

A Logic-based Approach to Learner Assessment

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Abstract: The effectiveness of an e-learning environment strongly depends on the proof that students actually learn what they are supposed to. The procedure of assessment in educational systems provides alternative ways to address this issue adequately, depending on the specific learning setting and requirements. Currently, we are witnessing the transformation of static e-learning environments to adaptive ones along with the gradual incorporation of semantic web technologies. These technologies enable more sophisticated user and content modelling, which in turn gives adaptation mechanisms new potential. This paper presents an overall categorization of assessment methods used in the e-learning domain and employs first-order logic to describe a number of indicative assessment mechanisms by proposing a set of atoms, predicates and rules to express the logic that produces the assessment decisions. First-order logic representation enables easier implementation of assessment strategies with semantic web technologies and provides a formal way for comparing alternative assessment schemes.

Key-Words: learner assessment, adaptive learning, assessment methods, first-order logic, semantic web.

1 Introduction

Assessment is the procedure applied for obtaining information about the progress of a student attending a specific learning course. Palombra and Banta [10] define student assessment as “*the systematic collection, review and use of information about educational programmes undertaken for the purpose of improving student learning and development*”.

Taking this one step further, student assessment is one of the components of e-learning that differentiates it from mere content delivery via web mechanisms. According to the learning cycle proposed by Piskurich [11] and as depicted in figure 1, the phase of assessment occupies an equally large area as preparation and learning phases in the overall learning process. Thus, the thorough consideration and the proper use of assessment techniques play a major role in the success and sustainability of a distance learning environment.

One of the crucial issues that needs to be considered before selecting the proper assessment method is the flexibility it provides. For instance, all students shouldn't be evaluated on the same terms regardless of their knowledge background and competencies.

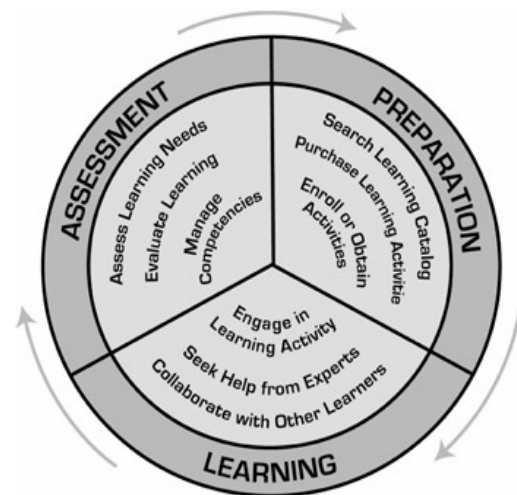


Figure 1. The Learning Cycle

Thus it is necessary to endow each assessment method with a degree of adaptivity, a direction towards which there have already been a number of noteworthy research and development activities conducted up to date. Adaptive education hypermedia systems, a term introduced by Peter Brusilovsky ([2], [3]) constitute an active research domain that has recently been given even greater

potential with the advent of the semantic web ([6], [7], [9]). In this setting, the first-order logic modelling of an adaptive educational hypermedia system provides crucial advantages as it allows the reuse of adaptation rules in different contexts and supports the understanding of the role of metadata for adaptation. For instance, Dolog et al. [6] implemented first-order adaptation rules in TRIPLE, an RDF rule-language for the semantic web (<http://triple.semanticweb.org/>).

This paper proposes a formal description of assessment methods used in the domain of adaptive learning systems in first-order logic enabling their easier implementation with semantic web technologies and providing a formal way for comparing alternative assessment schemes. More specifically, section 2 presents an overall categorization of assessment methods used in the e-learning domain. Section 3 provides a brief description to first-order logic terminology and the formal first-order logic characterization of adaptive hypermedia that is used as the basis for the current work. In section 4 the authors use first-order logic to describe a number of indicative assessment mechanisms and propose a set of atoms, predicates and rules to express the logic that produces the assessment decisions, while section 5 concludes the paper.

2 Online Assessment Methods

The assessment methods suggested by Buchanan [4] cover a wide spectrum and apply straight and effectively in the majority of e-learning settings [1]. These methods comprise participation, project portfolios, self assessment, peer assessment, as well as tests, exams and games, defined as follows.

2.1 Participation

One of the most widespread methods of online assessment relies on students' participation in the course. The issue though is finding the way participation can be defined in measurable terms, as usually it not clearly defined or articulated. Instructors should provide guidelines for their expectations of participation: in general, the decision whether it is a quantitative or a qualitative or a complex measure has to be made strictly by the instructor/administrator of the course and thus the aspects to be considered are viewed in two different ways. The quantitative approach takes into consideration the percentage of assignments a student completes, the number of replies to other

students' inquiries, the total remarks posed to other students work and so on. On the other hand, the qualitative approach comes to consider the content of the students' tasks and the method utilized to integrate them. The key issue in the assessment of the participation is the clear statement of instructor requirements on student participation (i.e. which activity is giving credits, how much credit is given by all the specific activities and so on).

2.2 Project Portfolios

Portfolios are collection of projects undertaken by learners over a training period and can include things like homework, papers, peer assessment reports, exams and tests, in-class writing, online discussion messages and so on. From an educational perspective, portfolios reflect the learner's experience on a thematic area. Project collections are very useful tools for measuring the student's progress, since they contain student work from the beginning to the end of a course attendance and the rules and principles of student assessment have to be thoroughly explained.

2.3 Self Assessment

The use of self assessment is a very promising technique in online education and is well matched with the pedagogical specificity of Web-based learning in general.

Due to the fact that students are out of the class, possibly "alone" on their personal computer, self assessment can transform hesitant participation to a more active engagement with the course. Students must be ready to adopt the technique of self assessment, as it is probable to fail if students cannot be honest with themselves and the instructor. The development of self-evaluation strategies helps students gain control over their own learning process. What is asked by the students in the self assessment techniques is to show where they stand as learners. This is not always an easy task since students may not know what they really know. In order to help them solve this problem, the instructor must provide supplementary material such as checklists, rubrics, or inventories. The self assessment technique adopts enough methods from the assessment of participation but the major difference is that in this case the student evaluates, for example, his own results of rubrics and based on them creates a report on individual progress.

2.4 Peer Assessment

Peer assessment is another way of removing part of the duties of evaluation from the instructor. Online environments are ideal for the use of this technique since it has the ability to encourage students to strive harder to complete assignments and participate more actively if they know their peers are evaluating them for their activity. Peer assessment online can be formed in a number of ways. For example students may correct and comment their 'classmates' work, or assess each other's participation in any kind of learning activity except from tests and exams. Instructors' role has to be active in this method as well. The instructor as a facilitator and mediator must first of all provide guidelines to the students about the assessment criteria and then work with both the assessor and the assessed to be sure the assessment was fair and systematic. Peer assessment requires long-term commitment for providing qualitative results in online classes and novice instructors should use this with some caution.

2.5 Tests, Exams and Games

The most popular way of student assessment in schools and academic institutions can be used in the online education, as well. The traditional tests, exams and quizzes where student responses are compared against a predetermined set of correct answers is very well applicable and technically less demanding in the case of online assessment. Nevertheless, the generation of sets of questions and potential responses can prove quite perplexing and time consuming. Bull and Dalziel [5] suggest the use of question banks. A question bank is a collection of uniquely identified questions that allows the selection of questions for the creation of tests based on various predefined criteria. Questions are annotated with descriptors such as: difficulty level, related topic, academic level, skill/knowledge component addressed, etc. although question banks require a long set-up time, they eventually offer substantial savings of time and energy over conventional test development. Question banks are considered of crucial importance in the domain of peer-to-peer e-learning platforms for the high degree of reusability they offer.

3 First-order logic and adaptive learning modelling

First-order logic was selected because it allows us to provide an abstract, generalized formalization. The notation chosen in this paper refers to [12] and uses

atoms, predicates and rules to represent objects, relations among objects and inference mechanisms respectively. Henze and Nejdil [8] employ first-order logic to characterize an adaptive educational hypermedia. More specifically, an adaptive educational hypermedia is defined as a quadruple of the form:

$$(DOCS, UM, OBS, AC)$$

where:

- *DOCS (Document Space)* is a finite set of first-order logic sentences with atoms for describing documents (and knowledge topics), and predicates for defining relations between these atoms.
- *UM (User Model)* is a finite set of first-order logic sentences with atoms for describing individual users (user groups), and user characteristics, as well as predicates and rules for expressing whether a characteristic applies to a user.
- *OBS (Observations)* is a finite set of first-order logic sentences with atoms for describing observations and predicates for relating users, documents/topics, and observations.
- *AC (Adaptation Component)* is a finite set of first-order logic sentences with rules for describing adaptive functionality.

Document space and observations describe basic data and runtime data respectively, while user model and adaptation process this data, e.g. for estimating a user's preferences, or for deciding about beneficial adaptive treatments for a user, respectively. In the next section we use these general principles as the basis for expressing assessment related procedures incorporated in adaptive e-learning systems with regard to the set of methods presented in section 2.

4 Logic-based Framework for Learner Assessment

This section presents the characterization of the assessment methods mentioned in section 2 in terms of first-order logic. Each method is used to examine the learner's knowledge on a specific domain and thus it is required to represent the domain's objects and their relations using a number of atoms and predicates.

More specifically, the knowledge topics of the domain are represented by the learning concept atom C_i . The ways that domain concepts can be related are represented by the corresponding predicates. In particular, the case where a concept C_i is a prerequisite for the perception of concept C_k is

described by the predicate $prerequisite(C_i, C_k)$. Respectively, the case where the system assumes that concept C_i is learned because the concept C_k is already learned by the user, can be modeled by the predicate $inferred(C_i, C_k)$.

Each document D_k of the system may contain one or more concepts C_i . This relation can be modeled by the predicate $contains(D_k, C_i)$. Nevertheless, each concept C_i of the knowledge domain is defined in a single document of the document space. The expression of this information in first-order logic is $defines(D_k, C_i)$.

Each concept C_i of the knowledge domain is tested by one or more questions Q_j . This is formally expressed by the predicate $evaluates(Q_j, C_i)$. To describe the correct or incorrect response of a learner U_j to a particular question Q_i the predicate $response(U_j, Q_i, status)$ is used and the atoms *correct* and *incorrect* to characterize the status according to learner's correct or incorrect response. Finally, the predicate $set(U_j, C_i, Learned)$ can be used for stating that the learner U_j has learned concept C_i .

Rules in first-order logic representation are used to describe the specific cases of learning procedure and decide the next action to be taken. When the learner provides a correct response to a question Q_i it is assumed that the concept C_k this question refers to is learned. This assumption procedure is modeled by the following rule:

$$\forall U_j \forall C_k \\ ((\forall Q_i evaluates(Q_i, C_k) \wedge response(U_j, Q_i, Correct)) \Rightarrow set(U_j, C_k, Learned))$$

According to an alternative scenario, the predicate $evaluates(Q_j, C_i)$ does not use a binary value for determining whether a Q_j evaluates user knowledge on C_i , but allows an extra argument for defining the difficulty of question Q_j concerning learning concept C_i . More specifically, assuming that the system distinguishes 4 levels of difficulty represented by respective values 1, 2, 3 and 4 (most difficult), a statement of the form $evaluates(Q_j, C_i, 3)$ means that Q_j is a quite hard question concerning concept C_i .

In the case of a system that characterizes a user as "well-qualified" when he/she has answered correctly all level 1, and 2 questions on a concept and at least one level 3 question the corresponding rule would be:

$$\forall U_j \forall C_k \\ ((\forall Q_i ((evaluates(Q_i, C_k, 1) \Rightarrow response(U_j, Q_i, Correct)) \vee (evaluates(Q_i, C_k, 2) \Rightarrow response(U_j, Q_i,$$

$$Correct))) \wedge (\exists Q_i evaluates(Q_i, C_k, 3) \Rightarrow response(U_j, Q_i, Correct)) \Rightarrow set(U_j, C_k, well-qualified))$$

To represent the level of user expertise on the specific concept, a new atom named "well-qualified" has been defined.

A rule to express that a user should be considered expert regarding a concept C_j when he/she has given correct answers to all level 4 questions regarding a certain concept C_j would have the form:

$$\forall U_i \forall C_k \\ ((\forall Q_j evaluates(Q_j, C_k, 4) \Rightarrow response(U_i, Q_j, correct)) \Rightarrow set(U_i, C_k, excellent))$$

In the above rule, a new atom has been defined to represent the level of user expertise on the specific concept, named "excellent".

Another interesting formalization in an assessment system can be performed on question banks. As already mentioned a question bank is a repository of questions from which questions are retrieved. Moreover, question banks can be used as a basis for adaptation decisions on the state of questions as they keep track of response statistics. For example, if all students respond correctly to a question which is considered quite difficult, it would be wise to decrease its difficulty indicator. A rule which formally expresses the above inference procedure is:

$$\forall Q_k \forall C_i \\ ((evaluates(Q_k, C_i, 3) \Rightarrow (\forall U_j response(U_j, Q_k, Correct)) \Rightarrow evaluates(Q_k, C_i, 2))$$

The results of the assessment may in turn be used for adapting the learning scenario applied to the user. More specifically, in the case where the user fails to provide a correct answer to an easy question concerning concept C_i , the system may recommend for reading the document D_k , which contains the definition of the concept formally expressed by predicate $defines(D_k, C_i)$, provided that such a document is available.

$$\forall U_j \forall C_i \\ ((\forall Q_i evaluates(Q_i, C_i, 1) \Rightarrow response(U_j, Q_i, Incorrect)) \wedge \exists D_k defines(D_k, C_i)) \Rightarrow set(U_j, D_k, Recommend_for_reading))$$

Another way to perform assessment is by calculating the participation level of the learner. Participation may be considered as a general activity measure and can thus be estimated in terms of various learner

activities: The number of visited documents, the number of questions answered, the number of messages posted to the forum, the number of peer assessments, etc. Assessment decisions are drawn based on preset threshold values depending on the learning scenarios that are realized in the system and the objectives of the tutors.

For example in the case where a tutor needs to assess the learner based on the number of answered questions the following formal expression can be used. The predicate *responded* (U_i , *quest_num*) is used to relate the user to the number of questions he has answered and the predicate *greater*(*quest_num*, *threshold*) determines whether the number of answered questions is greater than the threshold value. Thus the rule which assesses the learner participation may have the form:

$$\forall U_i$$

$$(responded(U_i, num_quest) \Rightarrow greater(num_quest, threshold)) \Rightarrow participation(U_i, high)$$

The predicate *participation*(U_i , *high*) is used to assess the learners in terms of quantitative participation. The count of peer assessments conducted by a learner may be integrated into the learner assessment scheme in a similar manner, i.e. the tutor assesses learner participation by comparing the number of assessments a user has performed against a threshold.

5 Conclusion

This paper presented an overall categorization of assessment methods used in the e-learning domain and employed first-order logic to describe a number of indicative assessment mechanisms by proposing a set of atoms, predicates and rules to express the logic that produces the assessment decisions. First-order logic representation enables easier implementation of assessment strategies with semantic technologies and provides a formal way for comparing alternative assessment schemes.

Summarizing, assessment should be considered as an ongoing process executing alongside with learning and in close interaction with it. In today's adaptive learning environments the feedback from the assessment results is usually directly fed to the user profile and the mechanisms for adjusting the learning experience to the specific user. Still, a successful assessment strategy is the one that, given a specific learning setting, takes into account and satisfies the needs and requirements of all interested

parties, the learner, the instructor and the e-learning course provider.

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