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An Adaptive Recommender-System Based Framework for Personalised Teaching and Learning on E-Learning Platforms

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Abstract: Current learning management systems such as Moodle and WebCT are considered as linear systems that provide e-learning material in a fixed-sequence, delivering the same content to learners regardless of their differences in background knowledge. For learners engaged in self-study online distance learning, this may result in material being presented at either too high or too low cognitive levels. According to the Zone of Proximal Development (ZPD) theory, this may result in either frustration or boredom among learners. This paper proposes a recommender-system-based adaptive e-learning framework for personalised teaching on e-learning platforms. The framework would assist designers, teachers and learners to identify issues they need to consider in order to address challenges of poor engagement in online distance settings, arising from a "one-size-fits-all" approach that does not recognise the role of individual differences in teaching and learning. Secondly, the framework may enable the identification of problems or obstacles that may be encountered when supporting learners in their quest to reduce frustration and boredom when using a Recommender-Based Pedagogical System (RBPS). A literature review was conducted on adaptive e-learning systems based on the ZPD theory, learner modelling, the Generic Adaptive Framework and a recommendation system model. 70 articles were selected from a database of 720 articles published between 2010 and 2017 to come up with the dimensions needed to develop such a model for the framework through deductive analysis. The research found out that the majority of the studies only consider three dimensions to an adaptive framework, that is, the learner model, the content model and the adaptation engine while the Generic Adaptation Framework proposes seven dimensions. In addition, the majority of the studies are based on the principles of macro-adaptation which provide a "static" snapshot of a learner's profile instead of dynamically adjusting the adaptation as learner variables. In the proposed adaptive framework, we identified five dimensions, including real-time dynamic adaptation and context modelling in addition to the learner model, the domain model and the pedagogical strategy.

Keywords: Adaptive framework, educational recommender system, zone of proximal development, generic adaptation framework

1. Introduction

Current learning management systems such as Moodle and WebCT are considered as linear systems that provide e-learning material in a fixed-sequence, delivering the same content to learners regardless of their differences in background knowledge. For learners engaged in self-study online distance learning, this may result in material being presented at either too high or too low cognitive levels. According to the Zone of Proximal Development (ZPD) theory, this may result in either frustration or boredom among learners. This paper proposes a recommender-system-based adaptive e-learning framework for personalised teaching on e-learning platforms. The framework would assist designers, teachers and

learners to identify issues they need to consider in order to address challenges of poor engagement in online distance settings, arising from a "one-size-fits-all" approach that does not recognise the role of individual differences in teaching and learning. Secondly, the framework may enable the identification of problems or obstacles that may be encountered when supporting learners in their quest to reduce frustration and boredom when using a Recommender-Based Pedagogical System (RBPS).

This paper focuses on the dimensions needed in developing an adaptive system which is based on educational recommendation techniques. According to [13], an adaptive learning system monitors the learning needs of each learner and provides them with a personalised teaching and learning environment. An adaptive learning system thus frees a learner from time and space constraints while affording them an online learning environment that allows them to work as if they have a personal tutor instead of "sitting through a mass lecture [1].

Over the last decade, the development of adaptive educational systems has attracted considerable research interest from the educational technology and informatics fields [2], [3], [10], [11]. The research outputs have included techniques for learner profiling, intelligent tutoring systems (ITS) and adaptive hypermedia educational systems (AHES). Despite various frameworks being proffered, high levels of frustration and de-motivation continue to be challenges experienced by online distance learners engaged in self-study (with minimal or no support from lecturers) when compared with their counterparts studying in a face-to-face environment [4]. This may be attributed to the lower peer-to-peer as well as learner-to-tutor engagement in self-study distance settings. On the other hand, according to the "Community of Inquiry Framework", it is generally accepted that the experience of learners in a teaching and learning environment depends on three types of engagement, that is, students' engagement with the teaching and learning material, peer-to-peer engagement, as well as engagement with teachers and instructors [6]. As such, researchers have continued to be seized by finding better ways to increase student engagement and thus minimise the high levels of cognitive disorientation associated with self-study distance setups.

Vygotsky's work on the Zone of Proximal Development [5], [7] is instrumental in understanding "cognitive disorientation", which in the context of this work is characterized by a learner experiencing anxiety if the material presented is too complex, or boredom if the material is too easy. A recommender system in an e-learning environment has the potential to assist the learners to discover relevant learning actions that matches an individual learner's profile and thus provide learners with personalised content "at the right time, in the right context and in the right way". The content recommended may be in the form of research papers, web pages, courses, lessons and other learning resources that meet pedagogical characteristics. The learning resources are typically based on learner models, thus enabling personalization.

Although many frameworks have been proposed, the Generic Adaptive Framework (GAF), is utilized in the research to inform the research on the adequacy of prevailing models and frameworks in addressing the issues raised in the research because it is the most comprehensive. The GAF will be a key source of possible dimensions that may be considered for the proposed framework, as well as an evaluation mechanism for current state-of-the art in adaptive, recommender-based systems and thus expose the research gaps.

The adaptive, recommender-system-based framework finds inspiration in face-to-face teaching, where a good teacher is considered to be one who dynamically adjusts their teaching strategies and teaching material depending on the feedback they get from constantly monitoring the learners [14]. Face-to-face teaching can thus be categorised as adaptive. In contrast, online distance learning has been noted as suffering from the constraints usually associated with minimal human actor mediation, such as dynamic real-time support [15]. Adaptive, recommender-system-based are therefore expected to have an

impact on how learners in distance environments are able to cope with challenges of engagement.

2. Objectives

The aim of this research was to develop an improved framework for adaptive teaching and learning on learning management systems.

The research has the following objectives that may be realized from developing the proposed framework:

1. Elaborate on the dimensions of a learner model that would enable the development of an adaptive system based on Vygotsky's Zone of Proximal Development theory, Generic Adaptive Framework and recommender systems.
2. Design a framework/model that denotes the important features of a recommender-system-based adaptive system.

3. Methodology

The design for this framework/model is a hybrid approach based on several dimensions. Based on literature review, we came up with components that are needed to develop an adaptive system. The literature was collected through searching Proquest, JSTOR, Emerald, the Educational Resource Information Center (ERIC), Google Scholar, IEEE Xplore, ACM Digital Library and EBSCO using a predefined set of search terms and restricting the dates of studies to between 2010 and 2017. A total of 720 articles was identified for possible consideration. Of the articles returned, only those deemed as relevant to the research criteria were be retained. The major research criteria was on the dimensions of adaptive e-learning and types of recommendation. After applying this exclusion criteria, 70 articles were eventually selected for detailed study. The state-of-the-art work in the field was compared against the Generic Adaptive Framework in order to derive the dimensions for inclusion in our framework. Based on these dimensions, we designed the proposed adaptive framework.

This framework will be implemented in Phase 2 of the research which is not reported in this paper. Phase 2 will consist of creating a context-aware, recommender system-based prototype web application. This prototype will be used to evaluate the framework proposed in this paper using real time data. The results, findings and comparative study on various other adaptive learning systems will be carried out after the completion of the main project.

4. Related Literature

3.1 The Generic Adaptive Framework

The Generic Adaptation Framework (GAF) is one of the most comprehensive frameworks on adaptive e-learning. The GAF proposes seven models that can be used to develop an adaptive system. According to [2] these building blocks are goal, domain, user, context, application, adaptation and presentation models. These dimensions are usually adequate for most adaptive hypermedia systems. However, education is unique in that it should also consider pedagogy and andragogy in its design. As such, any framework on e-learning must also include instructional strategies, and pedagogical models or constructs. An adaptive e-learning system must therefore be multi-dimensional. Although there are pedagogical models, our main objective in this study is to review the literature on adaptive e-learning systems. Those concepts are classified according to two ways of e-learning definitional dimensions. First, the concepts are classified according to the GAF. Second, we also identify the nature of adaptation from the state-of-the-art implementations of educational recommender systems (either macro or micro adaptation) in order to identify our research gap.

3.2 Adaptive Learning Systems

According to literature [12] the majority of adaptive learning systems consist of a content/domain model, a learner model and a pedagogical model/strategy upon which an adaptation engine is based for the adaption process. The content model is responsible for the structuring and sequencing of learning material that is needed for the teaching/learning system to achieve the learning goal. The learner model is usually based on dimensions such as a learner's prior knowledge and learning preferences. The learning preferences are based on learning styles, and other sources of individual difference. According to the Generic Adaptive Framework, another important dimension that needs to be considered is the context, which is mostly considered as a peripheral one [2]. In coming up with the proposed framework, the dimension of context has been given a prominent role.

According to [1]'s work on the classification of the different types of adaptive learning, dimension is also a very useful lens that informs this work on the nature and focus of research that has been carried out so far. Learning management systems may be distinguished between linear and adaptive systems [1]. Linear systems are the traditional learning management systems that "present the same material in the same fixed sequence to all learners." He further classifies adaptive learning systems into two categories. He calls the first type "Macro-adaptive systems", which are based on adaptation based on pre-determined criteria such as a learner's profile. Once a determination has been made about the adaptation needed, this is maintained throughout the learning process. A major criticism for macro-adaptation is that "snapshots" of a learner's profile at a particular "point-in-time" quickly become outdated, thereby adaptation may end up losing some of its accuracy. In response to such criticism, [1] proposed "micro-adaptation" which are capable of "dynamically adjusting to the student, based on their most recent actions." It was evident that macro-adaptation has received the most attention from the research community.

Adaptivity within the framework maybe achieved through one of several ways. First of all, adaptation may be achieved by tailoring a student's starting position in an e-learning course depending on their latent knowledge. In addition, depending on various factors surrounding a particular learner, their learning pathway may be altered in real-time. The recommender system is a key component and would be responsible for the selection of the most suitable content for an individual learner as well as the most suitable pedagogical elements and to adapt them accordingly in real-time [23], [25].

3.3 Problems in Self-Study Environments (including ZPD)

According to [9], cognitive learner data is unique since it is generated from learner activities around web pages, social profiles, and other online habits which raises potential to optimize user experiences over time and provide tangible value for students through the use of big data. Studying is not a once-off activity but requires a long period of engagement with teaching and learning material, which means that students have to remain on the platform for an extended length of time [14]. In addition, students must be intently focused on the activities they are engaging in, in order to try to improve their range of skills. This requires data to be generated continuously in order to personalize learning for each individual in real-time.

The loss of focus by students may be avoided through feedback that is immediate so as to allow students to self-correct [17]. This is usually missing in self-study online distance learning setups. Consequently, the Zone of Proximal Development theory suggests that learners may end up finding the presented material too complex, thereby causing frustration. On the other extreme, learners who may have the requisite background knowledge may find the content too simplified, and thus boring. Students in self-study e-learning environments can suffer from isolation which can worsen the challenges they

experience [18]. By taking into account social context, it should be possible to develop an adaptive system that enables both teachers and learners to collaborate on challenging work as well as providing peer review opportunities. It is also possible to form online groups or communities based on inferred complementarities among learners.

4. Results

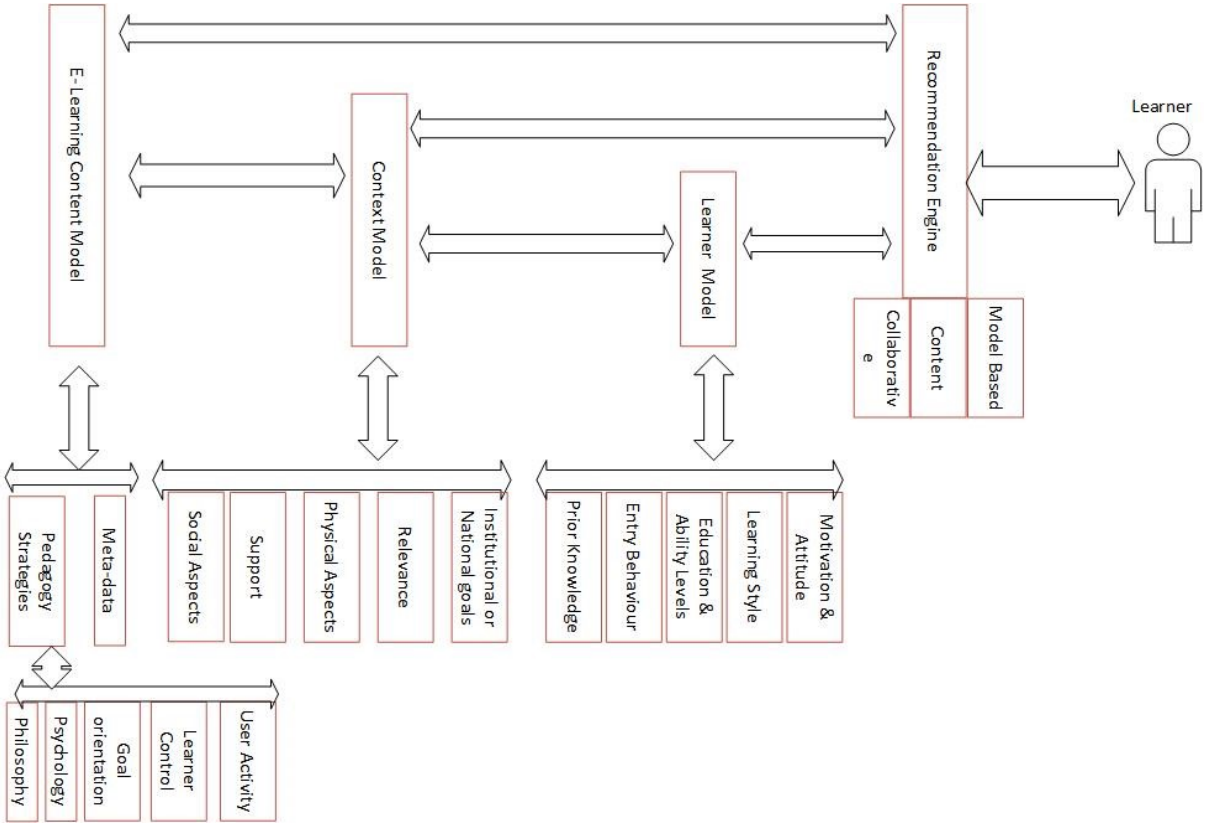
Based on the review of prior work, the following gaps were identified and informed the design of the proposed framework in the form of design criteria:

- Micro-adaptation is considered as more valuable than macro-adaptation
- For practical reasons, learner modelling is currently based on few dimensions such as prior knowledge, preferences and learning styles. There is need to expand this set of dimensions in order to improve the sensitivity of the recommendations being provided to learners
- There is need to determine the optimal number of learner dimensions that must be considered in a model
- Learners' preferences are not static but change over their lifetime. It is therefore vital to consider the dynamism of any proposed framework
- Teaching and learning are context-dependent. There is need for algorithms to consider the learning context in the proposed model
- Development of adaptive learning design must be based on a precautionary principle (ethical code) which means that we do not use stereotypical methods for modelling of the learner.
- The system must include user models which should reflect the learners' needs and preferences and their evolution over time.
- User models should include context-awareness methods to personalise the delivery of services.
- User profiles (including psychological profile).
- Learner preferences: instructional material presentation preferences, device interaction preferences, interaction preferences.

Data should contain: Cognitive style, Motivation and interests, Skills and capabilities, Bugs model, Demographic data about the users.

Figure 1 demonstrates how all these several components may be integrated into a framework for achieving adaptive and differentiated teaching and learning.

Figure 1: Proposed Framework



The key components of this framework are:

4.1 Real-time Recommendation System

The main source of adaptivity comes from the adaptive recommendation engine. The real-time recommendation system is designed to be sensitive to the characteristics of each individual student since students have different intellectual capabilities, attention spans and modes of learning. It is based on three theories, that is, Item Response Theory (IRT), Probabilistic Graphical Model (PGM) and Hierarchical Agglomerative Clustering (HAC) [14]. The Item Response Theory models student ability using question level performance instead of aggregate test performance. It does not assume that all questions contribute equivalently to our understanding of a student's ability but that the probability of a correct response to a test question is a mathematical function of parameters such as latent traits abilities, item characteristics such as difficulty, guess-ability and specificity to topic. The Probabilistic Graphical Model encompasses statistical methods such as Bayesian Networks and Markov Random fields that may be used by basing a student's known proficiencies to determine which other topics a student may be ready to master. The discovery of these relationships enables continuous refinement of recommendations. The Hierarchical Agglomerative Clustering seeks to construct a hierarchy or structure of clusters which allows the system to group students who are working on the same material by level of concept mastery [14].

4.2 Context Model

Various elements that constitute a learner's context were modelled. Some of the contextual variables considered include the social perspective based on learner interactions with the social web, the institutional context, where sustainable development goals (SDGs), national development plans (NDPs) and institutional plans (IPs) form the bulk of the input.

4.3 Learner Model

Prior knowledge ranges from none to a lot, with most learners in the "a little" and some categories [18], [19]. In addition, teaching and learning needs to start with the basics, to prevent gaps in cognitive development, while at the same time ensuring that the more knowledgeable students are not bored. The more knowledgeable learners need to be able to assist their less knowledgeable colleagues. There is also need to design instruction in such a way that learner motivation is kept high through keeping them actively engaged [18].

4.4 Domain/Content Model

The content model is domain and course-specific, encompassing learning concepts and relationships among the concepts [20], [22]. The model is informed by the pedagogical strategy as well as the learning goals that the system seeks to achieve. As a result, sequencing relationships such as which content is pre-requite to which content are considered [24]. The meta-data is also very crucial in building a domain model [27].

4.5 Pedagogical Strategy

Reeves' [19] multi-dimensional model of pedagogical dimensions has been used to inform on what the pedagogical model needs to consider. Some of the aspects include: philosophy, psychology, goal orientation, and learner control and user activity [23]. In addition, pedagogic strategies will be defined at three levels, that is, general instructional designs, designs applied to a teaching/learning unit and pedagogic methods [25], [26].

5. Business Benefits of the Framework

The architecture of the proposed adaptive framework has the potential to assist implementers of adaptive technologies to deliver a powerful learning system. For institutions, the integrated adaptive framework provides guidelines for developing a large-scale adaptive curriculum capable of supporting any topic or subject in a personalised way.

In addition, instructors will be able to get insights from granular data which they may use to support student activities in a flexible manner. Finally, the learners themselves are able to receive real-time personalised support which is based on research-led learning theory. As such, it is anticipated that their engagement will be better, resulting in lower drop-out rates and better pass rates for learners engaged in a self-study e-learning environment.

The framework would assist designers, teachers and learners to identify issues they need to consider in order to address challenges of poor engagement in online distance settings, arising from a "one-size-fits-all" approach that does not recognise the role of individual differences in teaching and learning.

Finally, the framework may enable the identification of problems or obstacles that may be encountered when supporting learners in their quest to reduce frustration and boredom when using a Recommender-Based Pedagogical System (RBPS).

6. Conclusions

This paper focuses on the dimensions needed in developing an adaptive system which is based on educational recommendation techniques. Despite various frameworks being proffered, high levels of frustration and de-motivation continue to be challenges experienced by online distance learners engaged in self-study (with minimal or no support from lecturers) when compared with their counterparts studying in a face-to-face environment

Vygotsky's work on the Zone of Proximal Development is instrumental in understanding "cognitive disorientation", which in the context of this work is characterized by a learner experiencing anxiety if the material presented is too complex, or boredom if the material is too easy. For practical reasons, learner modelling is currently based on few dimensions such as prior knowledge, preferences and learning styles. There is need to expand this set of dimensions in order to improve the sensitivity of the recommendations being provided to learners.

Learners' preferences are not static but change over their lifetime. It is therefore vital to consider the dynamism of any proposed framework. Teaching and learning are context-dependent. There is need for algorithms to consider the learning context in the proposed model. This paper presents the results of Phase 1 one of a three phase project. The research has reviewed the state of the art of user modelling and its application to personalisation processes. The research sought to address one of the main open issues identified in literature, that is, the socio-technical dimensions that are necessary for the development of a dynamic, recommender-system based adaptive system. The preliminary phase was based on review of literature.

Future activities in the research will involve, in addition to being coded according to the dimensions mentioned above, instructional strategies in the retained articles will be rated by an expert panel for usefulness. A proof of concept of the recommender-system based framework will be designed in the form of a prototype that will be experimentally tested with online datasets. This will inform revisions that need to be made to the framework. The envisaged design model is both participative and iterative in nature.

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