Extending Question & Test Learning Technology Specifications with Enhanced Questionnaire Models

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Abstract – **Questionnaires are a commonly used instrument for diverse purposes in the context of educational technology. Applications of questionnaires range from student's assessments to evaluations of teaching, and include also the evaluation of the learning contents, and even of the technology that delivers them. Although the IMS QTI specification addresses the interchange of questionnaires and their results, the scope of its information model is primarily oriented towards conventional student's knowledge or ability evaluation. In consequence, it requires extensions to represent some information elements needed for other uses, and additions are also needed to describe certain item characteristics that are used in adaptive testing. In this paper, an abstract model called QM is described, which is intended to provide the foundation for a more comprehensive questionnaire information model. Extensions of the IMS QTI XML data structures are sketched to show how QM can enrich existing specifications with extended semantics for a wide range of applications.**

I. INTRODUCTION

Questionnaires are currently an important and frequently used element in educational technology contexts, since they are commonly applied as an instrument to achieve a number of diverse objectives. These objectives include the formative or summative assessments of student's knowledge [1], the estimation of certain student's cognitive abilities [2], attitude measurements of users of learning technology [3], and evaluations of teaching [4]. They have been used also for the task of evaluating the educational technologies [5] that support the learning processes.

As such important instruments, questionnaires have received attention from standardization efforts in the area of learning technology. More specifically, the Question & Test Interoperability (QTI) Working Group of the IMS Global Learning Consortium[1] is committed to address the need for a common interchange electronic format for questions and tests. As a result, the "IMS Question & Test Interoperability specification" (currently in its final 1.2 version, see [6] and its related documents) specifies an information model for the representation of assessment data, including questions, tests and their results. More specifically, the technical structure of the QTI specification is based upon two independent components: the ASI (Assessment, Section, Item) component, used to describe the evaluation objects [7], and the 'result reporting objects' [8], used to contain the results of the evaluation (we focus here only in the ASI component, which describes the essential questionnaire's information structures).

Nonetheless, the QTI model could be enriched with some additional features in order to enhance some important aspects of questionnaire's structure regarding their use in educational contexts (as is described in [9]), mainly in two related aspects: scope and level of detail. On the one hand, there are different uses of questionnaires in educational settings that simply fall out of the explicit scope of the QTI specification, being some of the most relevant the encoding of specific aspects of attitude-gathering questionnaires (useful in usability, learning content quality and instructor evaluation) or even simple information-gathering questionnaires. As a matter of fact, the QTI defines *assessment* in the following, somewhat vague, terms: "An Assessment is equivalent to a 'Test'. It contains the collection of Items that are used to *determine the level of mastery*, or otherwise, that a participant has on a particular subject" [7]. On the other hand, the QTI lacks explicit support for some important meta-information about questionnaires, like internal characteristics as reliability and validity, and other important item measures needed to build item banks (difficulty and the like). Although all the IMS specifications are prepared for extension, some meta-attributes can be considered important enough to include them explicitly in the information models, and as so, they should be considered for addition – as optional elements – if a more detailed interchange format would be required or desired. In addition, the QTI model doesn't allow for a clear separation between the questions or items and how they should be presented to the users.

In this paper, we describe the essential components of an abstract model for questionnaires, that we have called QM (standing for *questionnaire model*), aimed at the general representation of questionnaires and question banks of diverse kinds, taking into account all the specific aspects about the topics described in [9]. We also briefly describe how the QTI specification can be extended, both to broaden its scope and to enrich the information it deals with, in order to demonstrate how QM could be used in concrete educational technology systems for a wide range of purposes.

The rest of this paper is structured as follows. Section II describes the main QM components along with the rationale for their inclusion, and Section III outlines how the QTI ASI XML binding [10] could be extended to

[1] <http://www.imsproject.org>

include some of the QM elements. Finally, conclusions and future work are presented in section IV.

II. AN ENHANCED QUESTIONNAIRE MODEL

A questionnaire can be defined in a straightforward manner as 'a set of questions for obtaining statistically useful or personal information from individuals'[2]. The process of obtaining information through the application of a questionnaire is often referred to as survey or questionnaire administration. The questionnaire design process (*lifecycle*) involves a number of phases – which can be enhanced with 'intelligent' techniques [11] –, from requirements definition to analysis of results, and including design and evaluation. In some cases, all these phases are carried out in an iterative refinement fashion, and sometimes they are used for knowledge acquisition [12].

The results of that process are a questionnaire *definition* and the *data* that comes from (in some cases, possibly multiple) questionnaire's administrations. The information model supporting these phases should be rich enough to capture all the content, presentation and metadata concepts needed to use questionnaires for different purposes and with diverse response types beyond multiple-choice tests [13], and to extract knowledge from large databases of evaluation facts [14]. The fact that question and questionnaire design considerations are different for different purposes should also be taken into account, e.g. *filters* or *intensity* questions are common in social science research [15] to establish the relevance of the question to each respondent, and the semantics of these constructs should be explicitly included in the questionnaire model.

QM is an abstract general-purpose model[3] that has been used for usability evaluation [16]. We describe here some of its aspects that are worth taking into account in common educational technology settings, without the intention of being comprehensive in the model's description. Our ultimate aim is to illustrate the need for such a complex model to deal with a wide range of questionnaire's uses. For simplicity's sake, we'll describe it informally and partially, focusing only on semantic issues that are beyond the current scope of the QTI specification, and omitting the details about the response structures.

A. Core Information Model

QM separates the major dimensions of a questionnaire in two components: the *dynamic model* (*flow model* in [12]), which specifies how questions in a questionnaire are presented to a specific user, and the *static model*, that specifies questionnaire and question properties and structure.

Static model elements include the overall question structure, the objects under evaluation, the questionnaire respondents and questionnaire metadata. All of these elements conform the questionnaire structure.

Dynamic model elements in QM comprise presentation options (device-dependant presentation, layout, etc.) used to render questionnaires and their items independently of the questionnaire or item's content. The dynamic model may include 'hooks' for using knowledge in user models to come up with *adaptive* presentation techniques (like those described in [17]).

A questionnaire Q is defined in QM as an element in the form:

$$Q = \{T, I, P, O, M\}$$

where T specifies the kind of questionnaire used in the evaluation, I is the set of questions, P is a set of collections of presentation attributes, O represents the evaluated object and M is the collection of questionnaire's metadata items. Each time a questionnaire is administered, an instance of Q (denoted as Q_i) is associated with the set S_{Qi} of respondents. Relationships can also be specified between items and questionnaires, as in done in [16].

Currently, three generic kinds of questionnaires are explicitly represented in QM, which differ in the type of object being evaluated, how results should be obtained, and how they should be analyzed. The first type (*K*), is used to objectively evaluate student's knowledge or ability about one or more topic. The second (*A*) is the attitude questionnaire[4] [15]. This kind of test can be used, for example, to evaluate the system's usability or the subjective satisfaction of the students with the instructor's teaching methodology quality. The third type (*C*), corresponds to those questionnaires that are aimed at collecting information about something or somebody, for example, student's personal data, her or his previous knowledge, etc. The taxonomy of questionnaires should be subject of refinement, since sub-types of the described types have a unique set of issues and constraints that would require the specification of additional characteristics. This is the case of *K*-type questionnaires that are used in many different contexts [18].

Each item i_j in set I is associated to a response domain $dom\ (i_j)$. This domain includes all response-types specified in the QTI information model [6] and others like Likert scale values. The question presentation options – $pres\ (i_j)$ – are also associated to the item. These options include the QTI ones and others useful, e.g., the linguistic labels that must be showed for the different scale values when Likert scales are used. Besides all these associated components, a questionnaire always has an *intention* (represented as one of the metadata items), which is taken into account in QM. The intention of a knowledge questionnaire item should be to evaluate some of the educative subject objectives: evaluate if the student had memorized something or if she/he can analyze some problem, and the like. The intention of an attitude questionnaire depends on the object that is being evaluated. For example, the intention of a questionnaire that is aimed to evaluate usability of the learning environment should include the evaluation of different traits, like, for example, navigability, learnability, efficiency, control, etc.

Meta-information about items can also be specified in QM. Important meta-data about an assessment question in a *K*-type questionnaire may include the parameters in its characteristic function [19]. This information is essential if

[2] According to the Merriam-Webster's online Collegiate Dictionary, available at <http://www.m-w.com/>

[3] It could be considered a *meta-model* in the sense that it is a language to describe concrete questionnaire models.

[4] An example of web tool to create attitude questionnaires can be found in http://whizquest.isis.vt.edu/

using and mixing item banks (one of the QTI specification requirements) and to perform *adaptive* tests [20].

The set *P* contains the attributes refereed to overall questionnaire presentation, and conforms the dynamic model. Attributes that can be included here are item and/or section randomize options, item presentation order and other related with question flow. Several different collections of attributes can be included in *P*, representing different renderings or administration strategies for the same questionnaire.

A questionnaire is always aimed at evaluating something. When we use a knowledge test K_i, the evaluated objects are the specific topics that questions are dealing with. When an attitude questionnaire A_i is used, the evaluated object is the object or class of objects about which the respondent shows her/his opinion. And, to finish, the evaluated object in an infomation questionnaire C_i can be considered the entity about which data are collected.

The set *O* in a questionnaire contains the evaluated objects. If questionnaire type is *A* or *C*, it contains only one object, while if questionnaire type is *K*, it's possible to specify one evaluation object or an aggregated collection of them. In other cases, questionnaires can be specified in a subject-independent manner, so that they can be applied to different objects.

The respondents (anonymous or not) of a specific questionnaire instance can be further specified with individual's background and other relevant personal data about she or him, and are associated to the specific instances of the surveys or administrations in which they participate.

In QM, the last component in a test structure is the questionnaire metadata set *M*. This set comprises data refereed to the overall questionnaire information, like, reliability and validity measures of the questionnaire, psychometric characteristics and the like. Question-level metadata are also permitted.

B. Item Banks

Item banks are large repositories of various test items that are organized by their content, their purpose or the cognitive ability they exercise. Calibrated item banks include a number of item characteristics (e.g., item difficulty and discriminating power) usually according to *Item Response Theory* (IRT) [19], which enable adaptive testing and the construction of tests from a number of item banks, since two items that evaluate the same trait can be used interchangeably if they have the same characteristics. From a modelling perspective, we can define *dynamic tests* as:

$$Q = \{T, B, P, O, M\}$$

that are defined on a set *B* of item banks, and including a set of test characteristics in *M* that define which kind of items are eligible for the test (basically item type and psychometric characteristics, since the trait/s that is/are measured can be made explicit through *O*). Fig. 1 depicts this relationship.

The model should allow the definition of the item bank with or without the definition of the items in the bank, and in the latter case, each item must associated metadata with the selected psychometric model.

C. Relationships between questions

The concept of relationship between questions provides a conceptual framework to represent diverse fact that can be found in different questionnaire uses. We have set three basic relationships: generalization, composition and association. Strictly additive variants of a question can be modelled as specializations of the original. Composite questions are essentially equivalent to the concept of Section in the QTI (this relationship can be also applied to elements in *O*). Associations between questions can be used as a general-purpose instrument for the definition of semantic relationships.

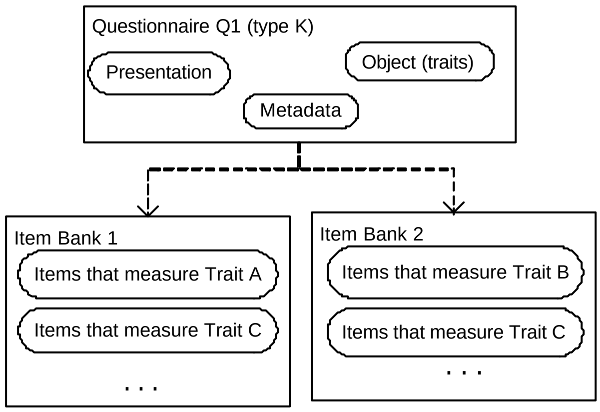

Figure 1. Overall structure of a test built from item banks

The definitions of the relationships are specified as metadata, at the item level. Questionnaire-level relationships can also be specified for different purposes, being one of them that of connecting versions of the same questionnaire, as a mechanism of change control.

III. EXTENDING THE QTI SPECIFICATION WITH QM ELEMENTS

The terminology adopted by the QTI is that an *Item* contains one or more questions and responses, along with response processing semantics, presentation and feedback information and metadata. An *Assessment* is a collection of Items with associated sequencing and scoring information. Finally, a *Section* is a general-purpose grouping mechanism, and *Object-banks* are collections of items and/or sections. These elements provide a basic framework from which semantically richer models can be built.

The IMS QTI specification defines itself as *extensible* and *customizable* [6]. *Functional* extensions in QTI can be specified through extension elements. We can introduce QM features in QTI schema using these mechanisms. This section describes a number of example extensions of QTI structures.

A. Item Banking

The QTI defines the concept of 'object bank' in a generic sense, as a set of questions, without specifying any additional properties regarding how they should be used. In order to interchange calibrated item banks, the XML format that is used to define the items should include psychometric information.

In order to provide support for item interchange between banks to construct new assessments, the information model of the QTI ASI specification should include ICC (item characteristic curve, see [19]) information. Usually, the curve is described by a logistic model equation. For example, a two-parameters logistic model applied to dichotomous item response data is given by the equation:

$$P_i(q) = \frac{e^{Da_i(q-b_i)}}{1+e^{Da_i(q-b_i)}}$$

where $P_i(\theta)$ is the probability that a randomly chosen examinee with ability θ answers the item correctly, b_i is the difficulty of item i, a is the discrimination parameter and D is the scaling factor.

The QTI XML binding can be extended to support the above described item information. As an example, the following XML fragment shows a simple QTI item description with added ICC information (in bold type face), using definitions in an external `irt` namespace:

```
<item ident="IMS_V01_I_BasicExample001a">
  <itemmetadata>
   <irt:icc type="TwoParameterLogistic">
     <irt:difficulty> 1.2 <irt:difficulty/>
     <irt:discrimination>1.5<irt:discrimination/>
   </irt:icc>
  </itemmetadata>
  <presentation label="BasicExample001a">
  <flow>
  <material> <mattext>
    Paris is the Capital of France?
  </mattext> </material>
       ...
  </presentation>
  ...
</item>
```

As ICCs are defined as well-known functions, the type of these functions can be codified as attribute values in extended markup (inside the QTI `<itemmetadata>` element, note that a more elaborated version could use the IMS *vocabulary* facility).

The following XML fragment shows how a QTI object bank (with the additional ICC information just described) can be embedded in a `<itembank>` structure that specifies two sub-banks for each of the traits that are evaluated.

```
<qm:itembank ident="bank1">
   <qm:sub-itembank trait="trait01">
       <item ident="IT01">
        ...
       </item>
        ...
   </qm:sub-itembank>
   <qm: sub-itembank trait="trait02">
      <section ident="S01">
       ...
      </section>
   </qm: sub-itembank>
</qm:itembank>
```

The organization of the QTI structures can be preserved inside item banks, in all of the forms permitted by the IMS specification. Since item banks, as any other digital resource, can be uniquely identified by a Universal Resource Identifier (URI), a dynamic questionnaire can reference them to take items from them to build tests "on the fly". The following example sketches the structure of one of this kind of questionnaires, extended from the QTI overall questionnaire structure.

```
<questestinterop>
<assessmentmetadata
     xmlns:q="http://www.uah.es/cc/QM">
   <q:referencesItemBank uri="..."/>
   <q:referencesItemBank uri="..."/>
    <!—- Item selection characteristics -->
     ...
</assessmentmetadata>
  ...
  <!—- No items defined-->
</questestinterop>
```

Only a number of references to existing item banks is specified, along with a specification of the item selection strategy (omitted in the above fragment).

B. Usability Evaluation

An attitude questionnaire for user satisfaction (along with its meta-infomation) can be defined by stating type *A* inside the `<assessmentmetadata>` element. We can use the `<itemmetada>` element to introduce a static definition of a question in the test. A partial definition for this example questionnaire is showed bellow. Note that, again, new elements that don't belong to QTI specification are bold type faced:

```
<questestinterop>
...
<assessmentmetadata
     xmlns:q="http://www.uah.es/cc/QM">
    <q:type> "Attitude"</q:type>
    <q:reliability> 0.82</q:reliability>
    <q:validity>    0.95</q:validity>
</assessmentmetadata>
  ...
<item title="Learnability_Question"
                 ident="I01">
<itemmetadata xmlns:i="http://www.uah.es/cc/QM">
  <i:questiondef ident= "UQ01">
      "Remembering where I am on this web
       site is easy"
  </i:questiondef>
  <i:responsedef type="Likert">
       <i:responsevalue ident= "UQR011">
          1
        </i:responsevalue>
         …
       <i:responsevalue ident= "UQR015">
          5
        </i:responsevalue>
</i:responsedef>

<i:mapping  qmid= "UQR11"   qtiid="LID01_E"/>
      …
<i:mapping  qmid= "UQR15"  qtiid="LID01_A"/>

</itemmetadata>
  <presentation label="Resp001">
    <response_lid ident="LID01">
      <material>
        <mattext></mattext>
      </material>
      <render_choice shuffle="Yes">
        <response_label ident="LID01_A">
```

```
          <material>
            <mattext>Strongly Disagree</mattext>
          </material>
        </response_label>
        …
        <response_label        ident="LID01_D"
        rshuffle="No">
          <material>
            <mattext>Strongly Agree</mattext>
          </material>
        </response_label>
      </render_choice>
    </response_lid>
  </presentation>
  </item>
</questestinterop>
```

In then previous XML code, the static item definition is separated from its presentation options, using the metadata section to describe a presentation-independent item, and linking the presentation options with the QTI elements through explicit mappings. This allows for the definition of more than one presentation without including the same contents several times. Note, for example, that the “strongly agree” label is associated to the highest value (5), although, in other cases, it would be associated to the lowest one (1).

C. Relationships between questions

The following example describes an example that includes two association relationships between questions. One of them is a similarity value (specified only in one direction, since similarity is reflexive) and the other represents a dependency from an intensity question to the question to which it applies. Note that both are included as part of an XML fragment that describes one of the items in the *IsoMetrics*^{L} usability questionnaire[5]:

```
<item title="Weighting question" ident="I01">

<itemmetadata xmlns:i="http://www.uah.es/cc/QM">
<i:questiondef ident= "INT01">
    "Please rate the importance of the item in
    terms of supporting your general impression
    of the software?"
</i:questiondef>
<i:responsedef type="Likert">
  <i:responsevalue ident= "INT011"
           label="Unimportant"> 1
  </i:responsevalue>
       …
  <i:responsevalue ident= "INT015"
           label="Important"> 5
  </i:responsevalue>
  <i:responsevalue ident= "INT016"
           label=Important type="no-opinion"> 0
  </i:responsevalue>

</i:responsedef>
 <i:associatedTo type="intensity">
    <i:target id="I02">
 </i:associatedTo >
...
</itemmetadata>

<presentation label="Resp001">
    ...
</presentation>

</item>
<item title="IsometricsL-A.6" ident="I02">
<itemmetadata xmlns:i="http://www.uah.es/cc/QM">
  ...
  <i:similarTo id="I03" grade="0.7">
  <i:questiondef ident= "ISL-A.6">
   "The way in which data is entered is suited to
   the tasks I want to perform with the software"
  </i:questiondef>
   ...
</itemmetadata>

<presentation label="Resp002">
    ...
</presentation>
<item title=" IsometricsL-A.7" ident="I03">
  ...
  <i:questiondef ident= "ISL-A.7">
    "I perceive the arrangements of the fields
    on-screen as sensible for the work I do with
    the software"
  </i:questiondef>
  ...
</item>
```

In this example, the labels for the responses are specified in the metadata section, which do not preclude a different presentation defined later. Note also that the above code fragment defines a *filter* option, labelled INT06, and specifies its nature through the use of a type label ‘*no-opinion*’ in a vocabulary.

IV. CONCLUSIONS AND FUTURE WORK

The QTI specification provides a useful and extensible information model for the representation and interchange of assessments and their results. But a number of extensions are required if we want the resulting information structures to be semantically rich enough to deal with advanced applications (like adaptive testing), attitude measurements, and general relationships between questions (e.g. similarities and dependencies). We

The current QM model represent a first step in the specification of a comprehensive model for questionnaire-based processes, and as such, is in an evolving state as new features for specific uses are added to its core model. Related work includes questionnaire frameworks like the IQML [21] and TADEQ QDL [22], but none of them have a broad scope as QM.

Future work will focus on validating QM for other uses apart from evaluation [4], and on expressing QM models in a more user-friendly and widely used notation (specifically, a UML *profile* is being considered).

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