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Constructing a Competence Structure in Recommending Study Materials Links

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***Abstract*—Existing structures of knowledge and competencies within eLearning systems may involve the risk of misunderstanding and do not consider a proficiency level. We describe the method of constructing a competence structure from learning outcomes. This method involves the task analysis of subject matters and the parent-child relationship assigning. In addition to this, a competence-based system for recommending study materials is proposed. The competence structure is considered within the process of dealing with learner competences and how the system generates the choices of learning paths in suggesting study materials links. Experiments were conducted to compare the generated learning paths. The results show that learners may have felt more satisfied in achieving their desired learning outcomes when more competence nodes are considered within a learning path. However, an appropriate learning path may vary according to the size of the competence structure and the chosen competences.**

Keywords*— component; competence structure; knowledge representation; pedagogy; learning path*)

I. Introduction

Knowledge representation techniques are adopted within eLearning systems to represent a content structure of learning materials [1, 2], structure of learner [3], and structure of learner knowledge [4]. However, the designed structures could involve the risk of misunderstanding and the authoring process is difficult since this is a complex task, and good models of users are deficient. We propose the method of designing a competence structure from existing course learning outcomes. This method involves a task analysis process which is used to consider the structure of the subject matter content and assign the decomposition levels including the parent-child relationships. With the design competence structure, a competence-based system can generate different learning paths by traversing such a structure. Learners can choose the learning path in order to receive the suggested study materials links. There are three types of learning paths on offer. Experiments were conducted to compare the three learning paths, in order to see the appropriate one(s).

This paper is organised as follows: Section 2 introduces the existing model of users and competence in eLearning system, Section 3 describes each knowledge representation language, Section 4 discusses the analysis and design of a competence-based system and the construction of a competence structure from an existing course syllabus, and Section 5 deals with the experimental methodology and presents the results. The last section acknowledges some limitations to this study, and proposes directions for further studies to address the drawbacks.

II. User and Competency Model

eLearning systems have different methods of modeling users and competency. The current methods have shown some limitations – there are difficulties in the authoring process, and the risk of misunderstanding. This section introduces notions of user and competency model, limitations of current design models and the COMBA competency model

A. *Current User and Competency Model*

The user model represents the level of individual users' knowledge and behaviour and this level affects their learning and performance [5]. eLearning systems use the benefits of user models in order to adapt their content and navigational possibilities to the particular user.

The word 'competency' refers to the ability to do a particular activity to a prescribed standard. The concept of competence has been associated with an education system [6] and professional development [7]. In professional development, competences are considered as criteria for selecting the most appropriate available person for a given task [7]. In the education system, competence could be used to describe final attainment levels of educational programmes [6]. There are existing competency standards, for example IMS-RDCEO [8] and HR-XML [9].

B. *Limitation of Current Designed Model*

User modeling has shown some limitations. Kobsa [10] discusses the application of the user model and makes the point that the user model components draw mostly on assumptions about the user, which may not necessarily be correct. The user model 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.

The limitations are also found within some existing competency models. There is the oversimplification of the concept of competency and the lack of provision for an adequate semantic level to support intelligent decisions within IMS RDCEO; it does not take into consideration explicitly important elements such as the knowledge and skills of learners [11]. There is also a discussion of IMS RDCEO and HR-XML given by Sampson and Fytros [12]. 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 [12].

C. *COMBA Model*

The proposed model for this research draws on the multidimensional competency model (called COMBA) proposed by Sitthisak, Gilbert and Davis [13]. This considers the learners' learnt capability instead of their knowledge level [13]. The COMBA model (Figure 1) consists of three major components: subject matter, capability, and context.

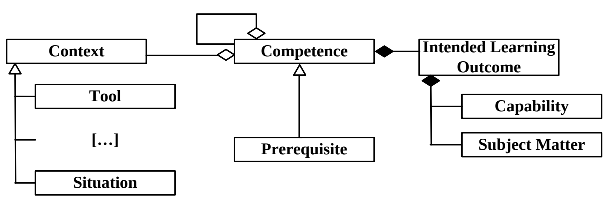

Figure 1. Competency Model Derived From COMBA model Proposed By Sitthisak, Gilbert, and Davis [13]

There are some 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. The third issue is the identified context of a learner's competence. Learners may have differing levels of proficiency in relation to a given intended learning outcome, depending upon the types of context.

III. Knowledge Representation

This section provides a discussion of KR with this study. What follows is a discussion of each language used for representing knowledge on the Web and its approach of representing learner's competences in this research.

A. *Knowledge Representation (KR) with this Study*

In view of the association of knowledge representation within this research, the way to represent the structure of competence requires an understanding of knowledge representation. The idea is to allow the content on the Web (learners' competences in this case) to be both machine processable and humanly understandable.

B. *The Semantic Web*

The Semantic Web is an extended version of the Web as introduced by Tim Berners-Lee [14]. In this research, three representations are considered: XML, RDF, and Web Ontology Language (OWL).

C. *XML, RDF, and OWL*

In this research, XML validation (such as XML-schema) 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 learners' competences, and information such as capability, subject matter, and context of any knowledge domains with the same elements and attributes.

The Resource Description Framework (RDF) is a general-purpose language for representing information on the Web [15]. 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. However, RDF is not yet considered at this stage, since the relations between subject matters are not considered within the system design.

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 [16]. 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 [16]. 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

IV. Analysis and Design of a Competence Structure and Its Application

This section 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.

A. *Process within the System*

The overview of the process within the system design, illustrated in Figure 2, 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.

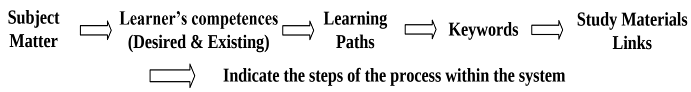

Figure 2. Process within System

First, a sub-process is required to construct a learner's competence structure (section B) 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.

B. *Constructing a Competence Structure*

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 (HCF) and photosynthesis for Key Stage 4 learners. At the first stage, a competence structure of HCF was designed (Figure 3). 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. This competence structure consists of sets of pairs which are combinations of edges (parent-child relationship) and nodes (competence node). The arrow heads to the child node.

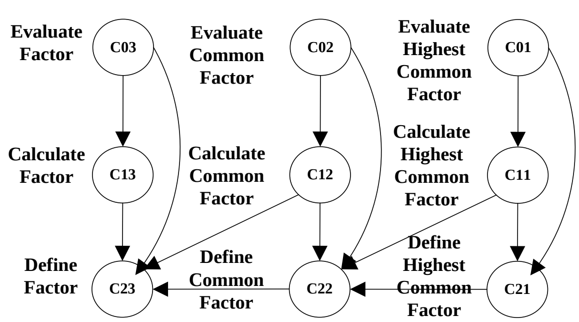

Figure 3. Competence Structure of Mathematical HCF

Later, a more complicated and larger structure was investigated. In order to design such a structure of competence, such as a photosynthesis domain for Key Stage 4 learners, the information on intended learning outcomes is required. Then an analysis of their structure into a categorisation 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.

To construct a competence structure, we need to consider the intended learning outcomes of the knowledge domain. All intended learning outcomes of the photosynthesis domain at a Key Stage 4 (GCSE) from AQA – revised version [17] were chosen for constructing the competence structure. Examples of considered intended learning outcomes are as follows: 'recall photosynthesis equation', 'define chlorophyll' etc.

Next, all intended learning outcomes are summarised into a list of subject matter items. Then, these subject matters are categorised into four fields based on Merrill's analysis CDT [18]. For photosynthesis at Key Stage 4, the list of subject matters and their categorisations is provided in Table I.

TABLE I. CONSIDERED SUBJECT MATTER CONTENTS OF PHOTOSYNTHESIS FOR KEY STAGE 4 LEARNERS

Subject Matter Type	Subject Matter
Fact	Photosynthesis equation, substance, etc
Concept	Chlorophyll, light, carbon dioxide, etc.
Procedure	Photosynthesis procedure
Principle	Photosynthesis rate

All subject matters are then considered as a diagrammatic approach [19]. Each category of subject matter has different notation representing its task analysis. For example, 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 CO2' is represented by a pair of two facts 'chemical formula' and 'CO2' as shown in Figure 4.

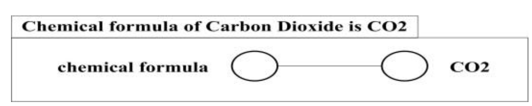

Figure 4. Competence Structure of Mathematical HCF

Task analysis of all subject matters is then levelled and the relationships are assigned. All subject matters are represented as one node, and structured. The relationship between subject matter nodes is parent-child. An arrow points to a child node. 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 5.

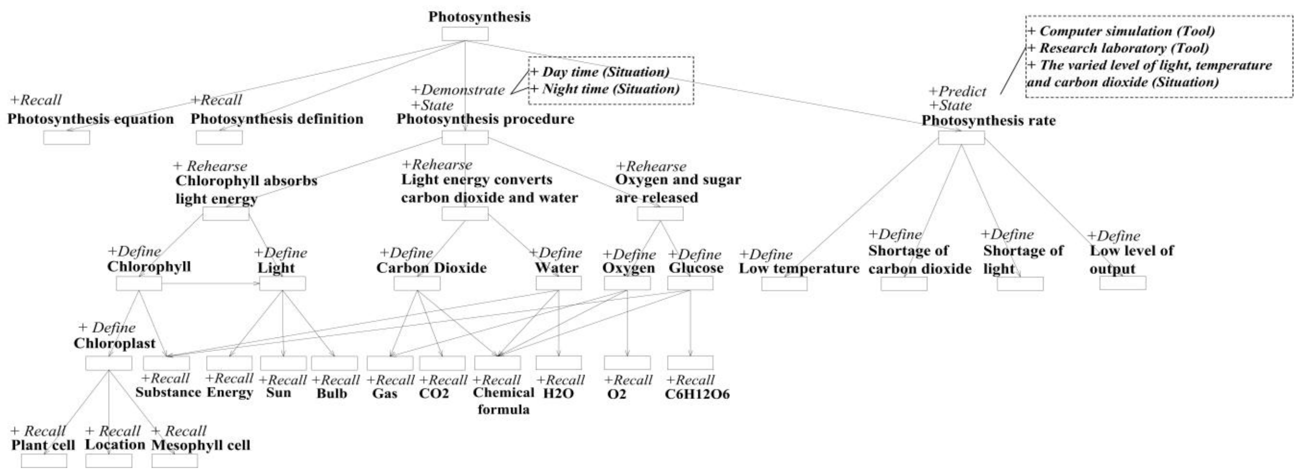

Figure 5. Competence Structure of Photosynthesis for Key Stage 4 Learners Domain

C. *Mapped XML Schema*

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 represents the structure of an XML-schema for a competence structure.

```
<!-- 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. XML-Schema of Competence Structure

D. *Learning Path*

There are three learning paths. The paths are defined as the routes from existing competence to desired competence. Competence gap nodes between desired and existing competences vary, depending on different learning paths.

Learning path 1 (Ignore All Gap Nodes) 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.

Learning path 2 (Consider Some Gap Nodes) 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. These routes in learning path 2 exclude the one route where all gap nodes are considered. Learning path 3 (Consider All Gap Nodes) involves all competence gap nodes. The route of learning path 3 can be seen as the longest route compared to the routes of learning path 2.

V. Experimental Methodology and Results

The experiment is conducted to compare three learning paths in two knowledge domains (mathematical HCF and photosynthesis for Key stage 4 learners). The focused dependent variable is 'learning outcome achievement'. Participants were the experts who had already learnt about these two domains. The expected sample size for each experiment was 9 which are obtained from G*power [20]. Participants reviewed and gave access to the experimental system. Participants were asked to 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 (5-point Likert scale rating).

In repeated measures, ANOVA was used to analyze the data obtained. Table II displays descriptive statistics. Table III shows the repeated measure ANOVA result. Table IV shows the F-test of significant difference for each pair of mean ratings for two of the learning paths.

TABLE II. MEAN AND STANDARD DEVIATION OF RATINGS FOR THREE LEARNING PATHS IN TWO DOMAINS

	Mean	Std.	N		Mean	Std.	N
LP1_HCF	3.4	0.73	9	LP1_Photosynthesis	2.7	1.23	9
LP2_HCF	3.4	0.73	9	LP2_Photosynthesis	3.4	0.88	9
LP3_HCF	4.2	0.67	9	LP3_Photosynthesis	4.0	0.71	9

TABLE III. REPEATED MEASSURES ANOVA –MULTIVARIATE TESTS

		Value	F	Hypothesis df	Error df	Sig.
HCF	Pillai's Trace	0.51	3.60	2	7	0.084
Photosynthesis	Pillai’s Trace	0.49	3.35	2	7	0.095

TABLE IV. TESTS OF WITHIN-SUBJECTS CONTRASTS

Source	Learning Path	Type III Sum of Squares	df	Mean Square	F	Sig.
HCF	LP 1 vs LP 2	0.00	1	0.00	0.00	1.000
	LP 2 vs LP 3	5.44	1	5.44	7.84	0.023
Photosynthesis	LP 1 vs LP 2	16.00	1	16.00	5.82	0.042
	LP 2 vs LP 3	2.78	1	2.78	5.26	0.051

Table II, shows that the mean rating for learning path 3 was higher than for the other two learning paths. Table III, shows the results of multivariate tests of significant difference between the mean ratings. Pillai’s Trace ($0.05 < p = 0.095 < 0.10$) suggests that there was a significant difference in the mean ratings for the three learning paths. Table IV 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 paths 2 and 3, while there was a significant difference between the mean ratings for learning paths 1 and 2 for photosynthesis domain.

Learning path 3 was shown to be the most appropriate for learners to achieve their learning outcomes. This suggests that the competence gap nodes helped learners to achieve competence. Learning paths with more complete gap nodes seemed to achieve higher ratings. However, the obtained results are varied; this could be because of different characteristics as the length of the learning path, the size of the competence structures, and the extent of a competence structure relies on the developers of that structure.

VI. Conclusions and Future Work

A competence-based system for suggesting study material links has been proposed in this research. The aim is to assist learners to achieve their learning outcomes. A competence-based system suggests appropriate links based on learners’ competences which are derived from a competence structure. With the provided instruction for designing a competence structure, it allows developers to construct a competence structure from the intended learning outcomes of an available course. The findings from experiments showed 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. However, appropriate learning path(s) may vary, depending on learners’ competences and the size of the competence structure. A further study on the size of acceptable competence structures and competence gap nodes can be carried out in future work. We will 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.

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