Development of an Adaptive Learning System

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***Abstract* - We investigate the requirements for an adaptive learning system. A conceptual model is explored which links together a student model, a tutor model and a knowledge model. We further consider the use of an adaptive engine which allows the system to respond to the needs of individual students, present learning objects according to the preferences of individual tutor styles, allows automatic self-exploration at the level of student maturity and encodes the curriculum in a form that is accessible to the adaptive engine. Our model accurately represents both the structure and content of learning objects in contrast with less structured data models implicit in ontological hierarchies.**

Keywords–e-learning; adaptive; metadata; semantic; ontology.

I. INTRODUCTION

In previous work [1], we proposed an Adaptive Multimedia Presentation System (AMPS) to provide a semi-automated tool for learning that adapts to students' needs. A prototype was constructed and evaluated in a real class environment in the Cisco Academy at Bournemouth University [2]. This showed that undergraduate students benefited from using the AMPS, but preferred a more 'adaptive' system – one that met their individual needs better with less tutor intervention. These results led the writers to consider how this might be undertaken in a systematic way. The principal aim of this paper is to look further at the conceptual, semantic, and ontological modelling issues involved in making a more rigorous adaptive learning system.

In section II, we set out our overview of the Adaptive Learning System and indicate the relation of its component parts. In section III, we look at the student model and indicate its possible structure. In section IV, we look at the tutor model and the demands placed upon the system by allowing tutors to teach in their own idiosyncratic ways. In section V, we discuss the knowledge model which we use to hold both the knowledge structure in a multi connected ontology as well as the learning objects themselves. In section VI we discuss the adaptive engine which links together all these components, while in section VII we conclude by reflecting on the limitations of the model and the role of adaptation in learning.

II. THE ADAPTIVE LEARNING SYSTEM

As in nature, so in computing adaptation can take many forms. But it is important to realise that adaption is always in response to a particular stimulus. As the external factors change so the system adapts its response. This is no less true in education in the case of a learning environment; a student is presented with a range of stimuli and a range of responses are observed. Table 1. Students may be presented with learning materials which are too hard or too easy, students may learn from the learning object and accommodate the new learning as new knowledge which is incorporated into their own knowledge or they may not. Any learning system needs to adapt to these responses of the student.

TABLE 1 ADAPTION METHODS

Stage	Stimulus/state	Adaption	Method
1	Student learns from new material	Next stage of material presented	Automatically determined from subject ontology
2	Student fails to learn from new material	Reinforcement material presented	Automatically determined from subject ontology
3	Student ability tested with new material	General IQ test	Real-time response
4	Student pre-knowledge	Subject knowledge test	pre-lesson test
5	Student learning styles	selection of appropriate formats	Learning style analysis

In normal education systems the adaption is performed with varying degrees of success by the tutor. Possible contributions to the student state will include student prior knowledge, student ability and student learning styles, which we call the basic "student signature".

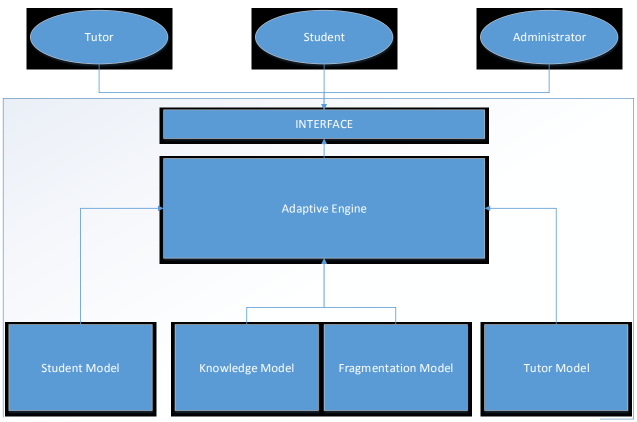

Figure 1 Adaptive Learning System

The system needs to be able to mimic the adaption of the tutor and response of the student as well as contain all the structure of the knowledge system in the form of an

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ontology together with all the teaching material in different forms to match appropriate learning styles. The structure of the adaptive system with these features is shown in Figure 1.

III. The Student Model

The student is the course subscriber, or person learning the course content and committed to completing a course. Once all courses to which the student has subscribed are complete the student ceases to be a student. The level of knowledge attainment that the student has reached during any point in the course has to be recorded and tracked. This means linking the attainment level to the subject ontology. The determination of whether a particular subject node has been assimilated is through the answering of test questions. The successful answering of these will update the student signature to record which subject nodes have been accessed and mastered. The component of the student model are shown in Figure 2 and will be elaborated below.

Part of the initial processing of the student will require an assessment of the pre-knowledge that the student comes to the course with and this will involve initial testing. The results of this will indicate the present level of knowledge of the student and this will be entered into the student profile or “student signature” as we call it here.

Other factors which determine the way learning is adapted to individual student needs will be include the motivation level of the student which will affect the degree of independence the student is given and the amount of reinforcement and checking on the student activity. Student ability will also be assessed to measure the speed and intelligence level at which a student is able to work.

These and other factors will be incorporated into the student signature which will be assigned to each student and which forms a central part of the Student model. The student signature proposed here is summarised in Table 2 which lists the parameters of the signature in the form of a data model structure.

TABLE 2 STUDENT DATA MODEL

Data Element	Data Type
Present Knowledge Status	Number
Ability Level	Number
Independence Level	Text
Student Signature Level	Text
Motivation Level	Free
Pre-knowledge Level	Number
Test Results	Text
Subject nodes accessed	Number
Subject nodes mastered	Number
Preferred Learning styles	Text
Student number ID	Text

IV. The Tutor Model

The tutor determines the intended delivery, format and content of courses, lessons and learning objects. As such the tutor is responsible for mapping out the ontology structure and knowledge learning map that shows what is to be learned and the relationship of the items being learned.

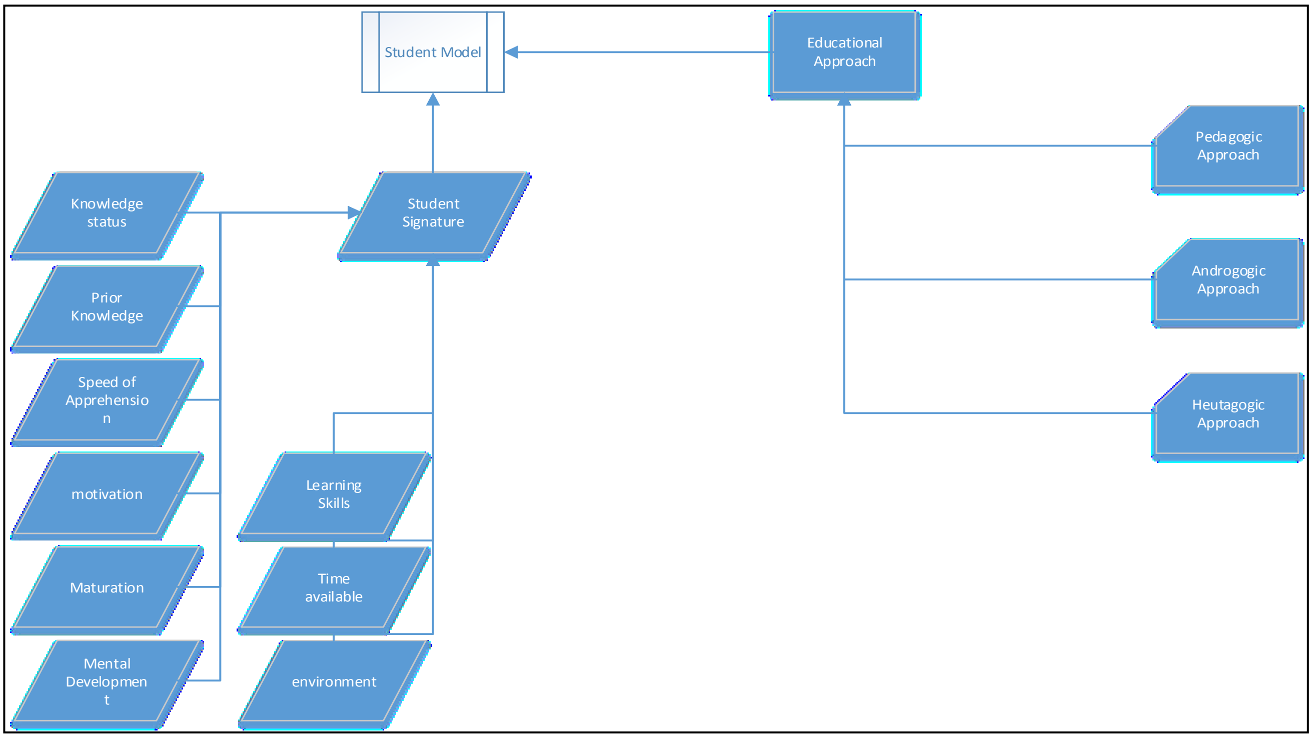

Figure 2 Student Model

The tutor is also largely responsible for determining the direction that learning should take through the knowledge field. The general educational approach that is taken with any student also depends on more general educational factors. Our tutor model is shown in Figure 3 and is designed to encompass the three educational approaches known as pedagogy, andragogy and heutagogy.

A. *Pedagogy*

Pedagogy is the usual approach adopted in learning institutions in which adults teach children. In this environment, it is recognized that the student has limited critical skills and even less experience. In this circumstance, the flow of knowledge is almost exclusively one way, from the teacher to the student.

B. *Andragogy*

As the student starts to take more responsibility for their learning [2] the teacher moves to a supportive role in assisting the student with their own learning. In the andragogical approach, learners are actively involved in identifying their needs and planning how they will be met [3].

C. *Heutagogy*

Heutagogy (from the Greek for “self”) was defined by Hase and Kenyon in 2000, as the study of self-determined learning [5]. Heutagogy extends learning to allow the student to dictate where and when the learning takes place and to choose the path to the learning objectives within the learning environment.

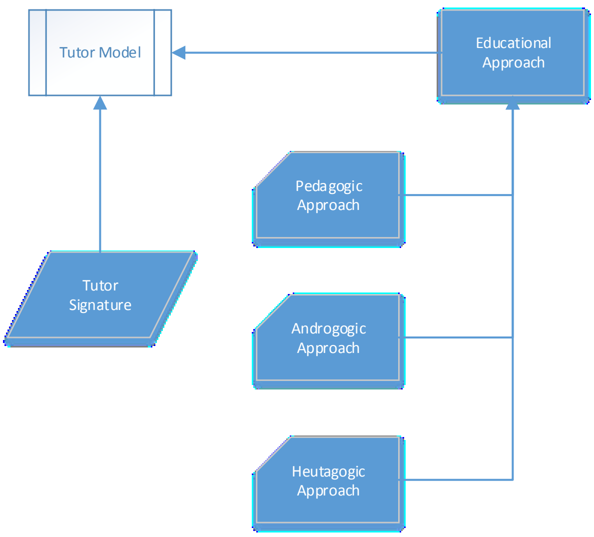

Figure 3 The Tutor Model

The student has the autonomy to choose not only content of the learning but also the order and format of the learning too. the way these ideas are incorporated into the adaptive model is to give the student a high degree of autonomy. This is at the discretion of the tutor who determines the amount of self-learning that would benefit a particular student. At the lowest level (pedagogical), the student has no say in what is learned. In the next level (andragogical), the student has the autonomy to choose which area to study next. In the final level (heutagogical) not only content is chosen but the form of learning object is chosen too.

The tutor model must contain mechanism then to 1. Determine the order in which the content is delivered to the student and it what format and 2. The degree of autonomy allowed to the student in choosing the learning direction. Different tutors may arrive at different assessments of students’ needs and different directions through the knowledge map.

The tutor signature is summarised in in the tutor data model Table 3 which indicates the basic parameters which define each individual tutor and their style of teaching.

TABLE 3 TUTOR DATA MODEL

Date element	**Data Type**
Present Knowledge Status	Type
Pedagogy	Number
Androgogy	Text
Heutagogy	Text
Knowledge presentation order	Free
Tutor Number ID	Text

V. The Knowledge Model

The curriculum to be delivered is to be stored in the adaptive system. The curriculum comprises three parts. First the structure of the knowledge shown in Figure 4 and its related parts which is contained in an ontology. Second the content of the learning which is the knowledge to be learned. Third, the different containers which hold the content. This is the form in which the knowledge is supplied and may be in text form, audio, video, PowerPoint, etc. The same knowledge may be presented in different formats to suit the student. In addition there is a requirement for test questions related to the curriculum.

It is necessary to define ontology metrics to provide measures of attributes such as complexity, level of detail or closeness of subject areas. The first step to defining these metrics is to provide each node with a unique address which defines its location on the ordered tree. Thus a body of knowledge is divided into section, sub-section, sub-sub-section etc. and so we adopt an addressing system which corresponds to this knowledge hierarchy where each address is correspondingly specified by sections, sub-sections, sub-sub-sections etc.

We use an ordered tree for this description where the branches from each node are ordered so that the sub-nodes have an order of preference. [8] This structure is then used to label an ontology where fragments of knowledge have an order determined by their pre-requisites. This model distinguishes between a taxonomy, ontology and what we call an anthology.

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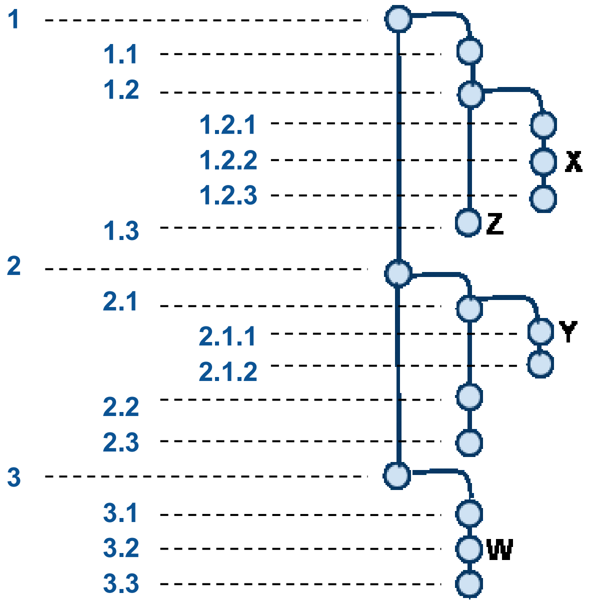

Figure 4: Knowledge hierarchy corresponding to an ordered tree

A. *Taxonomy, Ontology and Anthology*

Taxonomies specify the hierarchical relationships between concepts. Ontologies add to this attributes, properties and methods of the concepts. Anthologies take this and add to it the content of the information that the concepts specify. Ontologies are a way of sharing a common understanding of the structure of information. What Anthologies add to this is the content of the information itself.

B. *Anthology Formats*

We define Anthologies to be collections of information arranged in a hierarchical order. Where the taxonomy may be likened to the contents page of a book, the ontology is a detailed breakdown of the contents and the anthology would be likened to the whole book itself. The anthology should be understood as also containing the information for each section along with the headings. The data in each section can take the form of text, as may be found in a textbook, or a media file, video presentation etc. where the content that is stored is useful for teaching purposes. Thus we see taxonomies as a subset of ontologies and ontologies a subset of anthologies.

C. *Test Questions*

Test questions are used to test the students' knowledge of the content of a section of the curriculum. That section may be based on the course or lesson level. There may be many questions and many answers for each subject area using a Multiple Choice Question format. A dynamic set of questions is formed to become a student specific test for progress in a lesson or course. Questions and answers are determined and designed by the tutor.

TABLE 4 DATA MODEL FOR THE KNOWLEDGE SYSTEM

Data Element	Data Type
Node address	Number
Title	Text
Subtitle	Text
Content/Link	Free
Format	Video/audio/text/PP/other
Questions	Text
Tutor ID	Text

However it should be noted that this data model requires that the knowledge tree (or subject ontology) is contained within a relational database structure along the content-backbone where a unit is part of a course, and a lecture part of a unit and a segment part of a lecture. Segments can include learning objects.

COURSE-UNIT-LECTURE-SEGMENT

D. *Linking of Learning Objects*

Breaking up knowledge into learning objects based on the content structure highlights the importance of two aspects of the presentation of materials. Boyle [4], describes the learning object as a wrapper around content. The wrapper describes the structure of the object and includes the metadata about the object. The learning object is packaged in a standard container format which can be stored in a database. The included metadata permits fast effective searches to retrieve learning objects suitable for a particular purpose. Other data elements associated with the knowledge system are as follows.

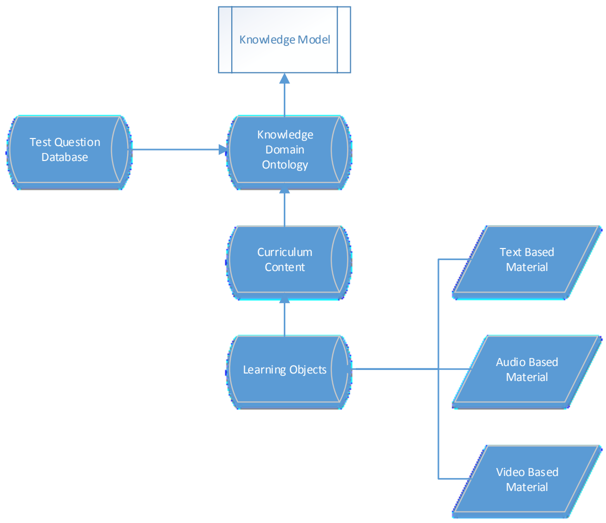

Figure 5. The Knowledge Model

E. *Segment*

A segment is defined as a learning node together with all its sub-nodes. The total number of nodes in a segment is a measure of the amount of detail contained within a segment of knowledge and can be associated with a node in the subject ontology.

F. Complexity

We define complexity of a knowledge node to be equal to the degree centrality minus 1which is the measure of the number of sub-nodes that are connected to a given node. Thus a knowledge node composed of many sub-nodes or subdivisions is deemed to be more complex than one with fewer subdivisions and is defined as a measure of **difficulty** of the knowledge node.

G. Level

We designate the term level applied to each node by the position it occupies in the representation. We say that the **level** of a knowledge node is equal to its **importance** and represents the level of detail that a knowledge node contains.

H. Distance

The distance or separation of one node from another is a measure of how close two knowledge segments are related to the subject ontology. For a tree network this is a unique value determined by the number of steps between the nodes. Distance is a measure of the **strength of connection** between two nodes. The knowledge model structure is seen in Figure 5.

VI. THE ADAPTIVE ENGINE

The purpose of the adaptive engine is to choose the next node of learning for the student and the way it is presented. The way the adaptive engine works is by using the student signature and the tutor model to determine the next learning object, present it to the student in the appropriate form and to test its effectiveness. This is performed by reference to metrics attributed to the student signature with direction indicated by the tutor model. The student is guided to the next knowledge node on the subject ontology and is provide with subject content in a form which is most suitable to the individual student. The student signature will contain a measure of the prior knowledge of the student to enable adaption of content, form, independence of choice, test questions etc.

If pre-assessment shows that a degree of independent learning is appropriate for the student then a range of choices will be available to the student for them to make a choice themselves as the direction they can go in their learning within bounds set by the tutor. The adaptive engine is shown in Figure 6.

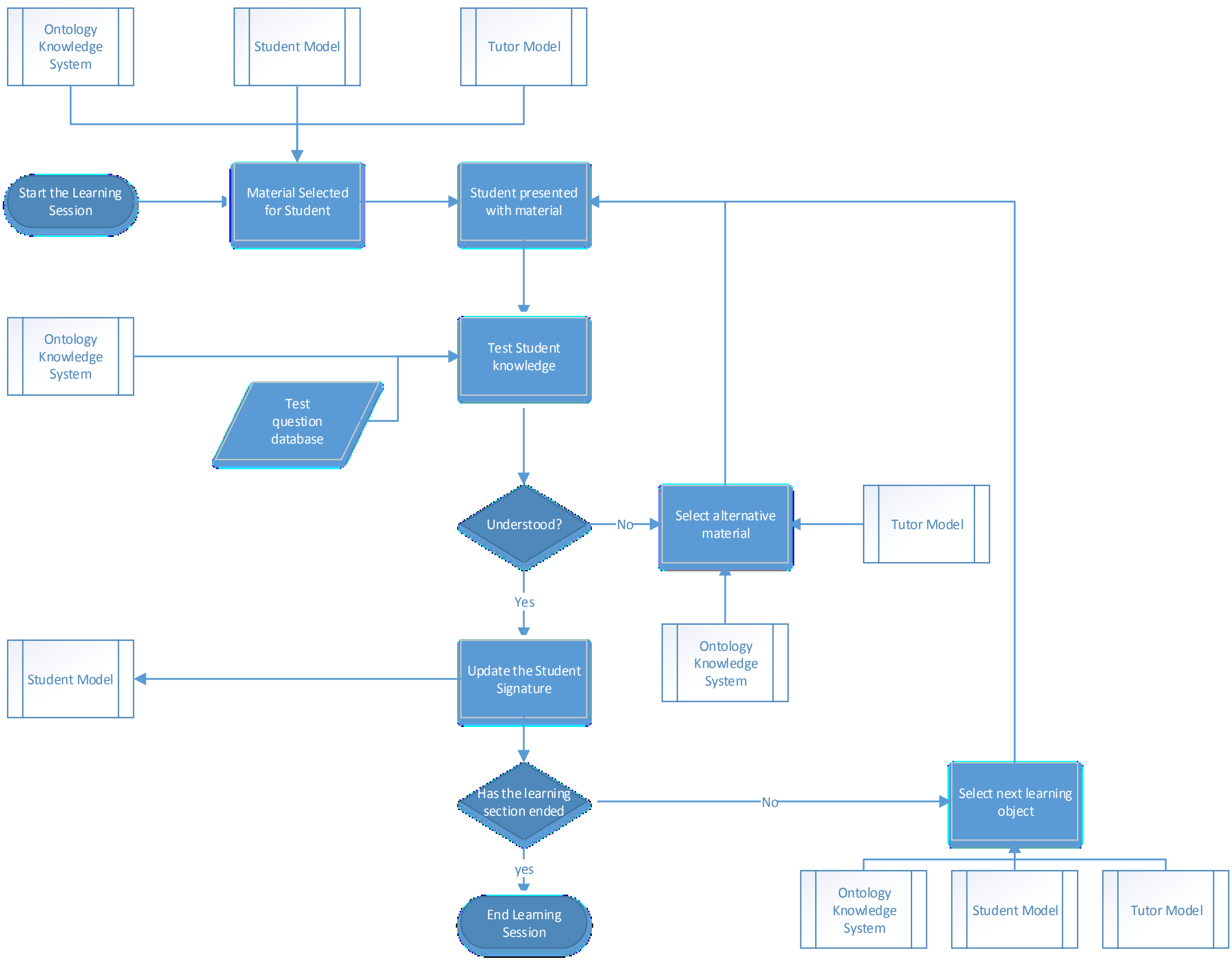

Figure 6 The Adaptive Engine

The adaptive engine will use the student signature to determine what has already been learned and what is still left to learn, It will use the tutor model to determine which elements need to be presented to the student to study next. We expect the segment entity to hold such attributes as **Level** (a measure of the importance of the segment) and **Complexity** (a measure of the difficulty of a knowledge node) as well as **Strength** of nodal links (a measure of the ontological proximity of the knowledge areas). Figure 1 depicts the rudimentary model of the Adaptive Learning System. Each of these three metrics are determined through an ontology calculus discussed in a previous paper. [2]

VII. Conclusion And Future Work

Investigations into semantic models and semantic modelling should be strictly logical explorations into how data models and integrity constraints can be modified without rendering the database contents (facts, meanings, and intelligent interpretations) uncertain or meaningless.

Meta-learning by the Adaptive Learning System requires awareness that it is participating in a learning process and therefore needs an explicit, built in 'tutor model'. The Adaptive Learning System presented here implicitly assumes there is a real-life tutor who will perform the role of the tutor model, which involves intelligent and experienced selection of learning objects appropriate to the student.

In future, we need to construct a full, robust tutor model to automate the segmentation process, which needs detailed investigation of the nature of meta-learning [14] [15]. Our vision is to build this into a novel abstract conceptual data model encompassing all the properties that are needed to make explicit the qualities of an effective 'tutor model'.

Finally, although work discussed in this paper answered research questions posed in previous papers, it has indicated further questions. In particular we would ask what further adaptation features are required and how are they to be evaluated? Also we need to further consider how should the adaptive engine structure be modelled and evaluated? Can fuzzy logic or data mining techniques be candidates for a useful algorithm? And finally we continue to explore how we determine the appropriate definition of an API, possibly by means of an IDL, between the ontology, the adaptation engine and the system's user interface? We leave these questions to further papers.

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