating the environment in which plants are grown.</td><td></td></tr>
<tr><td>Subject Content</td><td>Additional guidance</td></tr>
<tr><td colspan="2">B2.3.1 Photosynthesis</td></tr>
<tr><td>a) Photosynthesis is summarised by the equation:
carbon dioxide + water $\xrightarrow{\text{Light}}$ glucose + oxygen
b) During photosynthesis:
 light energy is absorbed by a green substance called chlorophyll, which is found in chloroplasts in some plant cells and algae
 this energy is used by converting carbon dioxide (from the air) and water (from the soil) into sugar (glucose)
 oxygen is released as a by-product.
c) The rate of photosynthesis may be limited by:
 shortage of light
 low temperature
 shortage of carbon dioxide.
d) Light, temperature and the availability of carbon dioxide interact and in practice any one of them may be the factor that limits photosynthesis.
e) The glucose produced in photosynthesis may be converted into insoluble starch for storage. Plant cells use some of the glucose produced during</td><td>Candidates should be able to relate the principle of limiting factors to the economics of enhancing the following conditions in greenhouses:
 light intensity
 temperature
 carbon dioxide concentration.</td></tr>
</table>

<table>
<tr><td>photosynthesis for respiration.
f) Some glucose in plants and algae is used:
 to produce fat or oil for storage
 to produce cellulose, which strengthens the cell wall
 to produce proteins.
g) To produce proteins, plants also use nitrate ions that are absorbed from the soil.</td><td></td></tr>
<tr><td colspan="2">Suggested ideas for practical work to develop skills and understanding include the following:</td></tr>
<tr><td colspan="2"> investigating the need for chlorophyll for photosynthesis with variegated leaves
 taking thin slices of potato and apple and adding iodine to observe under the microscope
 investigate the effects of light, temperature and carbon dioxide levels, (using Cabomba, algal balls or leaf discs from brassicas) on the rate of photosynthesis
 computer simulations to model the rate of photosynthesis in different conditions
 the use of sensors to investigate the effect of carbon dioxide and light levels on the rate of photosynthesis and the release of oxygen.</td></tr>
</table>

Appendix B

Five levels of task analysis of photosynthesis domain for Key Stage 4 learners:

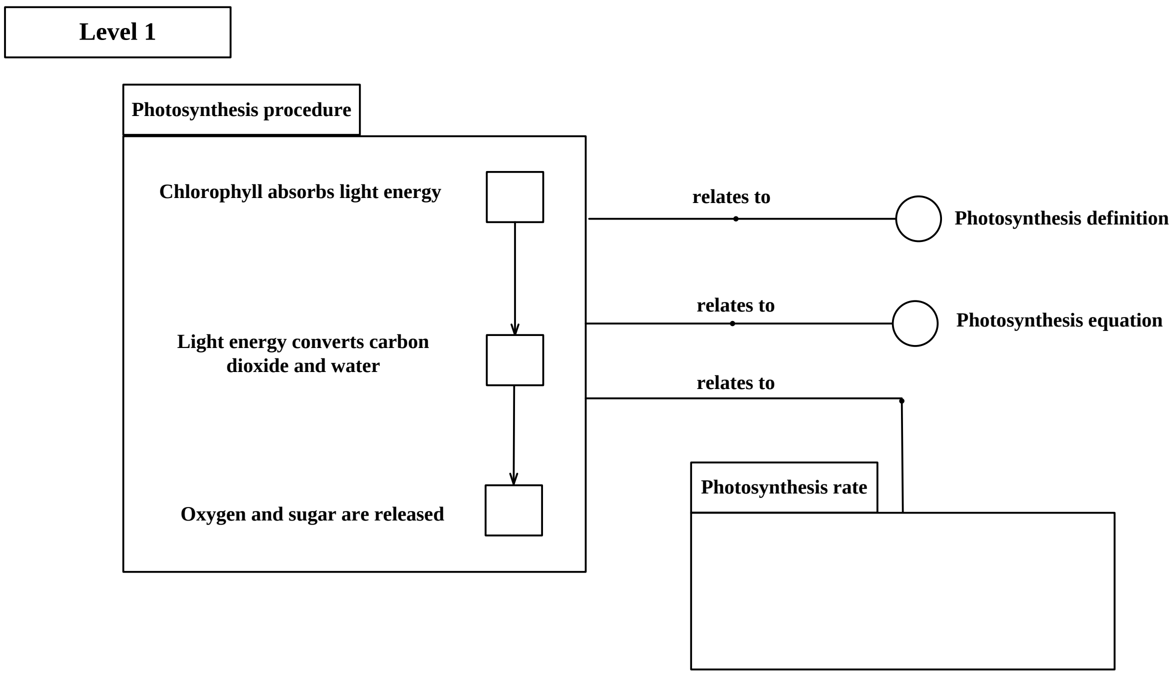


Figure AB-0-1: *Level 1 of Task Analysis of Photosynthesis Domain*

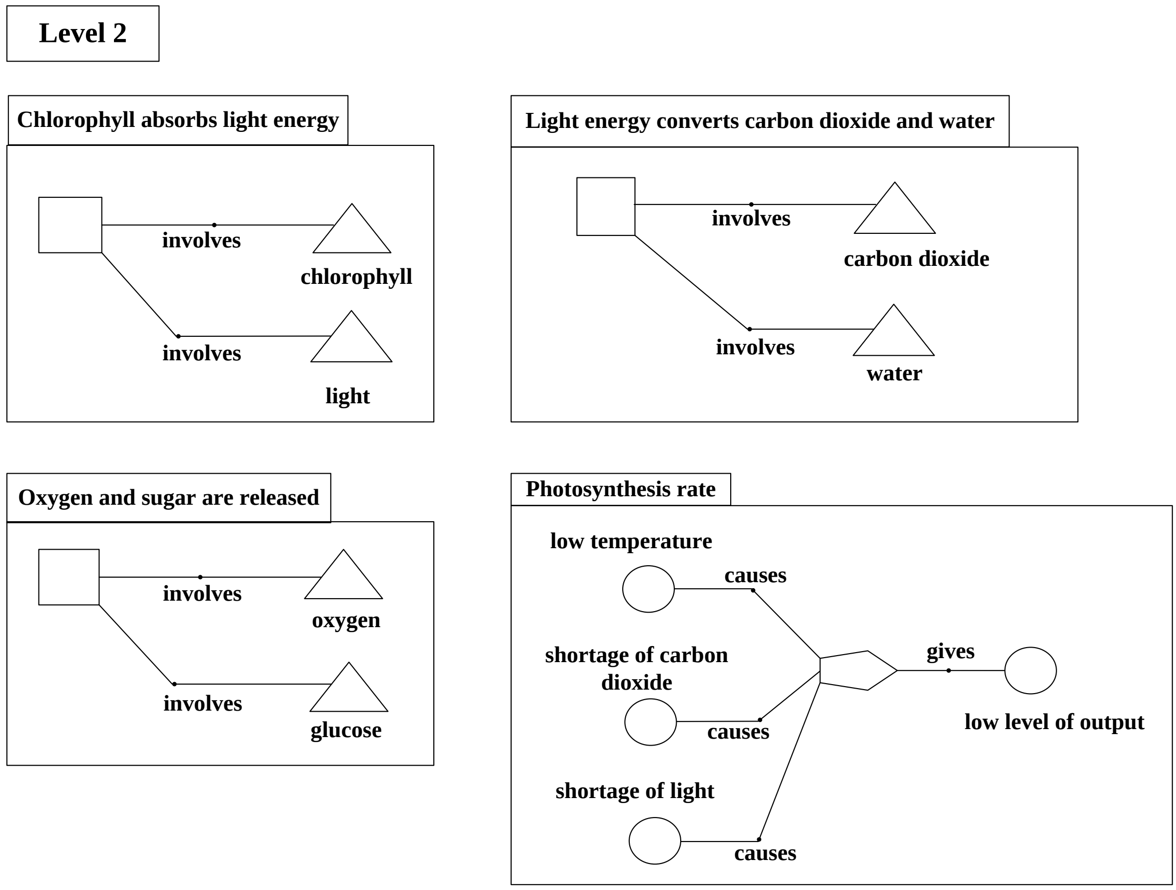


Figure AB-0-2: *Level 2 of Task Analysis of Photosynthesis Domain*

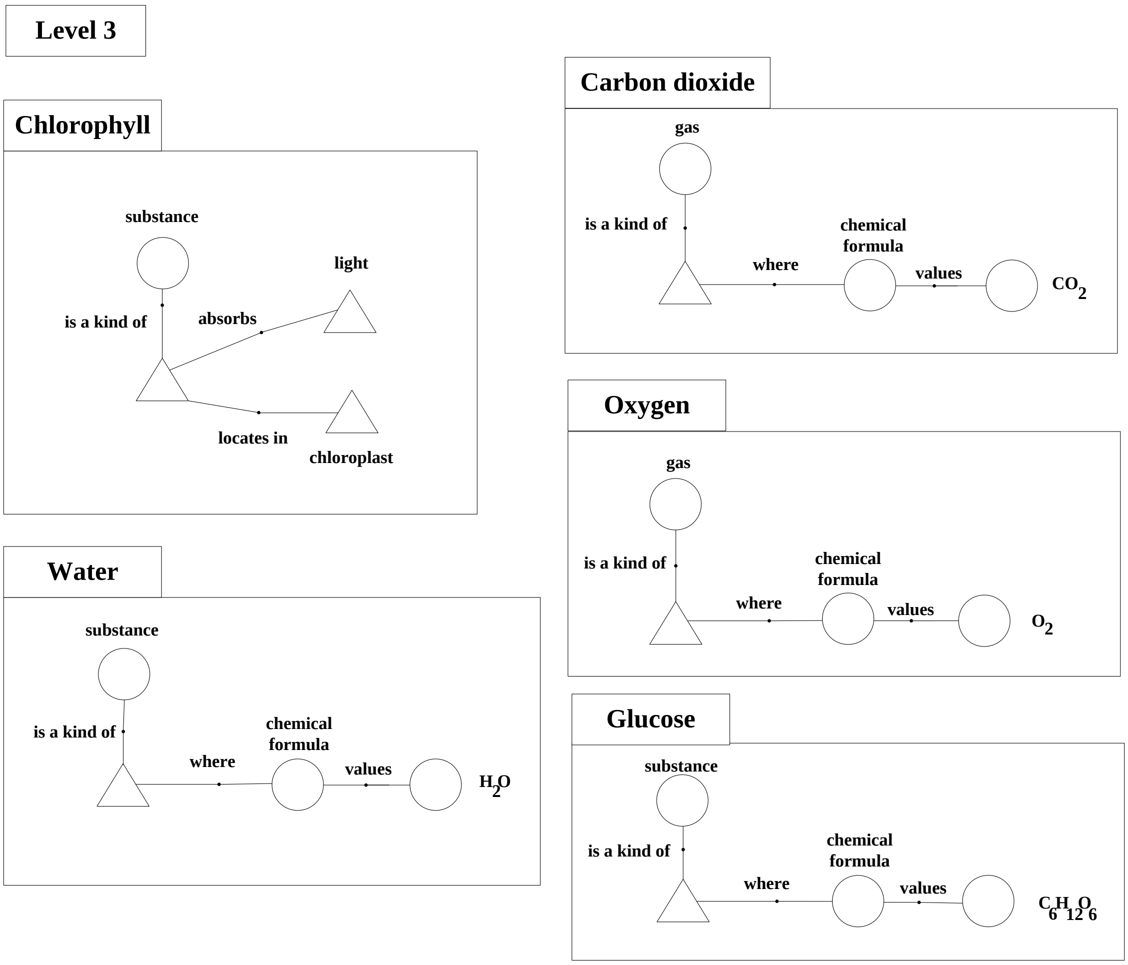


Figure AB-0-3: *Level 3 of Task Analysis of Photosynthesis Domain*

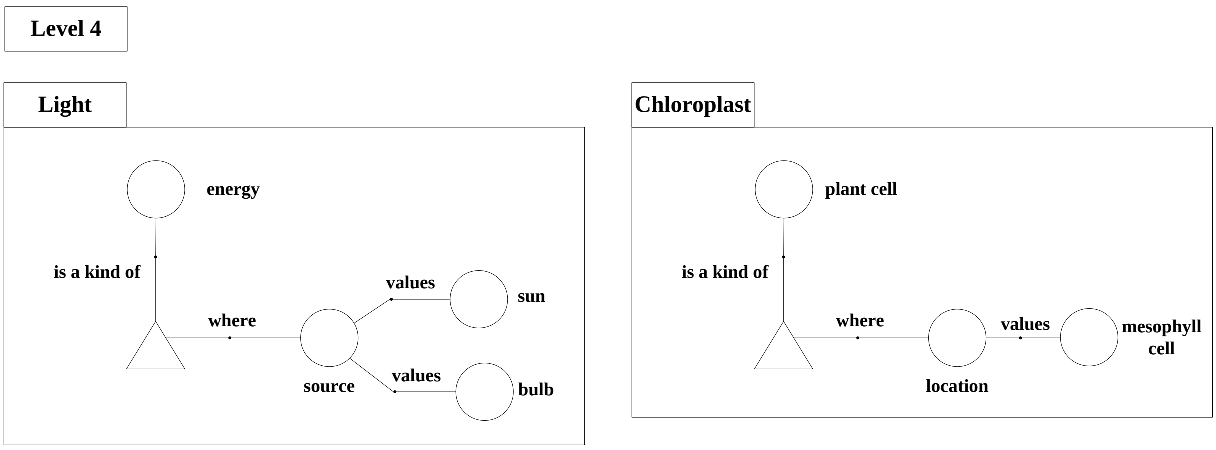


Figure AB-0-4: *Level 4 of Task Analysis of Photosynthesis Domain*

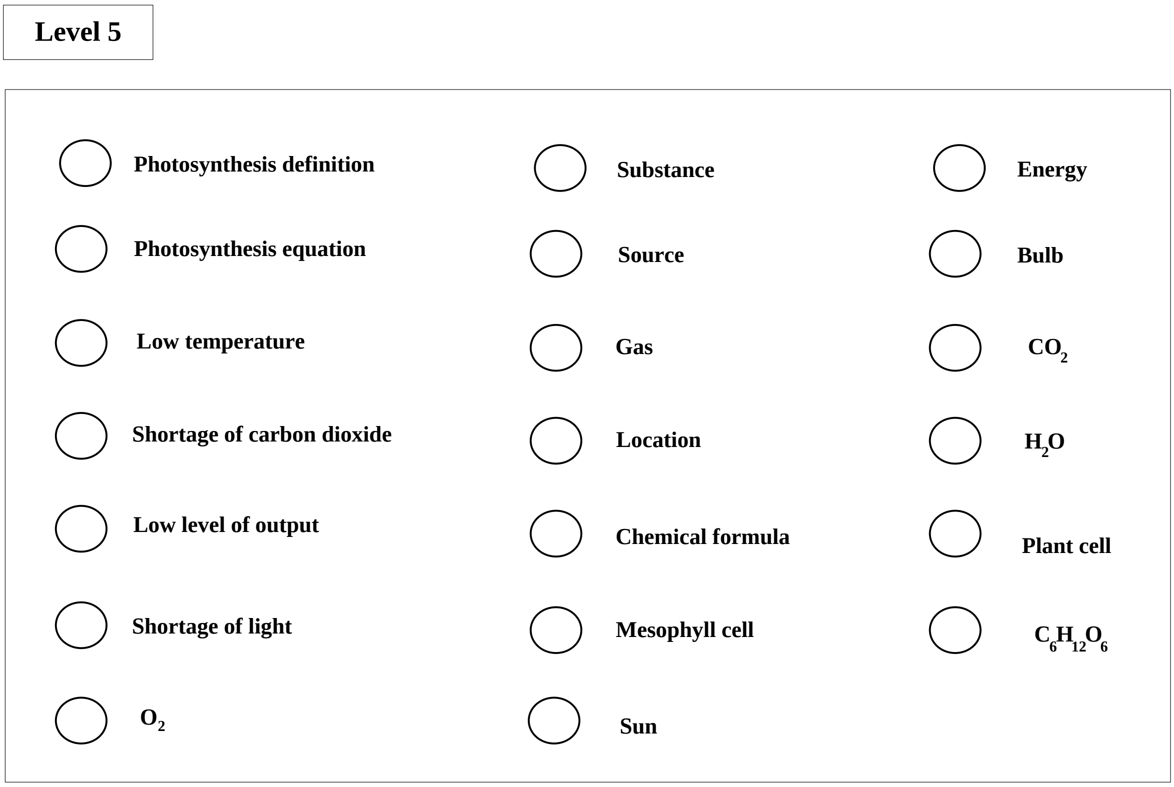


Figure AB-0-5: *Level 5 of Task Analysis of Photosynthesis Domain*

Appendix C

XML-schema of information of competence structure


```
<?xml version="1.0" encoding="UTF-8"?>
<!-- edited with XMLSpy v2010 rel. 3 (http://www.altova.com) by Athitaya (ECS) -->
<xsd:schema xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xsd="http://www.w3.org/2001/XMLSchema" elementFormDefault="qualified"
attributeFormDefault="unqualified">
    <!-- declare all types of table-->
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                <xsd:element name="Username" type="xsd:string"/>
                <xsd:element name="Password" type="xsd:string"/>
                <xsd:element name="Name" type="xsd:string"/>
                <xsd:element name="Email" type="xsd:string"/>
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        <xsd:sequence>
                <xsd:element name="DCompReg" type="xsd:string"/>
                <xsd:element name="User_ID" type="xsd:string"/>
                <xsd:element name="Competence_ID" type="xsd:string"/>
                <xsd:element name="DDate" type="xsd:date"/>
        </xsd:sequence>
    </xsd:complexType>
    <xsd:complexType name="UserECompType">
        <xsd:sequence>
                <xsd:element name="ECompReg" type="xsd:string"/>
                <xsd:element name="User_ID" type="xsd:string"/>
                <xsd:element name="Competence_ID" type="xsd:string"/>
                <xsd:element name="EDate" type="xsd:date"/>
        </xsd:sequence>
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    <xsd:complexType name="CompetencyType">
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                <xsd:element name="Competence_Desc" type="xsd:string"/>
                <xsd:element name="Competence_Update_Date" type="xsd:date"/>
                <xsd:element name="ILO_ID" type="xsd:string"/>
        </xsd:sequence>
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        <xsd:sequence>
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                <xsd:element name="ILO_Desc" type="xsd:string"/>
                <xsd:element name="SM_ID" type="xsd:string"/>
                <xsd:element name="Capability_ID" type="xsd:string"/>
        </xsd:sequence>
    </xsd:complexType>
    <xsd:complexType name="CapabilityType">
        <xsd:sequence>
                <xsd:element name="Capability_ID" type="xsd:string"/>
```

```
                <xsd:element name="Capability_Verb" type="xsd:string"/>
                <xsd:element name="Capability_Desc" type="xsd:string"/>
                <xsd:element name="Capability_Standard" type="xsd:string"/>
        </xsd:sequence>
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                <xsd:element name="SM_Type" type="xsd:string"/>
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minOccurs="0"/>
                <xsd:element name="SM_Procedure_ID" type="xsd:string"
minOccurs="0"/>
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minOccurs="0"/>
        </xsd:sequence>
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                <xsd:element name="Child_Competence_ID" type="xsd:string"/>
        </xsd:sequence>
    </xsd:complexType>
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    </xsd:complexType>
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                <xsd:element name="SM_Concept_Domain" type="xsd:string"/>
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        </xsd:sequence>
    </xsd:complexType>
    <xsd:complexType name="ProcedureType">
        <xsd:sequence>
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                <xsd:element name="SM_Procedure_Name" type="xsd:string"/>
                <xsd:element name="SM_Procedure_Goal" type="xsd:string"/>
            </xsd:sequence>
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        <xsd:complexType name="SM_SMConceptAttType">
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                <xsd:element name="SM_Concept_AttValID" type="xsd:string"/>
            </xsd:sequence>
        </xsd:complexType>
        <xsd:complexType name="SM_SMPrincipleCauseEffectType">
            <xsd:sequence>
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                <xsd:element name="SM_Principle_CauseEffectID" type="xsd:string"/>
            </xsd:sequence>
        </xsd:complexType>
        <xsd:complexType name="SM_SMProcedureStepDecisionType">
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                <xsd:element name="SM_Procedure_StepDecisionID"
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            </xsd:sequence>
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            </xsd:sequence>
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minOccurs="0" maxOccurs="unbounded"/>
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	</xsd:key>
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		<xsd:selector xpath=".//UserDComp"/>
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	<xsd:key name="PK_UserEComp_ECompReg">
		<xsd:selector xpath=".//UserEComp"/>
		<xsd:field xpath="ECompReg"/>
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            <xsd:selector xpath=".//ILO"/>
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refer="PK_Competency_Competence_ID">
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		</xsd:keyref>
		<xsd:keyref name="FK_FactSubjectMatter" refer="PK_Fact_SM_Fact_ID">
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			<xsd:field xpath="SM_Fact_ID"/>
		</xsd:keyref>
		<xsd:keyref name="FK_ConceptSubjectMatter"
refer="PK_Concept_SM_Concept_ID">
			<xsd:selector xpath=".//SubjectMatter"/>
			<xsd:field xpath="SM_Concept_ID"/>
		</xsd:keyref>
		<xsd:keyref name="FK_PrincipleSubjectMatter"
refer="PK_Principle_SM_Principle_ID">
			<xsd:selector xpath=".//SubjectMatter"/>
			<xsd:field xpath="SM_Principle_ID"/>
		</xsd:keyref>
		<xsd:keyref name="FK_ProcedureSubjectMatter"
refer="PK_Procedure_SM_Procedure_ID">
			<xsd:selector xpath=".//SubjectMatter"/>
			<xsd:field xpath="SM_Procedure_ID"/>
		</xsd:keyref>
		<xsd:keyref name="FK_ConceptSM_SMConceptAtt"
refer="PK_Concept_SM_Concept_ID">
			<xsd:selector xpath=".//SM_SMConceptAtt"/>
			<xsd:field xpath="SM_Concept_ID"/>
		</xsd:keyref>
		<xsd:keyref name="FK_SM_ConceptAttVal_SM_SMConceptAtt"
refer="PK_SM_ConceptAttVal_ID">
			<xsd:selector xpath=".//SM_SMConceptAtt"/>
			<xsd:field xpath="SM_Concept_AttValID"/>
		</xsd:keyref>
		<xsd:keyref name="FK_PrincipleSM_SMPrincipleCauseEffect"
refer="PK_Principle_SM_Principle_ID">
			<xsd:selector xpath=".//SM_SMPrincipleCauseEffect"/>
			<xsd:field xpath="SM_Principle_ID"/>
		</xsd:keyref>
```

```
        <xsd:keyref name="FK_SM_PrincipleCauseEffect_SM_SMPrincipleCauseEffect"
refer="PK_SM_PrincipleCauseEffect_ID">
                <xsd:selector xpath=".//SM_SMPrincipleCauseEffect"/>
                <xsd:field xpath="SM_Principle_CauseEffectID"/>
        </xsd:keyref>
        <xsd:keyref name="FK_ProcedureSM_SMProcedureStepDecision"
refer="PK_Procedure_SM_Procedure_ID">
                <xsd:selector xpath=".//SM_SMProcedureStepDecision"/>
                <xsd:field xpath="SM_Procedure_ID"/>
        </xsd:keyref>
        <xsd:keyref
name="FK_SM_ProcedureStepDecision_SM_SMProcedureStepDecision"
refer="PK_SM_ProcedureStepDecision_ID">
                <xsd:selector xpath=".//SM_SMProcedureStepDecision"/>
                <xsd:field xpath="SM_Procedure_StepDecisionID"/>
        </xsd:keyref>
    </xsd:element>
</xsd:schema>
```

Appendix D

PHP and SQL of listing children and children of children competence node of desired competence:

```
<?php
// Previous codes are to open connection to database and pass value of desired competence
//select all from compchild
$sql = "SELECT * FROM compchild ";
$result = mysql_query($sql) or die ("Error Query [".$strSQL."]");
$cnt = 0;
//store all from compchild into two arrays
$compIDArray = array();
$childIDArray = array();
while($row = mysql_fetch_array($result)){
    $compIDArray[$cnt] = $row['CompID'];
    $childIDArray[$cnt] = $row['ChildID'];
    //echo "compIDArray[".$cnt."] = ".$compIDArray[cnt];
    //echo ", childIDArray[".$cnt."] = ".$childIDArray[cnt]."<br>";
    $cnt = $cnt + 1;
    //echo "size1 = ".count($compIDArray);
}
// Store dcompid in tempid then query its child ...later will be child of child
$tempID[0] = $dcompID;
$resultArray = array();
$rCnt = 0;
while(count($tempID) > 0){
  $cID = array_shift($tempID);
  for ($i=0; $i<count($compIDArray); $i++){
    if($compIDArray[$i] == $cID){
        $resultArray[$rCnt] = $childIDArray[$i];
        $tempID[count($resultArray)] = $childIDArray[$i];
        $rCnt = $rCnt + 1;
    }
  }
}
//final array keeps all child and child of child
$finalResultArray = array();
$rCnt = 0;
for ($i=0; $i<count($resultArray); $i++){
    if(! in_array($resultArray[$i],$finalResultArray)){
        $finalResultArray[$rCnt] = $resultArray[$i];
        $rCnt = $rCnt + 1;
    }
}
// take repeated child or child of child out of array
$finalResultStr = "";
for ($i=0; $i<count($finalResultArray); $i++){
     $finalResultStr = $finalResultStr."'".$finalResultArray[$i]."',";
}
$finalResultStr = substr($finalResultStr,0,strlen($finalResultStr) - 1);
$sql = "SELECT * FROM competency where CompID IN (".$finalResultStr.") order by CompLevel";
```

```
$result = mysql_query($sql) or die ("Error Query [".$strSQL."]");
$tempLevel = 0;
while($row = mysql_fetch_array($result)){
    $ECompID = $row['CompID'];
    $ECompDesc = $row['CompDesc'];
    $ECompCapability = $row['Capability'];
    $ECompSubjectMatter = $row['SubjectMatter'];
    $ECompContext = $row['Context'];
    $ECompLevel = $row['CompLevel'];
    if($ECompLevel != $tempLevel){
    echo "<br><b>Level: ".$ECompLevel."<br></b>";
    }
//Print all children and children of children nodes
    if($ECompID == $chosenecompID){
    echo "<input type='radio' name='existingCompetence' id='".$ECompID."'
value='".$ECompID."|".$ECompDesc."|".$ECompCapability."|".$ECompSubjectMatter."|".
$ECompContext."' checked/>  ".$ECompDesc."<br>";
    }
    else{
    echo "<input type='radio' name='existingCompetence' id='".$ECompID."'
value='".$ECompID."|".$ECompDesc."|".$ECompCapability."|".$ECompSubjectMatter."|".
$ECompContext."'/>  ".$ECompDesc."<br>";
    }
    $cnt = $cnt +1;
    $tempLevel = $ECompLevel;
}
if($cnt == 0){
    echo "<font color=red>Warning : Your existing competence has no matched
desired competence. You can go back and select your existing competence again OR
log out to terminate</font>";
}
?>
```

Appendix E

A sample invitation email for participants is below. This was for experiment I, and II.

My name is Athitaya Nitchot: I am a PhD student in the LSL lab of the school of electronics and computer science at the University of Southampton. I am carrying out an experiment in which 18 participants have been asked to participate.

Aim of this experiment

The aim of this research is to investigate and design a system that can provide appropriate study materials as links from the Web to learners. The aim of this experiment is to find an appropriate algorithm or learning path to generate the query that is matched with the chosen competences of the learners.

What is involved?

During the experiment, the following steps will be conducted.

1) You will be given information on consent verbally.
2) Before conducting the experiment you will receive training and information so that you have a clear understanding of the terms of definitions.
3) You will be asked to read the scenario and the instruction on interacting with system and filling the questionnaire.
4) Following this you will be asked to complete the questionnaire about the overall system and learning paths.
5) As a reward for your participation in the experiment you will be offered a £5 gift voucher.

Date and Venue:

Date: 18 – 20 October 2010

Venue: Room 3067 in LSL lab (Building 32, Level 3)

How long will the experiment last?

The experiment will take approximately 45-60 minutes.

How to get involved?

If you would like to take part in the study, you need to choose a convenient time slot of your preference on Doodle. There are six time slots per day: 9am-10am, 10.15am-11.15am, 11.30am – 12.30pm, 1pm- 2pm, 2.15pm- 3.15pm, and 3.30pm – 4.30pm. There is a maximum 2 people per slot.

To protect your confidentiality and avoid divulging any personal information, you are required to enter a false name when booking your preferred time. Please make a note of this name and your time slot and bring this with you to the experiment.

Please click a below link to get involved with this experiment.
http://www.doodle.com/kux82p595s64658s

Further details

If you have any further questions about this study and your rights, or if you wish to lodge a complaint or concern, you may contact the principle investigator: Athitaya Nitchot by email (an08r@ecs.soton.ac.uk). The experiment has been given ECS ethics approval under reference ES/10/09/007.

Thank you very much and I hope to see you there.

Athitaya Nitchot

Appendix F

This training document was given to participants for experiment I and II.

Introduction and Terms of Definitions

1. Introduction

The aim of this research is to investigate and design a system which would provide appropriate study materials as links from the Web to learners. This experiment aims to find out an appropriate algorithm or learning path to generate the query which is matched with the chosen competences of the learners.

The system uses information about your competences to suggest Web links.

2. Terms of Definition

What is competence?

It is the ability to perform a particular activity to a prescribed standard.

How many types of learner competences are there?

Two types: desired competence and existing competence.

Desired competence

It refers to your intended learning outcome or the competence which you wish to gain.

Existing Competence

It refers to the estimation of your actual competence.

Competence Structure

Competence structure is designed to specify the range of competence elements/nodes for a particular knowledge domain. The competence structure highlights the relationship between competence nodes and the gap between desired and existing competence. The example of competence structure in this research is based on mathematical factor, common factor and highest common factor (HCF). The next figure shows the competence structure of this knowledge domain.

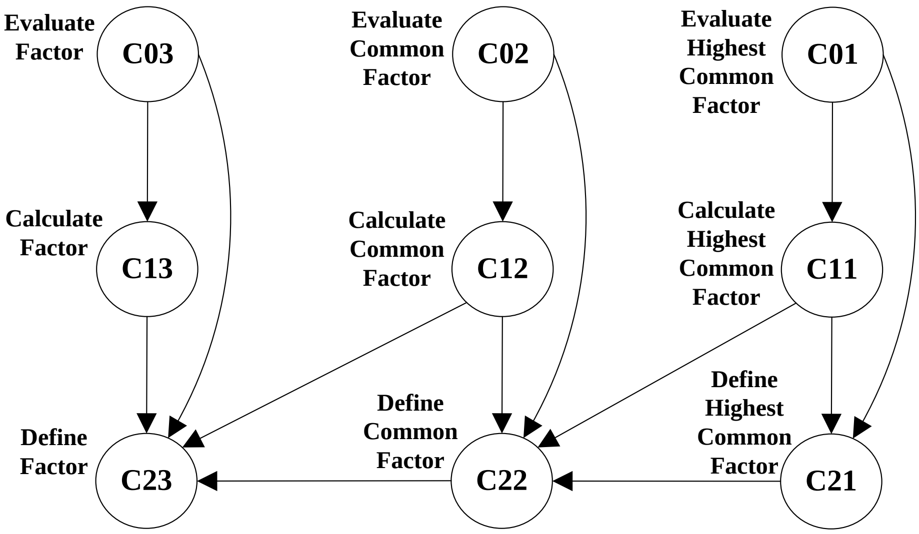

Figure AF-0-1: *Competence Structure (HCF Knowledge Domain)*

To briefly explain the parent-child relationship between competence nodes, consider this example. In order to achieve competence number C02, you must complete C12 and C22 beforehand. To attain C12, you must complete C23 and C22. To achieve C22, you must firstly achieve C23.

Assembled competences/Gap node competences

This term refers to the competence nodes between desired and existing competence. Consider this example. The desired competence is C02 and existing competence is C23. The set of assembled competences contains C22 and C12.

Learning path

It describes the study route to reach the intended learning outcome (or desired competence) from existing competence. Consider the previous example of desired (C02) and existing (C23) competence, the possible learning paths are

C23 → C02

C23 → C12 → C02

C23 → C22 → C02

C23 → C22 → C12 → C02

Appendix G

This is scenario was given to participants for experiment I and II.

Scenario

1. Overview

As you already have background knowledge about mathematical factorization, common factors and highest common factors, you are asked to review and access the experimental system. You will be given existing and desired competence. These two data will be the inputs to the system. It will show you the lists of learning paths as the output. You will be asked to choose the choices from the provided list. After that, you can access study materials from Web based on the chosen learning paths. You then review the accessed study materials based on three learning paths and express your opinions about each learning path by filling the questionnaire.

2. A Set of Desired and Existing Competence

Desired competence: 'Calculate highest common factor'

Existing Competence: 'Define factor'

3. Learning Path

The possible learning paths are:

Define factor → Calculate highest common factor

Define factor → Define common factor → Calculate highest common factor

Define factor → Define common factor → Define highest common factor → Calculate highest common factor

Appendix H

The instruction below was for experiment I and II.

Instruction (To use the system and fill the questionnaire)

1. Open the web browser and go to http://localhost/Prototypes2/Login.php .
2. You will see the login page as a Figure AH-0-1. Please enter username as "**Jack**" and password as "**abc11**".

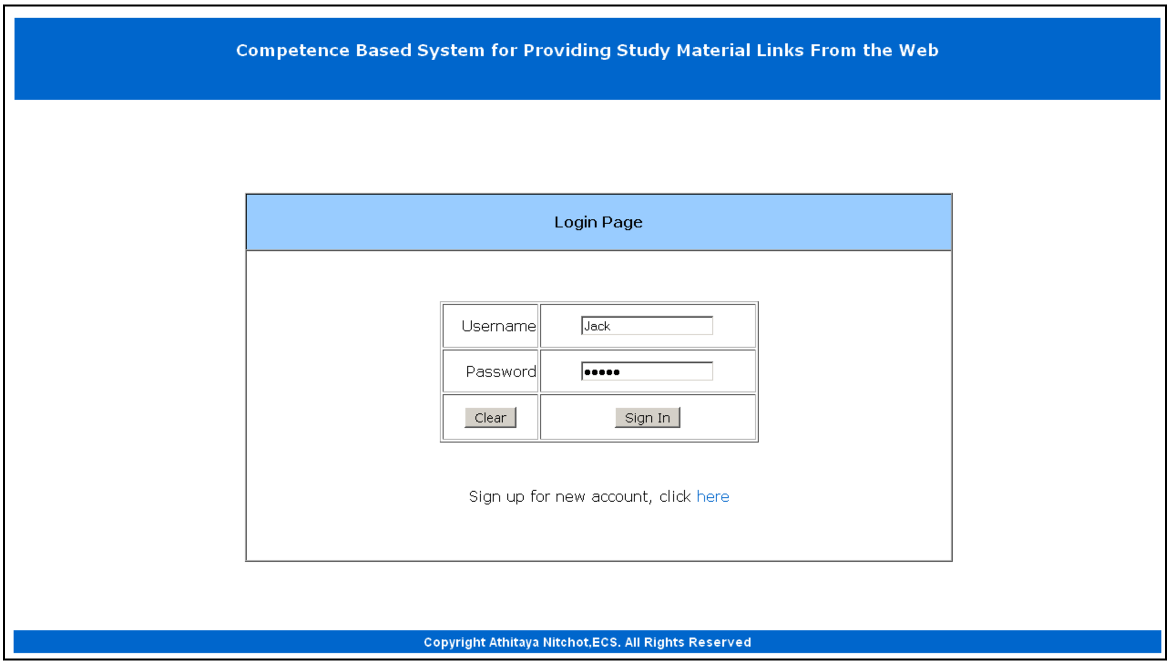

Figure AH-0-1: *Login Page*

3. After you login, you now see the main page. Scroll the page down and please click '**Next**'.
4. You need to choose the desired competence from the provided list. Then choose '**calculate highest common factor**' as your desired competence and click '**Next**'.
5. Then, you need to choose the existing competence from the provided list. Please choose '**define factor**' as your existing competence and click '**Next**'.

6. The system generates the list of learning path as you can see as in Figure AH-0-2. Please choose learning path ‘**define factor → calculate highest common factor**’ and click ‘**Next**’.

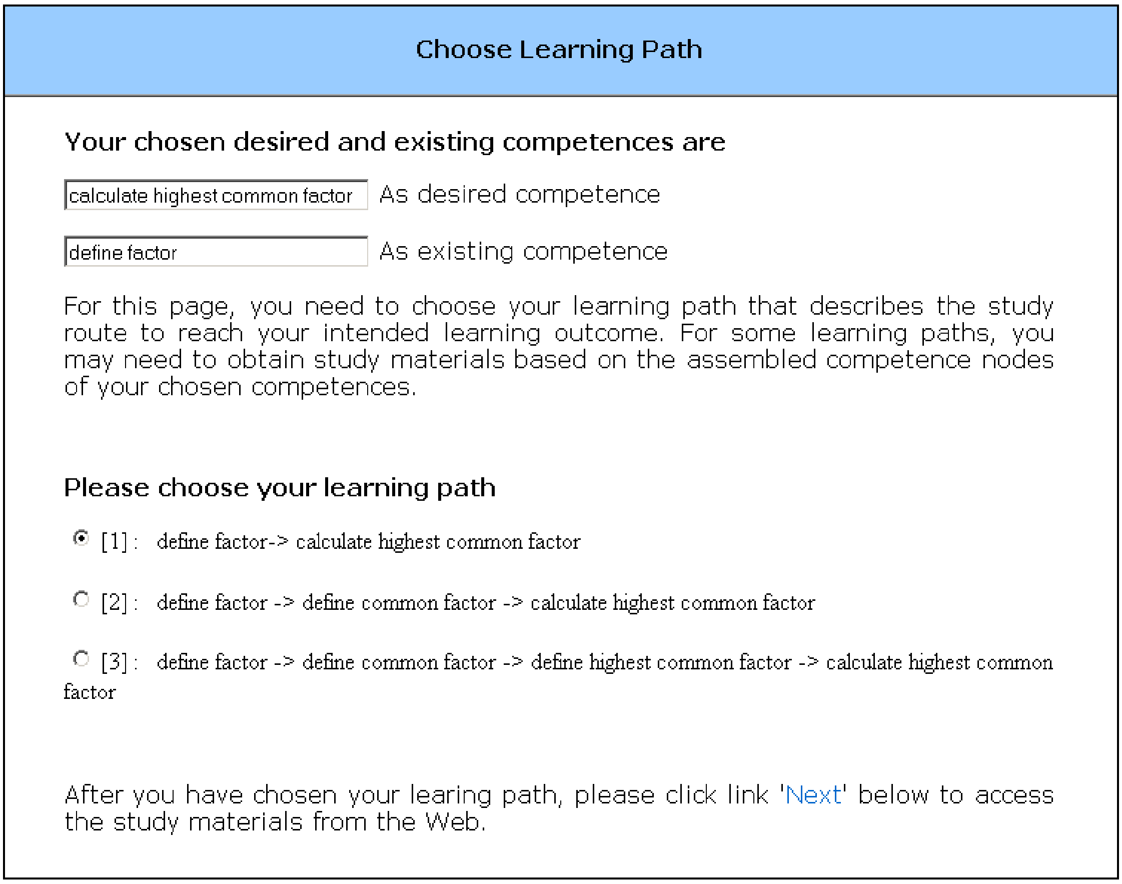

Figure AH-0-2: *Lists of Learning Paths*

(as Desired Competence: Calculate HCF and Existing Competence: Define Factor)

7. The page ‘Access the study material links’ then will appear on the screen (as in Figure AH-0-3). To access study materials from the Web based on the learning path ‘define factor → calculate highest common factor’, please follow the steps below:
    - Please click ‘**button 1**’.
    - Then **access the first three Websites**. For each Website, please look through the page and read the information related to competence element ‘calculate highest common factor’ (if applicable).
    - After you’ve reviewed the pages, please **close all link tabs except the tab of competence-based system**. Then, please raise your hand and the investigator will give you the questionnaire I.
    - Then, please fill the questionnaire I: section A (Appendix I).

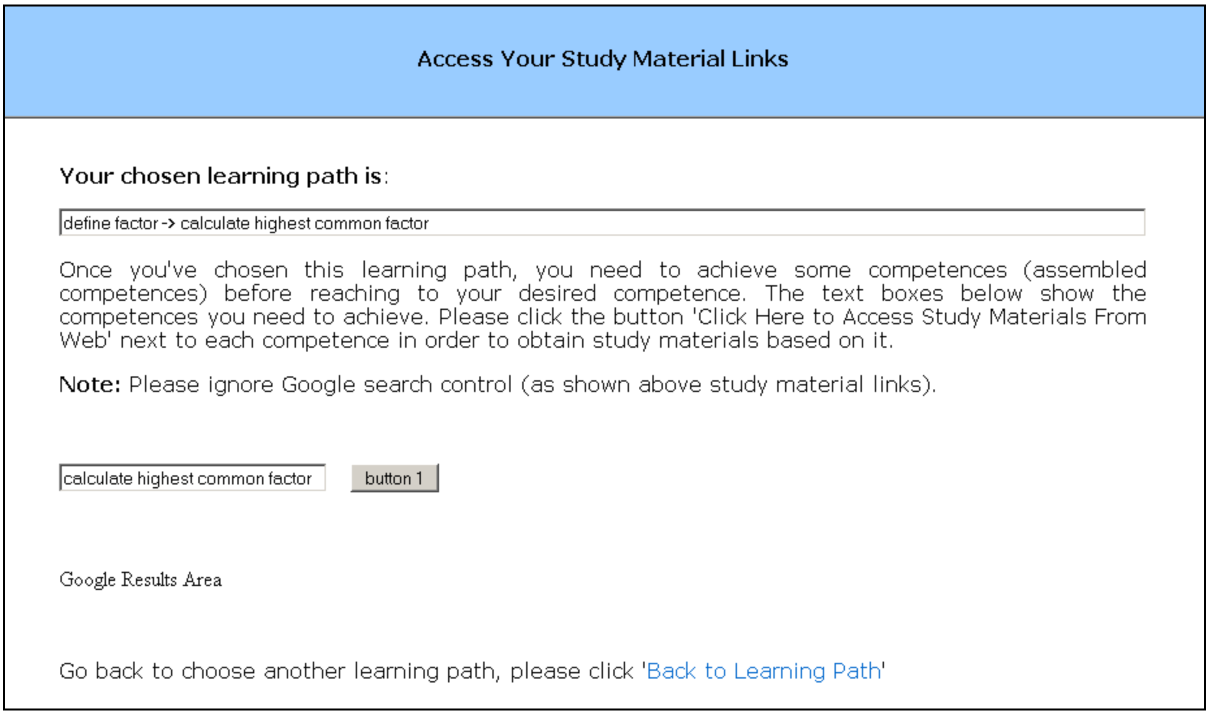

Figure AH-0-3: *Access Study Materials Page*

8. Click ‘**Back to Learning Path**’ at the bottom of the page.
9. Then choose ‘define factor → define common factor → calculate highest common factor’ and click ‘Next’.
10. The page ‘Access the study material links’ then will appear on the screen. To access study materials from the Web based on the learning path ‘define factor → define common factor → calculate highest common factor’, please follow the steps below:
    - Please click ‘**button 1**’.
    - Then **access the first three Websites**. For each Website, please look through the page and read the information related to competence element ‘define common factor’ (if applicable).
    - After you’ve reviewed the pages, please **close all link tabs except the tab of competence-based system**.
    - Please click the ‘**button 2**’.
    - Then **access the first three Websites**. For each Website, please look through the page and read the information related to competence element ‘calculate highest common factor’ (if applicable).
    - After you’ve reviewed the pages, please **close all link tabs except the tab of competence-based system**.
    - Then, please fill the questionnaire I: section B (Appendix I).

11. Click '**Back to Learning Path**' at the bottom of the page.
12. Then choose 'define factor → define common factor → define highest common factor → calculate highest common factor' and click 'Next'.
13. The page 'Access the study material links' then will appear on the screen. To access study materials from the Web based on the learning path 'define factor → define common factor → define highest common factor → calculate highest common factor', please follow the steps below:
    - Please click '**button 1**'.
    - Then **access the first three Websites**. For each Websites, please look through the page and read the information related to competence element 'define common factor' (if applicable).
    - After you've reviewed the pages, please **close all link tabs except the tab of competence-based system**.
    - Please click '**button 2**'.
    - Then **access the first three Websites**. For each Website, please look through the page and read the information related to competence element 'define highest common factor' (if applicable).
    - After you've reviewed the pages, please **close all link tabs except the tab of competence-based system**.
    - Please click '**button 3**'.
    - Please **access the first three Websites**. For each Website, please look through the page and read the information related to competence element 'calculate highest common factor' (if applicable).
    - After you've reviewed the pages, please **close all link tabs except the tab of competence-based system**.
    - Then, please fill the questionnaire I (Appendix I): section C and section D.
14. After you complete filling in questionnaire I, please raise your hand again. The investigator will give you the final questionnaire (questionnaire II – Appendix J).
15. Now you have finished the experiment, please hand in the questionnaires to the investigator. Thank you very much

Appendix I

Questionnaire I is for experiment I.

The purpose of this questionnaire is to allow you to give a rating upon each learning path (or algorithm). The results from this will help us to compare and determine an appropriate learning path. There are four sections in this questionnaire:

Section A: Question related to a first learning path
Section B: Questions related to a second learning path
Section C: Questions related to a third learning path
Section D: Question related to a comparison of three learning paths based on learner's efficiency (shortest time)

For each statement below, please indicate the extent of your agreement or disagreement by ticking √ in the appropriate box in each section using a provided pen**.**

Section A: First Learning Path

Questions	Scale				
	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1) A learner will be able to achieve his/her intended learning outcome after using the study materials.					

Section B: Second Learning Path

Questions	Scale				
	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1) A learner will be able to achieve his/her intended learning outcome after using the study materials.					
2) Using study materials based on the assembled learning outcome helps a learner to achieve his/her intended learning outcome.					
3) Using study materials based on the assembled learning outcome helps to improve a learner's motivation.					

Section C: Third Learning Path

Questions	Scale				
	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
1) A learner will be able to achieve his/her intended learning outcome after using the study materials.					
2) Using study materials based on the assembled learning outcomes helps a learner to achieve his/her intended learning outcome.					
3) Using study materials based on the assembled learning outcomes helps to improve a learner's motivation.					

Section D: Comparison of Three Learning Paths Based on Learner's Efficiency (Shortest Time)

Questions	
1) Compare the three learning paths, one allows a learner to reach his/her intended learning outcome spending the shortest period of time?	☐ define factor → calculate highest common factor ☐ define factor → define common factor → calculate highest common factor ☐ define factor → define common factor → define highest common factor → calculate highest common factor

Appendix J

Questionnaire II is for experiment II.

The purpose of this questionnaire is to allow you to rate the features of overall system functions and answer general questions regarding to your experiences with Web-based education. The questionnaire is designed to help us to measure the system effectiveness, quality of generated study materials and the familiarity of participator with a Web-based educational system. Your responses will be completely anonymous.
For each of the statement below, please indicate the extent of your agreement or disagreement by ticking √ in the appropriate box in each section using a provided pen.

Section A: General Questions Regarding to Web-based Education					
Question	**Strongly Disagree**	**Disagree**	**Neither Agree Nor Disagree**	**Agree**	**Strongly Agree**
1) I am familiar with a Web-based educational system.					
2) How do you find information related with your study materials on the Web? (Please choose one or more choices)	☐ Directly go to a Webpage location ☐ Hyperlinks derived from another Webpage ☐ Search Engine ☐ Other, please specify................................				
3) I think a search engine is appropriate for educational use.					
Section B: Overall System Evaluation					
Question	**Strongly Disagree**	**Disagree**	**Neither Agree Nor Disagree**	**Agree**	**Strongly Agree**
4) The system helps a learner to identify his/her intended learning outcome.					
5) Choices in the list of existing competence can indicate a learner's actual competence.					
6) The system helps a learner to identify assembled learning outcomes.					

Question	**Strongly Disagree**	**Disagree**	**Neither Agree Nor Disagree**	**Agree**	**Strongly Agree**
7) The generated Web pages give information related to each learning outcome.					
8) A learner can find sufficient information on the topic within one page.					
9) A teacher is required to help a learner in order to explain information on the links.					
10) The Web pages provide a learner not only with the text explanation but also other types of learning resources for example, figure, picture, video etc.					
11) I will suggest this system to other people for the future use.					
12) The reasons you will suggest this system to your colleagues (or friends).	(Please specify your answers here)				

Appendix K

Training document was given to participants who were experienced with a competence-based learning mode in experiment III.

Introduction, Terms of Definitions and How to use a competence-based system

1. Introduction

The aim of this research is to investigate and design a system (called a competence-based system) which would provide appropriate study materials as links from the Web to learners. The aim of this experiment is to find out whether a competence-based learning mode is better than a freely-browsing learning mode. The system uses information about your competences to suggest Web links.

2. Terms of Definition

What is subject matter content?

It is a subject knowledge which a learner tends to learn.

What is competence?

It is the ability to perform a particular activity to a prescribed standard.

How many types of learner competences are there?

Two types: desired competence and existing competence.

Desired competence

It refers to your intended learning outcome or the competence which you wish to gain.

Existing Competence

It refers to the estimation of your actual competence.

Learning path

It describes the study route to reach the intended learning outcome (or desired competence) from existing competence. Consider the example of desired ('Demonstrate a day time photosynthesis procedure') and existing ('Define glucose') competence, the possible learning paths are

- Define a glucose →Demonstrate a day time photosynthesis procedure
- Define a glucose →Rehearse the fact that Oxygen and sugar are released → State a day time photosynthesis procedure → Demonstrate a day time photosynthesis procedure

3. How to use a competence-based system

System flow

1. Login
2. Main Page
3. Choose your targeted subject matter content

4. Choose your desired competence
5. Choose your existing competence
6. Choose the learning path. The learning path(s) are generated from your chosen competences.
7. Obtain study material links based upon your chosen learning path. After you obtain study material links, you can go back to choose a new subject matter content again.

Appendix L

This is a scenario and instruction for experiment III. This is for participants who were experiencing a competence-based learning mode.

Before you do a pre-test/post-test and explore the competence-based learning mode, please read all the information below carefully.

1. *Scenario*

You are asked to experience a competence-based learning mode. You will be given a pre-test on photosynthesis at a Key Stage 4. Next you can obtain study material links by experiencing the provided mode of learning. You will be given a set of targeted subject matter which identifies the knowledge area you need to learn. After you finish a learning session, you then will be given a post-test on the same knowledge domain.

Targeted Subject Matter

The following list indicates the targeted subject matter contents. You are recommended to learn only this scope of knowledge area.

- Photosynthesis definition
- Photosynthesis equation
- Photosynthesis rate
- Photosynthesis procedure
- Chlorophyll

2. Instruction (To do a pre-test, experience with a competence-based learning mode and to do a post-test)

1. Before you experience a learning mode provided by a competence-based system, please answer some questions related to your educational background and complete a pre-test provided by the investigator.
2. After you finish the pre-test, open the web browser and go to http://localhost/Prototypes3/Login.php .
3. You will see the login page as in Figure AL-0-1. Please enter username as "**Jack**" and password as "**abc11**".

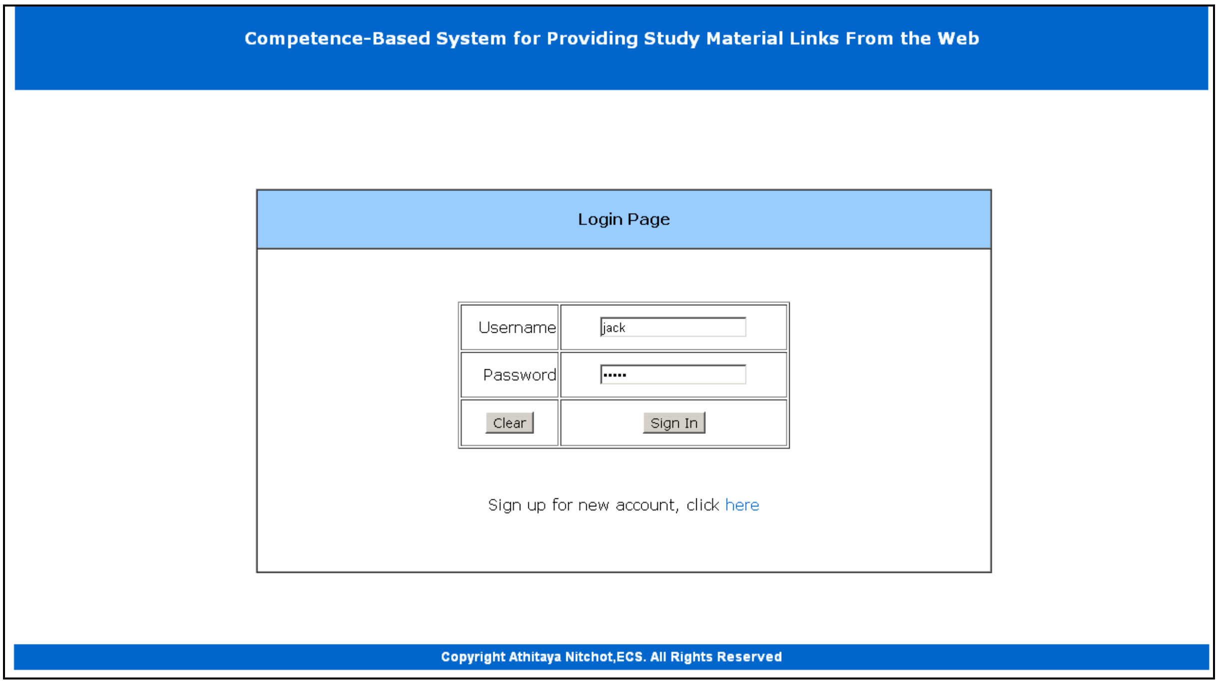

Figure AL-0-1: *Login Page*

4. After you login, you will now see the main page. You are suggested to learn these subjects:
    - Photosynthesis definition
    - Photosynthesis equation
    - Photosynthesis rate
    - Photosynthesis procedure
    - Chlorophyll
5. Now you can explore the competence-based learning mode and the study duration will be 30 minutes.
6. When you finish the learning session, please complete a post-test provided by the investigator.
7. Now you have finished the experiment, please hand in the both tests to the investigator. Thank you very much.

This is a scenario and instruction for experiment III. This is for participants who were experiencing a freely-browsing learning mode.

Before you do a pre-test/post-test and explore the freely-browsing learning mode, please read all the information below carefully.

1. Scenario

You are asked to experience a freely-browsing learning mode. You will be given a pre-test on photosynthesis at a Key Stage 4. Next you can obtain study material links by experiencing the provided mode of learning. You will be given a set of targeted subject matter which identifies the knowledge area you need to learn. After you finish a learning session, you then will be given a post-test on the same knowledge domain.

Targeted Subject Matter

The following list indicates the targeted subject matter contents. You are recommended to learn only this scope of knowledge area.

- Photosynthesis definition
- Photosynthesis equation
- Photosynthesis rate
- Photosynthesis procedure
- Chlorophyll

2. Instruction (To do a pre-test, experience with a freely-browsing learning mode and to do a post-test)

1. Before you experience a learning mode by freely-browsing, please answer some questions related to your educational background and complete a pre-test provided by the investigator.
2. After you finish the pre-test, open the web browser and go to **http://www.google.com/**
3. You will see Google search engine main page.

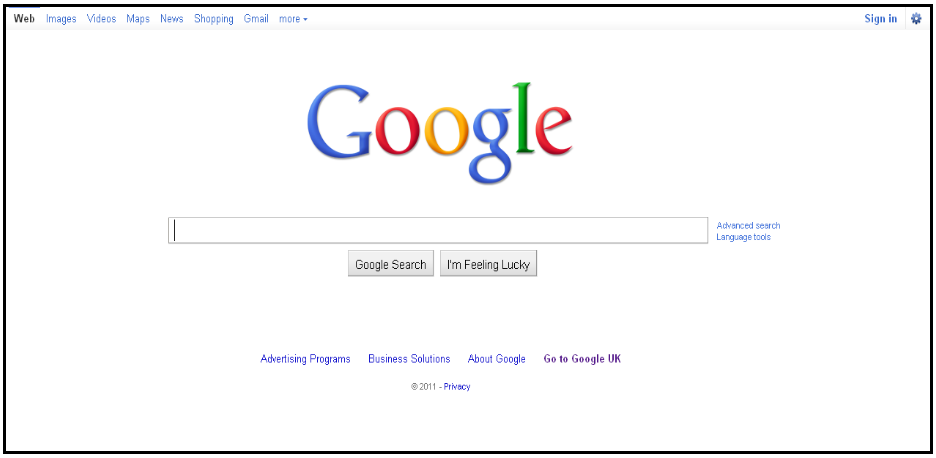

Figure AL-0-2: *Google Search Engine Main Page*

4. With the targeted subject matters as:
   - Photosynthesis definition
   - Photosynthesis equation
   - Photosynthesis rate
   - Photosynthesis procedure
   - Chlorophyll

You are suggested to learn these subjects. In the freely-browsing learning mode, you can freely search any course materials for learning and give any keywords input to Google search engine.

5. Now you can explore the learning mode by freely-browsing and the study duration will be 30 minutes.
6. When you finish the learning session, please complete a post-test provided by the investigator.
7. Now you have finished the experiment, please hand in the both tests to the investigator. Thank you very much.

Appendix M

Pre-Test and Post-Test – Photosynthesis at Key Stage 4

Targeted Subject matter: Photosynthesis rate, photosynthesis procedure, chlorophyll

1. What are the products of photosynthesis?

(**Related SM:** Photosynthesis procedure)

A. Water and Carbon Dioxide

B. Water and Glucose

C. Oxygen and Water

D. Sugar and Oxygen

2. What chemical traps sunlight energy?

(**Related SM:** Photosynthesis procedure)

A. Chlorophyll

B. Chloroplast

C. Xylem

D. Glucose

3. In what form are the products of photosynthesis stored in a plant?

(**Related SM:** Photosynthesis procedure)

A. Glucose

B. Starch

C. Cellulose

D. Chlorophyll

4. Which cells in a leaf contain chlorophyll?

(**Related SM:** Chlorophyll)

A. Phloem

B. Mesophyll cell

C. Xylem

D. Lower epidermis

5. Which factor does not affect the rate of photosynthesis?

(**Related SM:** Photosynthesis rate)

A. Level of light

B. Level of carbon dioxide

C. Level of oxygen

D. Temperature Level

6. In the process of photosynthesis,

(**Related SM:** Photosynthesis procedure)

A. Carbon dioxide and water are oxidized

B. Carbon dioxide is reduced and water is oxidized

C. Carbon dioxide and water are reduced

D. Carbon dioxide is oxidized and water is reduced.

7. Which chemical formulas represent carbon dioxide, oxygen, water and glucose respectively?

(**Related SM:** Carbon dioxide, Oxygen, Water, Glucose)

A. CO_2, O_2, H_2O, $C_6H_{12}O_6$

B. CO_2, O_2, H_3O, $C_6H_{14}O_7$

C. CO_3, O_2, H_2O, $C_6H_{14}O_7$

D. CO_2, O_2, H_2O, $C_6H_{14}O_7$

8. The light reactions of photosynthesis cannot occur in the absence of

(**Related SM:** Photosynthesis rate)

A. Carbon dioxide and water

B. Light energy and water

C. ATP, NADPH, and oxygen

D. Carbohydrates and oxygen

9. Which plant structures contain chlorophyll?

(**Related SM:** Chloroplasts, Chlorophyll)

A. Chloroplast

B. Cell membrane

C. Mitochondria

D. Ribosome

10. A key molecule NOT found in a chloroplast is …

(**Related SM:** Chloroplast)

A. Chlorophyll

B. Carbon dioxide

C. Water

D. Steroids

Appendix N

This is a scenario and instruction for experiment IV, V, and VI.

Before you give the rating to the Web links and fill in the questionnaire, please read all the information below carefully.

1. Scenario

Overview

You are asked to access the links and give a rating to them. This rating shows the levels of relevancy for each page in order that a learner can get information from it and will be able to achieve the competence. For our study, a competence indicates the ability to perform a particular activity to a prescribed standard.

You will be given a list of links. Next you can use the web browser to open the links from their URL. After you finish accessing each links, you then will need to rate them by filling the provided questionnaire.

Targeted Competence

- Recall a photosynthesis equation
- Recall a photosynthesis definition
- Demonstrate a day time photosynthesis procedure
- Predict a photosynthesis rate
- Define chlorophyll

2. Instruction

1. Open your familiar web browser for example, IE – internet explorer, Firefox, Google Chrome and so on.
2. You will see the web browser as in a Figure AN-0-1 (in case if you choose Firefox as your familiar web browser).

Figure AN-0-1: *Firefox Web Browser*

3. By using the web browser, please access each link and give the rating on it based on the criteria provided. The list of all links is:

Competence	Links	URL
Recall a photosynthesis equation	1	http://www.hobart.k12.in.us/jkousen/Biology/photosynthesis.html
	2	http://www.onlinemathlearning.com/photosynthesis-biology.html
	3	http://www.google.com/url?sa=t&source=web&cd=4&ved=0CCwQFjAD&url=http%3A%2F%2Fwww.collinseducation.com%2Fresources%2FAddUnitB2aLesson07.doc&rct=j&q=recall%20photosynthesis%20equation&ei=ffHLTfPaM8WyhAe2-eCoAg&usg=AFQjCNGog-3suIaG8dpewSeGku6RaFAUwA&cad=rja
	4	http://mansfield.osu.edu/~sabedon/campbl10.htm
	5	http://employees.csbsju.edu/ssaupe/biol327/lecture/transpiration.htm
Recall a photosynthesis definition	6	http://www.wordiq.com/definition/Photosynthesis
	7	http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/energyflow/energyflow.html
	8	http://www.answers.com/topic/photosynthesis
	9	http://employees.csbsju.edu/ssaupe/biol327/lecture/transpiration.htm
	10	http://www.splammo.net/bact102/102enrisol.html
Demonstrate a day time photosynthesis procedure	11	http://wiki.answers.com/Q/What_time_of_day_does_photosynthesis_happen
	12	http://wiki.answers.com/Q/When_does_photosynthesis_happen_night_time_or_day_time
	13	http://www.ftexploring.com/photosyn/chloroplast.html
	14	http://www.blurtit.com/q108058.html
	15	http://www.caryinstitute.com/education/curriculum/dissolved-oxygen-and-respiration
Predict a photosynthesis rate	16	http://www.neiljohan.com/projects/biology/rate-of-photosynthesis.htm
	17	http://answers.yahoo.com/question/index?qid=20101129213430AA9pKDb
	18	http://www.marietta.edu/~spilatrs/biol103/photolab/physfacs.html
Define chlorophyll	19	http://dictionary.reference.com/browse/chlorophyll
	20	http://www.biology-online.org/dictionary/Chlorophyll
	21	http://www.thefreedictionary.com/chlorophyll

4. After you access each link, please give a rating to the links by filling the questionnaire.
5. Now you have finished the experiment, please hand in the questionnaire to the investigator. Thank you very much.

Appendix O

This is a questionnaire to be filled for experiment IV, V, and VI.

The purpose of this questionnaire is to allow you to give a rating upon each link against six scales. The scales are:

1 – This website is not related with any materials in order to learn how to achieve a competence

2 – This website gives little information in order to learn how to achieve a competence

3 – This website gives some information in order to learn how to achieve a competence

4 – This website gives useful information in order to learn how to achieve a competence

5 – This website gives very useful information in order to learn how to achieve a competence

6 – This website gives not only the very useful information but also with systematic feedback in order to learn how to achieve a competence

For each link, please indicate the extent of your agreement or disagreement by ticking √ in the appropriate box in each section using a provided pen.

Links	Scale					
	1	**2**	**3**	**4**	**5**	**6**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

Links	Scale					
	1	2	3	4	5	6
16						
17						
18						
19						
20						
21						

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