Using Psychometric Approaches in the Modeling of Abstract Cognitive Skills for Personalization

Victoria Macarthur[1], Owen Conlan[1],

[1] School of Computer Science and Statistics, Trinity College, Dublin 2, Ireland
{macarthv, owen.conlan}@cs.tcd.ie

Abstract. "Learning to learn" is the informal phrase often used to describe the acquisition of abstract cognitive skills such as metacognition and social cognition. Current personalization approaches within Adaptive Learning Systems typically support cognitive gain without explicitly enhancing such key skills. This paper compares the acquisition of two metacognitive factors, planning and information management strategies, between learners who have eLearning experience and those who have not. Such complimentary skills should be fostered alongside learning activities in order to ground their relevance and applicability in a genuine learning experience. This paper presents an exploration of how psychometric approaches, which are used to study and measure human cognition, may be utilized to better model and facilitate the learner's acquisition of abstract cognitive skills. Specifically, it presents the modeling and organization of mental structures according to schema theory and the development of standardized inventories through factor analysis.

Keywords: Psychometrics, Factor Analysis, Lifelong Learning, Adaptive Services, Personalization

1 Introduction

There is a lot more to learning than curriculum. Abstract cognitive skills, essentially higher-order cognitive skills, have been proven as antecedents to some of the aspects of positive lifelong learning [13]. This includes skills like communication, application of prior knowledge, and metacognition. Currently, Adaptive Learning Systems (ALS) are stimulating a shift towards the needs of the individual [1]. These systems support the acquisition of diverse types of knowledge by mediating the conditions for learning according to individual differences [1][6][10]. However, conventional ALS deal directly with knowledge gain, rather than the acquisition of learning or cognitive skills. We propose that these skills, which stimulate personal development and lifelong learning, need to be emphasized alongside online courses. Although there have been a number of ALS that address cognitive ability [2][5], they either regard it as a by-product, or have attached self-reflection tools. However, these attempts to explicitly incorporate cognitive skills within an online learning environment have been developed as monolithic stand-alone systems [2][5]. In practice, it is very difficult to reuse such systems across domains.

The fundamental nature of learning invovles creating and assimilating new information. This uptake is mediated by the skills and strategies that a learner already has. There are a number of metacognitive skills that support learning. Two of the key components of successful self-directed eLearning are *planning* and *information manegment strategies*. Classroom schedules and the direction of the lecturer often guides the learner's planning. Online however, the learner is often afforded a greater amount of flexability. Students are expected to be aware of their own cognitive strengths and weaknesses. It is hypothesised that learners who engage in eLearning courses must actively adjust their metacognitive skills, and that this results in strengthening of these skills. The following includes a study which adresses whether there is a significant difference between both the *planning* score and *information manegment* score given by participants who have taken part in traditional eLearning and those who have not. The results of this study indicate that there is no real difference between classroom and eLearning students. However, eLearning technologies have given affordances towards the development of methods of modeling and adaptivity within ASL. It is aruged that these methods could be leveraged not only to deliver personalized coursework, but also support on a one-to-one basis, the acquisition of abstract cognitive skills.

We propose that it is necessary to have a discrete and separate service that will work in symbiosis with an ALS. This service will model the user and provide useful higher-order cognitive skills training that is aligned with the knowledge gain goals of the ALS. To date, there are no adequate models of higher-order cognitive skills that may be used for this purpose [5]. This paper presents the ETTHOS (Emulating Traits and Tasks in Higher-Order Schemata) model that has been implemented within the Goby service [7]. Goby, a third-party symbiotic service, aims to support the acquisition of a higher-order cognitive skill repertoire. Work is underway to incorporate the Goby service with APeLS [3], an adaptive eLearning service that uses a metadata driven adaptive engine to personalize courses. This paper presents a study exploring whether traditional eLearning enhances metacognitive awareness, and theoretical background from psychology that underpins the ETTHOS model. It gives an overview of this model, specifically the relationships between traits and tasks to measurable user behavior. The technical implementation of this model and how it is realized in the Goby service is also presented. The paper concludes with the proposed future work in this area.

2 Does traditional eLearning enhance metacognitive awareness?

An online survey, targeting people living in Ireland was distributed over a number of social networking media. A selection of 101 participants (male 67, female 34; ages 18 to 50; each with a level of third level education (from Degree to PhD), particapted in this survey. Schraw & Dennison's Metacognitive Awareness Inventory [11] was used to assess the populations understanding of how they regulate their own cognition on a 5 point Likert scale. The inventory comprises of a two-component model of metacognition that includes knowledge and regulation of cognition. We are interested in regulation of cognition. Regulation refers to the knowledge about five components; planning, information management strategies, debugging, comprehension and evaluation. The survey also asked each participant to indicate whether or not they had taken part in an eLearning experience. 43 of the participants had previous experience with eLearning, whereas 58 indicated that they had little or no experience (n = 101). As such, this was an observational rather than controlled study. In particular, we are interested in two of the factors which will later be modelled in the ETTHOS model: *planning* and *information management strategies*. For each of these factors, a t-test for independent samples compared those with eLearning experience to those who have none. The independent variables were previous eLearning experience and dependent variables were the mean planning factor or the mean information manegment strategies factor. Each participant responded to 7 items related to the planning factor. This included statements like "I pace myself while learning in order to have enough time" and "I ask myself questions about the material before I begin". Participants responded to 10 items relating to the information manement strategies factor. This included statements such as, "I slow down when I encounter important information" and "I try breaking study down into smaller steps".

Within the *Planning* factor data, a number of outliers were removed to ensure that the data were normal. The total number for comparison were eLearning 41, no eLearning, 56 (n = 97). The mean (eLearning, 3.261, no eLearning, 3.101) difference of 0.159 indicates a marginal difference between the two groups. However, a t-test of the long-run mean difference (T-value = 1.23, P-value = 0.221) indicates no difference. Accordingly, the null hypothesis is not rejected. From this perspective, traditional eLearning has not displayed a significant interaction with learners planning ability. The *Information Management Strategies* factor was addressed in a similar manner. The total number of participants in the groups for comparison was eLearning 42, no eLearning, 56 (n = 98). Similar to planning, the mean (eLearning, 3.9, no eLearning, 3.671) difference of 0.229 indicates a marginal difference between the two groups. A t-test for independent samples indicates no significant difference between the long-run mean estimate (T-value = 2.50, P-value = 0.014). Once again, the null hypothesis cannot be rejected. Similarly, eLearning experience has not displayed a significant interaction with learners' information management strategies.

The results of this experiment are purely observational. However they are useful for decision making by indicating that there is more work to be done to support metacognitive awareness in eLearning. The affordances of adaptive eLearning may be leveraged to better support cognitive skills. We propose a new methodology of modeling the user, the ETTHOS model, which focuses on abstract cognitive skills. This model is used to guide the Goby service that will facilitate the acquisition and development of a learner's cognitive skill repertoire. The results of this observational experiment will inform the design of a controlled experiment to evaluate the performance of the Goby service by indicating a likely population standard deviation and necessary sample size.

3 The ETTHOS Model

Cognition is diverse. The proposed ETTHOS model draws from a number of different theories that have been developed within the psychological domain, in order to structure and embody abstract cognition within a technical model. The generalized models, and descriptions of cognition from this domain are well established, emerging from in-depth user studies and factor analysis. This research leverages three approaches to describing and analyzing cognitive structures; schema theory, protocol analysis, and psychometric tests. We believe that these could prove to be key representational requirements of future user models. ETTHOS takes a generalized view of the representation of thought, analogous to the way human cognition interprets and represents the world. In essence, it is based in schema theory [12]. According to this theory, a schema is a cognitive system that helps us organize and make sense of information. More explicitly, the model leverages the way that factor analysis has been used for the development of psychometric tests across cognitive and personality domains. The ETTHOS model is focused on the representation of useful cognitive skills and has been implemented to work within the Goby service. It will achieve this through alignment with the ALS, and by engaging in a dialog with the learner and by using task triggers that are inferred from ALS meta-data. As such, the goals of the ETTHOS model are that it is structured generally in order to reflect different cognitive skills and that it may be used to promote the acquisition of these skills.

The theoretical foundation for the ETTHOS model pools a number of key areas of research in psychology. The general structure of the ETTHOS model has been developed according to schema theory [12]. Schemata encompass information about an object or event that is generally true in a particular context. Knowledge acquisition and integration is mediated by the activation of appropriate mental models, resulting in deeper cognitive processing. New information is interpreted, inferred and expanded on through the reorganization of these schemata. The structure of the model is arranged according to two main sub-systems: traits and tasks, both of which come from different psychological constructs; psychometric tests, and protocol analysis.

The components of the task sub-system are drawn from a protocol analysis study, which identified the verbal protocols that a learner undertakes during constructively responsive reading [9]. These describe the sequence of useful cognitive activities that the learner undertakes as they attend to reading and comprehending new information. Each task comprises of a number of component activities and sub-activities. As the learner progresses through the learning scenario, metadata from the ALS informs task triggers.

A trait refers to a person's enduring characteristics or dispositions which give rise to their behaviors or behavior patterns [13]. For example, you may view yourself as a communicative type of person. In this case, communication is one of your traits. In general, traits are enduring and lead you to act in specific ways (like being able to explain complex ideas in more simple ways). The components of the trait sub-system have been adopted from the way that psychometric tests are broken down. Psychometric measurements refer to standardized measures and inventories. For example, in studying personality, an investigator is likely to use a self-report survey such as the Myers Briggs Type Indicator. Theses inventories comprise of a number of factors, identified by factor analysis. Factor analysis [12] can be described as compressing a large number of related observed variables into a smaller set of descriptive, but latent variables. Taking into account measurement error, where a group of variables are highly correlated then they measure the one thing. Inventories employed by psychologists use multiple items that correspond to the observable characteristics. Hence, the trait sub-system comprises of a number component factors, each of which has a number of component items.

3.1 The ETTHOS Model within the Higher-Order Cognitive Skill Domain

Higher-order cognition describes a set of complex skills that are built out of previously learned skills. The abstract cognitive skills that control the regulation of learning and thinking are considered to be higher-order cognition. Early in life hereditary and automated systems develop that are tied to the survival function of an infant. As we grow older, we learn to employ cognitive skills such as reading and communicating, and eventually begin to develop more critical thinking. The acquisition these involves practicing and automation. This means, that cognitive thinking is a multifaceted activity built up out of other skills that are simpler and easier to acquire.

This research is particularly interested in metacognition due to its inherent usefulness as a learning skill. A general model of metacognitive theory has been adopted from literature [4][8][11]. Aspects of learners' cognition are described according to the ETTHOS model. In this case, generalizations about metacognitive traits have been derived from the Metacognitive Awareness Inventory (MAI) [11]. This includes factors such as planning, comprehension and evaluation. The relevant cognitive tasks that a learner employs as they work their way though a piece of academic work, have been identified from the comprehensive protocol analysis undertaken by [9]. This includes activities such as constructing a goal, and generating initial hypothesis.

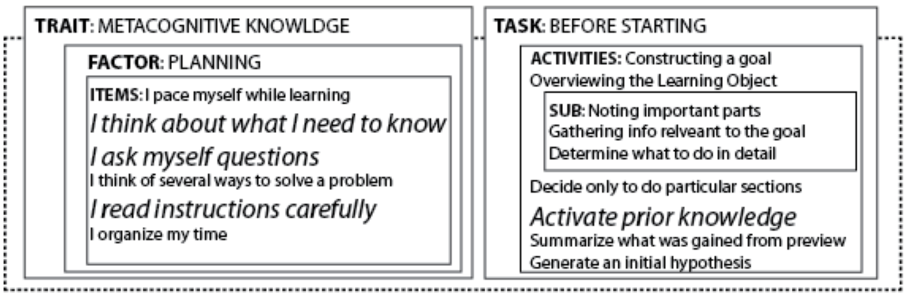

Fig. 1. The relation of the 'Activate Prior Knowledge' task to planning items

The two main sub-systems; traits and tasks are linked. This link is under examination. A survey of educators should indicate which trait is important for what tasks. Take for example *planning* as shown in Fig. 1. Planning includes items like 'I think about what I really need to learn', and 'I read instructions carefully'. Constructively responsive reading includes a sequence of verbal protocols before the learner begins the learning objective. This includes activities such as 'Constructing a goal', Over-viewing the learning object', and 'Activating prior knowledge'. For each component activity undertaken, there are one or a number of corresponding observable items that are related conceptually. The component activity 'activate prior knowledge', would require that the learner was someone who 'thinks about what they really need to learn', 'asks themselves questions' and 'reads instructions carefully'.

3.2 The Technical Implementation of the ETTHOS Model

The underlying architecture of the ETTHOS model is representative of schema theory. This positions that components are individual blueprints for what is generally true in a particular context. These have been implemented in a Java system that utilizes the Drools rule-engine platform and an XML native database. Common attributes include metrics such as a Likert value, confidence in accuracy, relative importance, its relationships and dependencies, and the context in which it is activated or altered. Figure 2 presents the core division of traits and tasks into two separate sub-systems. On inception, the service builds initial facts representing each item from a psychometric inventory. Each activity relates to a number of these items. The creation of new activity components is triggered by incoming metadata that indicates the current status the learner during a learning task.

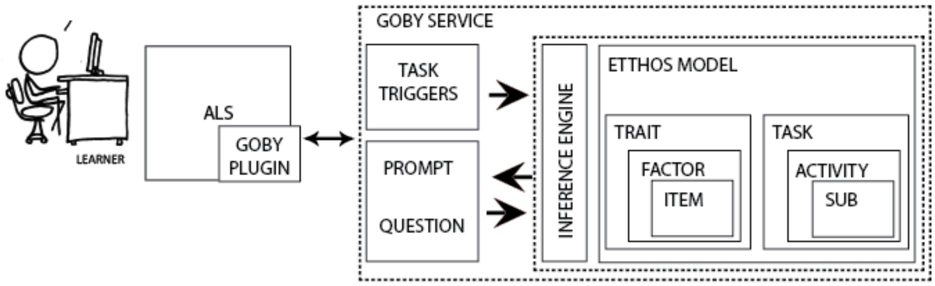

Fig. 2. Architecture to support the ETTHOS model

The ETTHOS Model has been implemented within the Goby service. The symbiotic-dialog approach [7] positions Goby as a third party service that works in symbiosis with ALS by engaging in a dialog with the learner. This symbiosis comes from understanding and alignment of both abstract cognitive skills, and the goals of the learning system. Specifically, the learner model is decomposed into traits described according to a psychometric test, such as the MAI [11] and related to activities or tasks.

Consider a learner interacting with personalized physics material as an example of how the ETTHOS model will serve as part of Goby. Metadata from the ALS the learner is using notifies the Goby service that the learner is about the start an experiment to compare gravity in a vacuum. Using this information Goby triggers a new activity within the ETTHOS model, 'construct a goal'. The relationship attributes indicate the planning factor, in particular the items 'what do I need to know' and 'read instructions carefully'. 'Read instructions carefully' is chosen as its metrics 'value' and 'confidence' are low. To promote this characteristic, and to gather more information for the model, Goby asks the learner a question: 'Have you read the instructions carefully?' Answering yes triggers the creation of a new activity with an increased value and confidence measurement. Continued dialog with the learner updates the trait sub-system, and metadata from the ALS informs the task sub-system, in turn directing future dialog.

It is envisioned that the Goby service, developed as a discrete third-party service, could interact with the metadata from several ALS to inform its decision-making [7]. Thus further updating the schema model of the learners' cognition, as well as engaging in useful dialog. As such, it should be possible to take the general view of the ETTHOS model in order to incorporate other higher-order cognitive skills that are antecedents to positive lifelong learning. The theories that underlie the ETTHOS model; schema theory, protocol analysis, and psychometric analysis could be key to developing personalized services that benefit learner cognition in symbiosis with a range of applications.

4 Future Work and Conclusions

This paper has introduced a novel approach to modeling abstract cognitive skills that is grounded in psychological methodologies. Specifically it describes how schema theory, protocol analysis and psychometric approaches may be utilized to represent cognition. The aim of the new framework is to provide a general model of abstract cognitive skills that are useful to learners. The analysis of an online survey indicates there is more work to be done to correlate eLearning with metacognitive awareness. As self-directed planning and information manegment are important components of succeeding in an eLearning course, there could be benefits to leveraging the modeling and adaptivity techniques used by ALS to support online learner metacognitive awareness. When implemented within the Goby service, the ETTHOS model will support learner's acquisition of a higher-order cognitive skill repertoire. Goby will engage in a reflective dialog that promotes the knowledge, skills, and confidence necessary to cope with the full complexity of applying metacognitive strategies to a learning task.

It is asked whether psychometric elements of a learner's higher-order skill repertoire be effectively reflected in a technical model. The theory and structure supporting the ETTHOS model are currently being evaluated. A comparison of their pre and post-test MAI scores as well as comparisons of the model metrics and post scores will indicate the success of the modeling. The results from this experiment will drive the future development. Once the model has been ratified, the service will be loosely integrated with the host adaptive eLearning system, APeLS. This will dictate how ALS metadata may be used to trigger activities, and update the ETTHOS model. It is envisioned that this approach will mean that the model is transferable across abstract cognitive skills.

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