Abstract

A model for the interactions in an assessment to support learning identifies the need for response options and for contingent feedback, both of which pose problems when computer-aided. The "Knowledge Space Theory (KST)" model of the domain "problems" provides some opportunity for response options. The "Competence Based Assessment (COMBA)" model of the required knowledge provides some opportunity for relevant feedback. The paper explores ComKoS, a model which integrates both approaches, identifies key benefits and some disadvantages, and suggests possibilities for future work.
Interactivity in assessment

In broad terms, an “atomic” learning and teaching transaction might be considered to involve three key interactions: presenting information and supporting materials, “show and tell”; asking the student to undertake some appropriate learning activity, “ask”; and providing pertinent feedback on performance, “feedback” (Gilbert, Sim, & Wang, 2005). Where such a transaction explicitly comprises an assessment for learning (formative assessment as distinct from summative assessment of learning) (Whitelock & Cross, 2012), Figure 1 illustrates a more developed model. In particular, this model of an interactive cycle explicitly identifies the need for choices or alternatives to be available to the student, from which one or more selections must be made as a response to the “ask” and which will be judged for correctness and “feedback” provided.

![Figure 1. Cycle of interactivity (Gilbert & Gale, 2007).](image)

Figure 1 identifies a number of the difficulties faced by any computer-aided assessment system intended to support learning, and particularly one which wishes to do so automatically or semi-automatically. Apart from the difficulties of allowing arbitrary student responses, of judging them for correctness or error, and of providing appropriate specific and contingent feedback, explicitly identifying a range of options or alternatives (shaded box in Figure 1) from which a student may make selections remains an unsolved research problem. While the application of Figure 1 to objective or multiple-choice types of assessment items is clear, it may be worth noticing that free response, free text, or essay types of assessment also, albeit implicitly, require the student to selectively respond from a potentially infinite set of possibilities.
Integrating Competence Models with Knowledge Space Theory for Assessment

Knowledge Space Theory (KST)

Knowledge Space Theory provides a framework for domain and learner knowledge representation and supports the implementation of intelligent e-learning solutions. Albert & Lukas (1999) developed KST as a technique for modelling problems or questions which students needed to be able to answer and the solutions which teachers needed to teach. The key insight was to model these problems as a dependency graph or network. In such a network, given a particular problem \( a \), another problem \( b \) depends upon it if the solution to \( a \) is required before \( b \) can be satisfactorily solved. In KST, the dependency relationship is referred to as a prerequisite relationship. A domain of knowledge is represented by a set of typical assessment problems (subsequently denoted by \( Q \)). The knowledge state of an individual is identified with the subset of assessment problems the person is capable of solving. Not all potential knowledge states (i.e. subsets of problems) will be expected to be observable in practice. By associating assessment problems with learning objects, units of learning, or similar, a structure can be established which constitutes a basis for learning paths which are adapted to the learners knowledge state (Steiner & Albert, 2008).

Two problems \( a \) and \( b \) are in a prerequisite relation whenever a correct solution of problem \( a \) is a prerequisite for mastering problem \( b \). Correspondingly, each knowledge state will contain also \( a \) whenever it contains \( b \). Prerequisite relations can be illustrated by a so-called Hasse diagram (see Figure 2 for an example), where ascending sequences of line segments indicate prerequisite relationships. According to the prerequisite relations shown in Figure 2, the correct solution of problem \( b \) is a prerequisite for mastering problem \( d \), while for solving problem \( c \) correct answers to problems \( a \) and \( b \) are prerequisites. A prerequisite relation restricts the number of possible knowledge states and forms a quasi-order on the set of assessment problems. The collection of possible knowledge states of a given domain \( Q \), including the empty set \( \emptyset \) and the whole set \( Q \), is called a knowledge structure. Given a knowledge structure, there is a range of possible learning paths from the novice knowledge state \( \{ \emptyset \} \) to the expert knowledge state of full mastery \( \{ Q \} \). One possible learning path suggests the initial presentation of material related to problem \( a \) (or, equivalently, \( b \)), followed by material related to \( c \), and so on.

In this way, a knowledge structure can provide the basis for creating personalised learning paths. Furthermore, a knowledge structure is at the core of an adaptive assessment procedure (Conlan & Wade, 2004). By exploiting the prerequisite relationships among the problems and presenting problems depending on the learner’s previous answers, the knowledge state of a learner can be determined by presenting him/her with only a subset of the problems. The result of such an assessment can be utilised as a starting point for realising individualised learning.

![Figure 2. Example of a Hasse diagram depicting prerequisite relations (Steiner & Albert, 2008)](image)

KST’s approach to modelling problems makes it relatively easy for teachers and trainers to populate a KST knowledge structure with the content of what needs to be taught and what needs to be assessed. The competences being addressed and assessed remain implicit in such a structure, however, and there is no obvious way of automating the provision of feedback for right or wrong answers to the encoded problems. Such feedback
would typically reference the desired competence which the assessment item tests, yet in a KST structure these competences are not explicit.

### Competency model (COMBA)

The issue of how to represent competency as a rich data structure is focused on supporting collaboration between different communities and the tracking of the knowledge state of the learner. The same competencies may appear in more than one place in the competency hierarchy. Thus, it makes sense to capture the data model of those competencies in some reusable form, so they have to be defined only once. A competency model, named Competence-Based learner knowledge for personalized Assessment (COMBA), was proposed by Sitthisak, Gilbert & Davis (2008). The heart of this model is the treatment of knowledge, not as possession, but as a contextualized multidimensional space of either actual or potential capability. An improved version of the COMBA model is represented in Figure 3.

COMBA is informed by the results of comparing the competency standards against the desired taxonomy of competence (Sitthisak, Gilbert, Davis, & Gobbi, 2007). A competency involves a capability associated with subject matter content and optionally a contextualisation (the situation or scenario, tools, and standard of performance). A competency can be linked to one or more resources, and a student may evidence a competency in one or more ways.

**Figure 3. COMBA competency model**

Capability is behaviour that can be observed, based on a domain taxonomy of learning such as Bloom’s (Bloom & Krathwohl, 1956), Gagné’s Nine Areas of Skill (Gagne, 1970), or Merrill’s Cognitive Domain (Merrill, 1999). Subject matter content is the subject domain of the student’s capability. The competency evidence substantiates the existence, sufficiency, or level of the competency, and might include test results, reports, evaluation, certificates, or licenses. External knowledge resources and tools support and promote the problem solving, activity performance, or situation handling of the competency. The situation identifies the particular circumstances and conditions of the competency, for example, its time limit.

The proposed competency model involves three important principles: an orientation towards, and focus upon, activity-based teaching and learning; the identification and integration of appropriate subject matter content within a broader teaching and learning
context, represented by a hierarchy of linked competencies; and the identification of the assessment that would demonstrate successful teaching and learning has been accomplished. In a COMBA structure, the competences which support and are linked to a given competence are termed enabling competences, while the competence being supported is termed a top-level competence. In its simplest form, a competence structure is a structure of intended learning outcomes (ILOs) or, equivalently, educational objectives, as shown in Figure 3.

When combined with an ontology, COMBA has been used to automate question generation in adaptive assessment systems (Sitthisak, Gilber, & Albert, 2013). The system focuses on the identification and integration of appropriate subject matter content (represented by a content taxonomy) and appropriate cognitive ability (represented by a capability taxonomy) into a hierarchy of competencies. The resulting competencies structure has been shown to be able to generate questions and tests for formative and summative assessment. These questions can be expressed as IMS Question and Test Interoperability (IMS QTI) compatible XML files to enable interoperability.

The system was built on an ontological database that describes the resources (subject matter, capability, competency) and the relationships between them. An assessment for a competency often actually tests component competencies, and is supported by the linked nature of the competencies hierarchy. For example, a statistics course may test knowledge of the confidence interval (Field, 2005) by testing the students’ ability to calculate, explain, and define the confidence interval in a variety of situations. An assessment item can be directly formulated from a competence by using the parameters of that competence: capability, subject matter content, and other contextual elements. For example, the assessment corresponding to the (top-level) learning outcome, “Students understand the concept of a confidence interval” might be something like “Calculate the confidence interval for the following situation”, or “Explain the importance of the confidence interval in the following situation”, or “Define standard error”.

COMBA’s approach to modelling competence makes explicit the competences being addressed and assessed, and there are obvious opportunities to automate the construction of assessment items and the provision of feedback for right or wrong answers. On the other hand, teachers and trainers find it relatively difficult to populate a COMBA competence structure with the intended learning outcomes of what needs to be taught.

**ComKoS: Integrating KST and COMBA**

While assessment items and appropriate feedback can, in principle, be generated from a COMBA competence structure, there are numerous practical problems in doing this. Yet a KST network already comprises the set of required assessment items, which practitioners find straightforward to identify, articulate, and structure. Further, while the assessments in a KST network have no explicit connection to the underlying competences which are being taught and tested, a COMBA structure already comprises the set of required competences. Integrating the KST and COMBA models promises to provide the best of both: a knowledge structure more easily constructed by practitioners, with the required assessments explicitly articulated and their underlying competences explicitly identified and associated. The resulting merged structure might be called a Competence Knowledge Space (ComKoS).

Integrating KST and COMBA models may be expected to provide some further practical advantages derived from the process of merging a KST domain structure with the associated domain COMBA structure. In parsing a KST structure in preparation for its
merge with a corresponding COMBA structure, the practitioner or instructional designer would check that each KST assessment or problem could be associated with a COMBA competence, and that the KST prerequisite assessments or problems were in turn associated with COMBA enabling competences. Similarly, in parsing a COMBA structure in preparation for its merge with the corresponding KST structure, the practitioner or instructional designer would check that each COMBA competence could be associated with one or more KST assessments or problems, and that the COMBA enabling competences were in turn associated with KST prerequisite assessments or problems.

In addition, the problem identified earlier of explicitly identifying a range of options or alternatives from which a student may make selections could be solved by appropriate processing of a ComKoS structure. Distracting or alternative options could be extracted from competence nodes which were neighbours of the target competence, and could be added to the KST problem or assessment statement.

Finally, a ComKoS structure would be expected to give a longer life to a KST structure of assessments and problems when merged with its underlying COMBA structure.

**ComKoS conceptual model**

ComKoS would be a competence structure where each competence node would be associated with a number of assessment or problem items. Conceptually, the data model would be the simple structure of Figure 4.

**ComKoS process**

Constructing a ComKoS structure would involve the merging of a COMBA structure with an associated KST structure. In practice, it is likely that a practitioner or instructional designer would have a list of competences or ILOs which were considered relevant to a particular domain rather than a developed COMBA structure. Similarly, it is likely that the practitioner or instructional designer would have a list of assessment items or problems rather than a developed KST structure. We propose the following process.

1. *Preliminary KST structure.* The assessments or problems are arranged into a linked list or hierarchy, such that assessments or problems earlier in the list or towards
the top of the hierarchy are linked to prerequisite items which are later in the list or lower in the hierarchy. Every KST problem must link to at least one other.

2. Preliminary COMBA structure. The ILOs or statements of competence are arranged into a linked list or hierarchy, such that competences or ILOs earlier in the list or towards the top of the hierarchy are linked to enabling items which are later in the list or lower in the hierarchy. Items which remain unlinked are listed separately. The linkage process in this step may be omitted, and the result of the step would simply be an unstructured list of all the competences or ILOs of the domain.

3. Merge. For each KST problem, associate the relevant competence. Where there is more than one candidate competence, associate the one which is lower or lowest in the COMBA structure. It is expected that a given competence will be associated with more than one KST problem or assessment item. That is, a given competence or ILO could well be assessed in a number of ways or through a number of different assessment items. (a) It is likely that, at first sight, a given problem might be associated with more than one competence. Resolve this either by associating the problem with a competence higher in the preliminary COMBA structure or with a competence listed separately, or construct a new competence whose components (capability, subject matter, context) underlie the problem under consideration. (b) It is possible that a particular KST problem is not, at first sight, associated with any competence. Either construct a new competence as earlier which underlies the problem, or remove the problem from further consideration. At the end of the first pass, every KST problem is associated with a COMBA competence. There may be unassociated COMBA competences.

4. Preliminary ComKoS structure. Identify those competences which have associated problems. Construct a tree structure of these competences, and list unassociated competences separately. For each competence node in the tree, link to their enabling competence(s) which are those associated with the KST problem(s) which are prerequisites to the competence’s associated KST problem.

5. Refine the ComKoS structure. Consider the competences which do not have associated problems. For each, either construct an appropriate problem and iterate steps 3 and 4, or remove the competence from further consideration.

Conclusions

The ambition of the ComKoS model is to provide all the elements of the interactivity cycle of assessment of Figure 1 to underpin any computer-aided assessment system intended to support learning, particularly one which wishes to do so automatically or semi-automatically. In principle, the model holds the promise of being able to provide two key elements currently missing from practical implementations of computer-assisted assessment – identifying plausible options or alternatives in objective assessments, and providing more satisfying feedback to support learning. Plausible options may be obtained by extracting distracting alternatives from neighbouring competence nodes and associated KST problem statements. Better feedback given an answer to a KST problem may be obtained by extracting relevant information from the COMBA competence statement which is associated with the problem.

Future work is planned to implement and evaluate a prototype ComKoS system, using an existing KST service (INNOVRET, 2013) within a Moodle VLE (Moodle 2.3, 2012) and delivering assessments using an IMS QTI-compliant application (Barr, Mckain, & Milne, 2012).
References


Moodle 2.3. (2012), from https://moodle.org


