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Student Model Dialogue

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1 Executive Summary

This report represents the *Student Model Dialogue* deliverable (D32) and describes in detail the improvements that have been made to the dialogue component of the Open Learner Model (OLM) since its original description in D29. In this document, the term "dialogue" in the Open Learner Model should not be understood in the broad sense of open-ended conversation, but rather as the *verbalisation*, in ordinary language, of the interaction between learners and the OLM, including the medium through which such interactions are assisted, such as the *Graphical User Interface*.

The work on the prototype described in this document is the continuation – and conclusion – of two previous deliverables: the *Student Model Specification* (Deliverable D10 [6]) and the *Open Student Model* (Deliverable D29 [5]). For the readers' convenience, this document includes a summary of the current state of the OLM.

The core of this document is a description of two parallel lines of improvements that have been pursued since D29: augmentation of the Graphical User Interface of the OLM to better support interaction between the system and the learner, and the elaboration of the template-based verbalisation of various aspects of this interaction. The former follows the recommendations outlined in Deliverable 38 [7], *Evaluation Student Model*.

2 Introduction

One of the most critical aspects of any adaptive system is how to maintain an accurate model of the users' abilities that represents their preferences, knowledge, aims, skills, gaps and misconceptions. Traditionally, learning systems such as ITS's have kept these models of the learner hidden from the learners themselves, encapsulating such models as "black boxes". But newer versions of these systems have opened up their models to inspection by the learner, using a "glass box" approach, or even literally breaking the glass and actively involving the learner in helping adjust the model.

The Extended Learner Model (and in particular its interactive component the Open Learner Model) is the result of a sustained attempt to provide LeActiveMath with just such an approach. A first version of the prototype has been delivered, and is described in Deliverable D29 [5].

The main thread for this deliverable is the interactivity associated with the OLM, including both the Graphical User Interface that acts as a medium for the interaction between the system and the learner, and natural language facilities intended to further support the exchange of learner modeling data between the system and learners. Deliverable 29 represents a preliminary version of the OLM, and includes (1) a means for representing the learner model itself, (2) displaying data and inferences from the model to the learner, and (3) a graphical and language-based interface for querying and exploring that data.

The recently completed *Evaluation Student Model* deliverable (D38) [7] provides an extensive report on the evaluation of the Extended Learner Model as a whole and, specifically, the Open Learner Model as presented in D29. This evaluation highlighted a number of important issues to address in terms of usage by real students, and has been crucial in guiding this latest stage of implementation of the OLM as described in this document. The current deliverable thus presents improvements to the D29 version of the OLM, specifically concerning its improved graphical interaction and dialogue capability for learners.

2.1 Motivation for Interactions with the OLM

A learner model must build, update and return a portrait of the learner on various interrelated traits based on their prior problem-solving history. The aim of the Open Learner Model (OLM) in particular is to provide the LeActiveMath learning environment with an interface for the learners to access, explore and challenge the evidence-based judgements that the xLM holds about them. The OLM supports several external representations for displaying the various sources of information that the xLM uses to establish its judgement (belief, evidence, etc.) and a mechanism - loosely based on the Toulmin Argumentation Pattern - to control the exploration and negotiation of the beliefs.

One of the most critical aspects of any adaptive system is how to maintain an accurate model of the users' abilities, representing their preferences, knowledge, aims, needs, skills, misconceptions, etc. Traditionally, learning systems like ITS's have kept these models hidden from the users. Opening up such knowledge to the scrutiny of the learner brings two benefits. First, the OLM is itself a source of learning for the students, encouraging them to reflect on their own knowledge: some studies have even shown that learners could gain from assessing their own knowledge [1, 2, 8]. Second, the OLM offers an alternative for inferential diagnosis by encouraging the active and explicit involvement of students (or even peers and teachers) in the diagnosis process and in influencing the system's judgments. This external involvement has the potential for "bypassing the intractable problem of learner modelling" identified by John Self [9].

Deliverable 29 described the initial implementation of the Open Learner Model along these lines, and its subsequent formative evaluation in Deliverable 38 revealed a number of problems with the interface which have now been resolved.

2.2 Overview of the OLM (Deliverable 29)

The initial release of the OLM was described in Deliverable D29 [5]. For completeness, we summarise the most important aspects of the system:

- The OLM is one component of the Extended Learner Model (xLM), the prototype learner modelling sub-system of LeActiveMath. Its aim is to provide learners with an interface to access, explore and challenge the judgements that the xLM holds about them.
- Such judgements are built over time, by taking into account several sources of evidence of a learner's ability over several inter-related layers (see Figure 2.1. These layers are the domain (containing topics covering differential calculus such as *chain rule*, *difference quotient*, etc.), mathematical competencies (such as ability to *model* or *think* mathematically), affective factors (such as *satisfaction* or *pride*), motivational factors (such as *interest* or *confidence*), metacognitive abilities (such as *monitoring* or *control*) and domain-related conceptual and procedural errors.

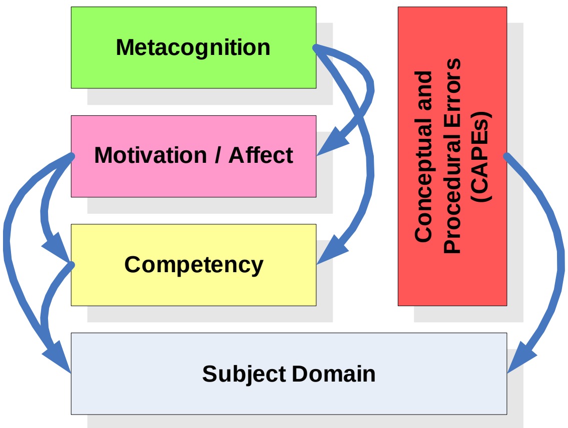


Figure 2.1. The 5 layers of the Learner Model

- The OLM provides learners with a multi-turn dialogue interface for exploring the beliefs about them that the system holds, for requesting justification of the judgement expressed in terms of their abilities, and for challenging such judgements. This multi-turn architecture is based on a restricted set of exchanges between the OLM and a learner called dialogue moves (see Figure 2.2), specifying the possible requests the learner can express and the response provided by the OLM: "**Show Me** what you think of me", "**Here Is** what I think of you", "**Explain** [1] your reasons for your judgement", "I **Disagree** with your judgement", "Let's **Move On** to a different topic", etc. The text for these buttons in the interface are similar to the "sentence openers" commonly employed in ITSs lacking dialogue capability and in collaborative learning environments [10].
- The OLM provides learners with several external representations for accessing the different types of information delivered by the system and used in establishing a judgement about their

[1]The **Explain** dialogue move corresponds to the **Baffled** move of the taxonomy presented in D29. It has been renamed because of the ambiguous and potentially pejorative nature of the latter.

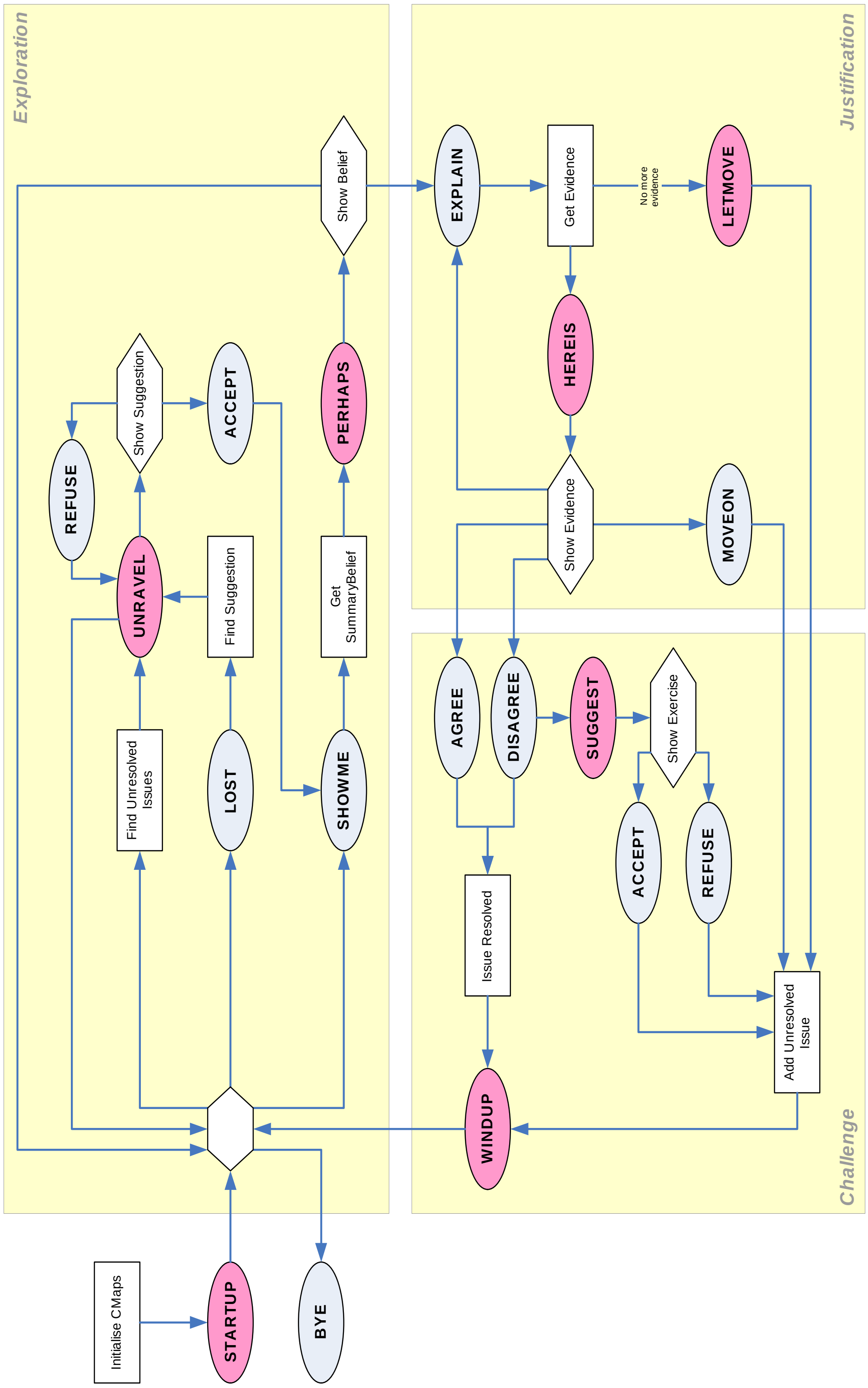


Figure 2.2. Overview of the organisation of the Dialogue Moves in the OLM

abilities: summary belief (Fig. 3.3a), mass distribution and pignistic functions representing the complete structure of the belief (Fig. 3.4a), a quantitative and qualitative description of the evidence supporting the belief (Fig. 3.6a), etc. A simple natural language component also complements the dialogue-based interface, by providing verbalisations for the dialogue moves and major interaction acts.

- Finally, the interactions between learners and the OLM are captured and analysed as evidence of their metacognitive ability (in terms of *monitoring* and *control* of their activities), providing the Extended Learner Model in turn with an alternative source of diagnosis for this particular layer of the learner model.

The beliefs of the xLM about a learner are represented via a probabilistic distribution over the different levels of that learner's abilities. The data assigning belief in the learner's level initially comes from the PISA framework and later from the learner's performance in solving problems and the metadata associated with those problems. There are four levels used in the OLM ranging from low to high ability: Level I, Level II, Level III and Level IV. These terms can together be seen as a generic placeholder for the Learner Model diagnosis which, in the OLM, will be replaced with proper terminology derived from the phrasebooks.

Toulmin Argumentation Pattern As a basis for organizing its internal representations, presenting visualizations of those representations to the learner, and allowing the learner to interact with the representations, the Toulmin Argumentation Pattern (TAP) [23] was chosen. Proposed by Stephen Toulmin, it lays out a theory and model of argumentation that represents a more abstract and informal approach to dealing with arguments than does formal logic. it is much closer to the typical reasoning used in daily life. Its terminology includes "Data", the fundamental facts and information that are the initial reason for a claim; a "Claim" which is a position on an issue, the purpose behind the argument, or the conclusion that the arguer is advocating; a "Warrant" that is the component of the argument that establishes the logical connection between the data and the claim (*i.e.* the reasoning process used to arrive at the claim); a "Rebuttal", which is any exception to the claim presented by the arguer; and "Backing", any material that supports the warrant or the rebuttal in the argument.

2.3 Results of the Formative Evaluation (D38)

The formative evaluation (D38) of the xLM (including the OLM) conducted at Edinburgh and involving actual students presented a wide array of problems and suggestions for improving them by both the learners themselves and the researchers who observed them. Appendix B presents the full set of suggestions, although those specifically related to the OLM are summarised here for convenience:

- Open Learner Model itself: Students were not told that the OLM existed, what it was for, or how to invoke it. The OLM also uses different conceptual terminology than the main LeActiveMath interface.
- Descriptor View (where learners select topics to examine further): Mouse actions, such as double clicking to expand the topic map below were unintuitive, the dependencies between descriptor items were unclear, there was a lack of understanding of what descriptors are and how to read their representations, and students felt they were given an overwhelming number of descriptors.
- Claim View (where learners explore what the OLM thinks about their abilities): As above, learners found the interface initially overwhelming and requested the addition of help files.

They didn't realize what information was accessible, although some tried double clicking on the claim map (which they couldn't get to work). Some of the graphs presenting the summaries were not understood by the learners, and the use of the dialogue buttons and language required significant improvement.

- Challenges (where learners can change the OLM's beliefs about them): After they were instructed about the purpose of challenges, learners were surprised to discover that there was no resistance or negotiation involved, and the mechanism itself seemed confusing.
- Topic Map: Issues regarding the topic map mainly of interface-oriented problems (mouse clicks, help files and the like). The topic map was described by the learners as being the preferred part of the OLM.

We believe that the use of the Toulmin Argumentation Pattern in the OLM has been a success since learners in the formative evaluation reported in D38 mentioned almost exclusively their problems with the interface rather than confusion with the underlying model itself.

3 Improving Multimodal Interaction with the Open Learner Model

The latest stage in the design of the Open Learner Model, guided mostly by the comments obtained during the formative evaluation of the OLM (D38, outlined in annex B), has been organised around three lines of improvement:

1. Improving the underlying model of the data for the Toulmin Argumentation Pattern, mainly by reorganising the justification of a judgement made by the OLM;
2. Improving the overall Graphical User Interface of the OLM;
3. Improving the verbalisation that supports the interaction between the learner and the OLM.

These three points will be discussed and illustrated below in turn. The objective of this section is not to give a complete list of all the improvements implemented in the latest release of the OLM [1] but to offer an insight into what has been achieved overall as well as the motivation behind the most significant changes.

3.1 Toulmin Argumentation Pattern

As described in Deliverable D29 [5], the Toulmin Argumentation Pattern is the framework used in the OLM to support and carry out the justification of a judgement by the system and, ultimately, the challenge of some of its aspects by the learner. The basic idea behind its application in the OLM is to represent the Toulmin Argumentation Pattern as a graph, whose nodes can be expanded in sequence (to the extent desired by the learner) in order to represent a progression in the justification of the judgment. Each of the nodes in the graph (Figure 3.1) is also associated with a particular viewpoint of the information supporting the judgement:

- The `Claim` node is associated with the summary belief, i.e., a short, straightforward judgement about the learner's ability on a given topic, e.g. the "Claim: Level II" node in Figure 3.1;
- The `Data` node is associated with the belief itself, represented either by its pignistic function (i.e., the simplest internal encoding), its certainty distribution or its mass functions (the most complex internal encoding), for instance the node marked "Data" in the figure;
- `Warrant` nodes are associated with the evidence supporting the belief, represented by their mass distribution. There is one warrant for every piece of evidence used by the Learner Model to build its current belief;
- `Backing` nodes are associated with the attributes, both qualitative and quantitative, used by the Learner Model for building the numerical interpretation of the evidence. `Warrant` and `Backing` nodes are now combined into the "Evidence" nodes in Figure 3.1 as described in Section 3.1.1.

[1] It would have been a difficult task in any case, as the design work described in this deliverable was based on a lot of small but vital fixes and upgrades.

The use of the Toulmin Argumentation Pattern seemed acceptable to learners during the D38 evaluation, albeit with some initial confusion on the exact procedure for further expansion of the graph. Thus, we decided to retain it as the core of the dialogue between the system and the learner, both as an interface for controlling the interaction and as a tool for supporting the verbalisation of the interaction (see Section 3.3 below).

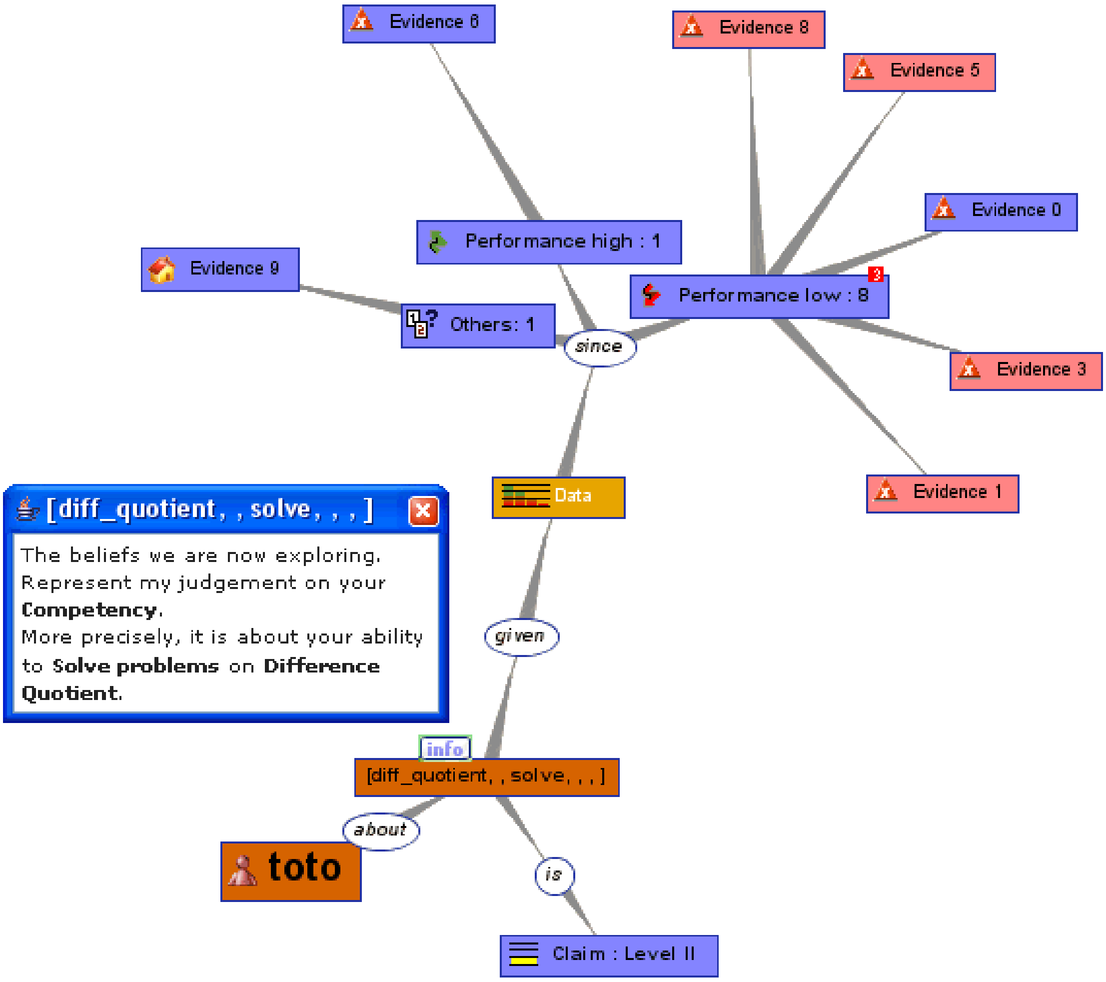


Figure 3.1. An expanded view of the Toulmin Argumentation Pattern, supporting the justification of a judgement from its claim to its individual pieces of evidence. Rather than verbalisation, tooltips are used here to explain belief descriptors. Here the student has placed the mouse over the belief descriptor node [diff_q,,solve,,,] which has brought up the popup window seen on the left hand side. Evidence nodes combine the previous `Warrant` and `Backing` nodes, and are shown here partitioned according to performance.

Nevertheless, some changes have been made in the way the Toulmin Argumentation Pattern is applied in the current release of the OLM (see Figure 3.1). These changes were designed to alleviate student confusion and avoid unnecessary effort (e.g. `Warrant` nodes were only used to connect the `Backing` node to the claim node).

3.1.1 Reorganisation of the nodes

The `Claim` and `Data` nodes are now both connected to the central `Belief Descriptor` node, which is chosen by the learner from the list in the Descriptor View in Figure 3.2(b). (The belief descriptor is shown as the root node in Figure 3.1: [diff_quotient,,solve,,,].) This is a small deviation from their standard "structural" dependency in the Toulmin Argumentation Pattern (the `Data` being a refinement of the `Claim`) but it makes the layout of the graph more visually balanced and compact [2] which should improve learner interaction.

The `Warrant` and its associated `Backing` nodes have been merged into a single node, referred to as the `Evidence` node. This decision was taken in order to alleviate the difficulty learners had with the `Warrant` and its mass distribution: seen in isolation, it was a difficult – almost impossible – task to get a sense of the importance and meaning of this part of the justification. Moreover, learners saw the `Warrant` node as an obstacle for accessing more important information; the `Backing` node, which is associated with the "physical" aspect of the evidence, was deemed more helpful. But in order to explore the `Backing` node in the previous version of the OLM, learners had to go through several other nodes which had no function in the interface. Merging the nodes allows quicker access without losing information, since the Backing also contains the mass distribution associated with the event it represents.

3.1.2 Partitioning the Evidence

Once the student has completed a large number of maths problems in a particular area, the learner model then has a correspondingly large number of pieces of evidence to present to the user. In the graphical visualisation, these nodes clutter up the visible area, making it difficult for the learner to understand what are the commonalities between the individual pieces of data.

Thus in order to break down the number of individual pieces of evidence into separate meaningful sets, a partition mechanism has been incorporated into the OLM. This mechanism allows the separation of evidence into different spaces, depending on criteria that could be changed dynamically by the learner, such as problem type, level of difficulty, or actual outcome (for more on this issue see Section 4.2). This partition is represented in the Toulmin Argumentation Pattern by introducing new nodes representing sets of individual nodes, where each node can be represented inside one and only one partition node.

Figure 3.1 is a snapshot of such a Toulmin graph using partitions to separate evidence. The criteria used in this example is the `performance` of the learners (as diagnosed from their behaviour in running exercises in LeActiveMath) and is arbitrarily divided in two categories: `low` and `high`. The corresponding nodes can be seen in Figure 3.1, with information about the number of pieces of evidence they include (`Performance low: 8` and `Performance high: 1`). Organised into each of these partition nodes are all the relevant pieces of evidence: `Evidence 6` supporting high performance and `Evidence 0`, `Evidence 1`, `Evidence 3`, etc. supporting low performance.

Because of the heterogeneous nature of the sources of evidence used in LeActiveMath, it may often be the case that individual pieces of evidence do not fit into any of the partitions. We have thus added an extra partition node as a default, universally labelled as `Others`, for clustering all remaining data that are not based directly on performance (in this case, evidence reporting an agreement with the OLM judgement).

Allowing such partitions fulfills two purposes: a better organisation of the `Evidence` nodes (broken down into separate groups rather than in a single mass) benefitting the learner in terms of interactivity, and an extra layer for the verbalisation of the justification (see Section 3.3 below).

3.1.3 Expansion and Collapse of Nodes

Finally, by using the existing graphical capabilities of the Java-based graph library software used to render the Toulmin Argumentation Pattern in the OLM, nodes can be hidden or shown, expanded

[2] Attempts were made to keep the OLM interface as small as possible, given its deployment as an applet. Keeping the Toulmin graph as compact as possible in order to fit in the limited space has not been totally successful, as can be seen in Figure 3.6(b).

and collapsed both by direct manipulation and programmatically. The OLM uses this mechanism to expand, step-by-step, the justification of its judgement but also for indicating important nodes in the graph. This is the case in particular with evidence. The learner modelling system allows a potentially huge number of individual pieces of evidence to be used to establish a judgement but, because of decay [3], not all of them have the same impact on the resulting belief. Showing and hiding important nodes is therefore highly useful to ensure easy access to the relevant information for the learner. For example, in Figure 3.1, the node `Performance low` is associated with 8 pieces of evidence (as its label makes clear) but only five of them were presented to the learner as the most important ones.

The same facility is provided to the learners who, in turn, could expand or collapse part of the graph they want (or don't want) to focus on.

3.2 Graphical User Interface

In the following sections, the various improvements to the Graphical User Interface (GUI) are illustrated by showing snapshots of the OLM both as it was at the time of Deliverable D29 and as it now stands in the current release. Three major issues have been addressed: the dialogue moves, the interface for building belief descriptors, and the various external representations used in the OLM.

3.2.1 Relocation and Extension of the Dialogue Moves

The main issue in improving the dialogue with the OLM, i.e., the interaction between the learner and the system, has been to reorganise the various dialogue moves used to control such interactions, both conceptually and graphically.

Figure 2.2 represents the organisation of the dialogue moves in the OLM, as it was initially described in Deliverable D29. This framework proved to be quite effective in controlling the dialogue with the OLM but some problems became obvious during user testing and the D38 evaluation.

The initial design for the dialogue move interface was to have all the associated widgets located in the same place in the OLM (near the verbalisation output view, as in Figure 3.2(a)). These widgets were always "on", or able to be pressed, even if they were not valid dialogue moves in the current context of the dialogue. One option was to use the context of the dialogue to enable or disable appropriate widgets, effectively restricting the range of possible dialogue moves that the learner could enact, but this was nevertheless a design decision that could lead to confusion for the learner. First, it was not always clear which option the learner should choose next and what would be the purpose of such actions; second, the location of the action's trigger was a significant distance away from the action's target.

In order to alleviate this problem, a major overhaul of the interface was undertaken, including relocating all the widgets for dialogue moves nearer their targets (see the difference between the previous and the current release of the OLM in the "before" (top) and "after" (bottom) screenshots in Figures 3.2, 3.3, 3.4 and 3.6). For instance, in Figure 3.2(a), the dialogue widgets have been moved above the dialogue window.

Another aspect of the refactoring of the dialogue moves was to disambiguate the semantics of some of the nodes, most notably the former **Baffled** move, which has now been split into several distinct nodes. The original purpose of this node was for the learner to request more information

[3] The decay of evidence is the result of its decreasing reliability over time; see Deliverable D30 [4] for discussion on this issue.

about the judgement expressed by the OLM. By doing so, it was conflating a number of different situations (e.g., explanation about the judgement, about the summary belief, about individual pieces of evidence, about their combination into the belief, etc.). From a pure GUI viewpoint, this was not a real problem, as the use of the Toulmin Argumentation Pattern for controlling the dialogue – and therefore contextualising it – did clearly identify the assumed learners' action and expected system response.

But when the verbalisation of the dialogue moves was improved in the current scheme, it proved to be an obstacle to providing the learner with a clear and specific explanation for each type. As a consequence, the old dialogue move was split into three distinct new ones: **Explain** for dealing specifically with a request for justification of the judgement (i.e., running through the Toulmin Argumentation Pattern), **Tell Me More** for requesting detailed information about a specific external representation, and **Swap** to request an alternative view of a specific external representation [4].

3.2.2 Belief Descriptors: Hiding and Filtering

The question of navigation in the learner model is still an open issue (see Section 4.1 for a discussion); in the meantime we decided to keep the current interface, but modified it to be based on an explicit construction of a belief descriptor. Some improvements were suggested by the evaluation of the OLM in D38 and implemented accordingly (Figure 3.2(b)).

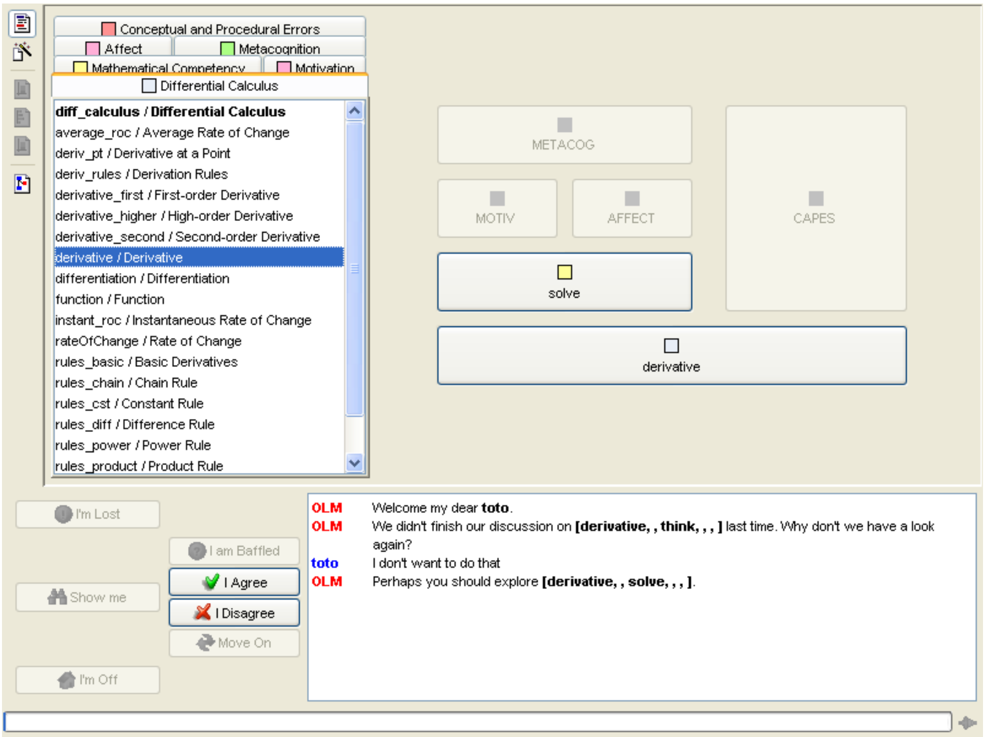
First, the various upper layers of the learner model (i.e., competency, affect, motivation, metacognition and misconceptions [5]) are now configurable at run-time and can be displayed or not on demand. The layout of the *descriptor builder*, sketched on the right-hand side of the interface (see Figure 3.2), is adapted dynamically to reflect the available layers, as are the panes containing the *topic lists* for each layer on the left-hand side.

Second, the original interface previously provided learners with a *descriptor list*, representing existing beliefs held by the system. This separate list, located among the topic lists on the upper left of the interface, was a source of confusion for the students who evaluated the OLM because of the low readability of the descriptors and the difference between the descriptors and the elements of the other topic list members (Metacognition, Motivation, etc.). In the current release of the OLM, the descriptor list is now a master list, but whose individual elements are dynamically filtered via the topics selected elsewhere. For example, when starting from an empty descriptor, the master list contains an exhaustive set of all beliefs stored by the system. But as soon as the learner selects one topic from a list and moves it into the descriptor builder (the boxes in the top right of Figure 3.2), the descriptor list becomes dynamically restricted to the descriptors that can subsequently take part in this topic. Step-by-step, the learner builds up the descriptor while still having an idea of all the possible beliefs available for investigation given the constraints of the elements selected so far for the descriptor.

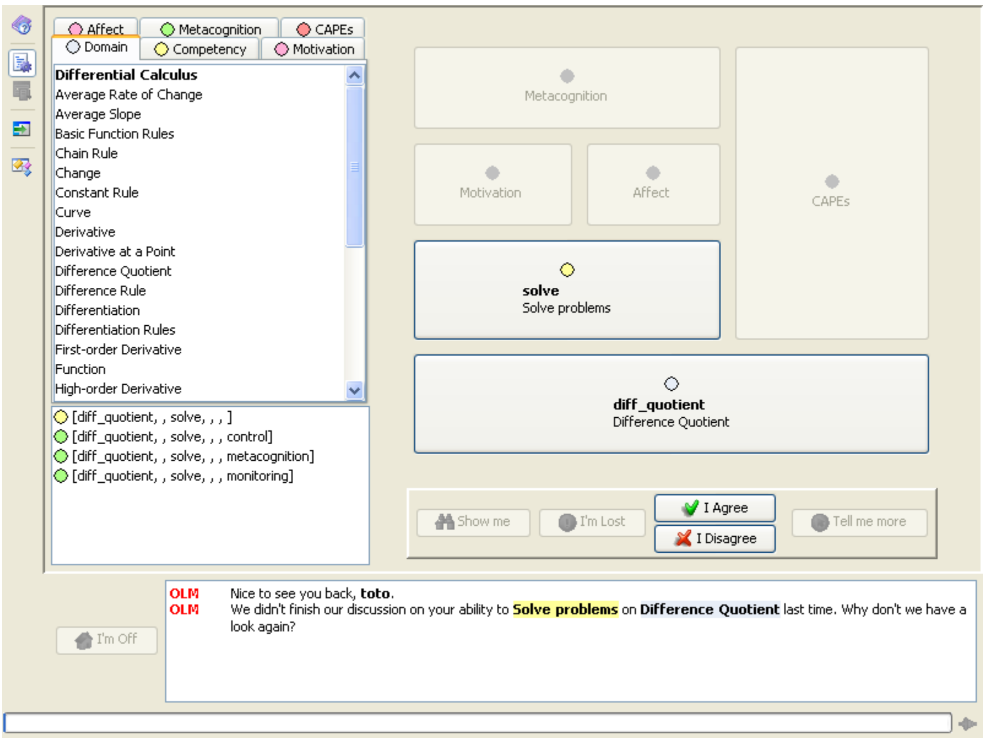
The confusing nature of the belief descriptor as described in D38 has been improved in several ways. A natural language verbalisation of the descriptor is now fully supported and integrated in OLM dialogues (see Section 3.3 below). This verbalisation is immediately available both in the field of the descriptor builder and with the use of the **Tell Me More** dialogue move, located just below the descriptor. At any stage of the construction of a descriptor, the learner is thus introduced to the nature of the belief under construction. An example of the improvement in natural language in the new version can be seen in the difference between the two dialogue windows at the bottom of Figure 3.2(a) and Figure 3.2(b).

[4] These last two dialogue moves are not visible in Figure 2.2, as all three occur in the same position but in different contexts.

[5] The domain layer, being a mandatory component of all belief, cannot be disabled.



(a) The OLM selection interface as described in Deliverable D29



(b) The current release of the OLM interface, with filtered descriptors, shortcuts, relocated widgets, annotations on the boxes, and improved dialogue.

Figure 3.2. The Descriptor View.

3.2.3 External Representations

Auxiliary data in the OLM that helps explain reasons for beliefs are called *external representations* and are presented as graphs in the upper right corner. The most important changes in the different external representations available in the new version of the OLM include:

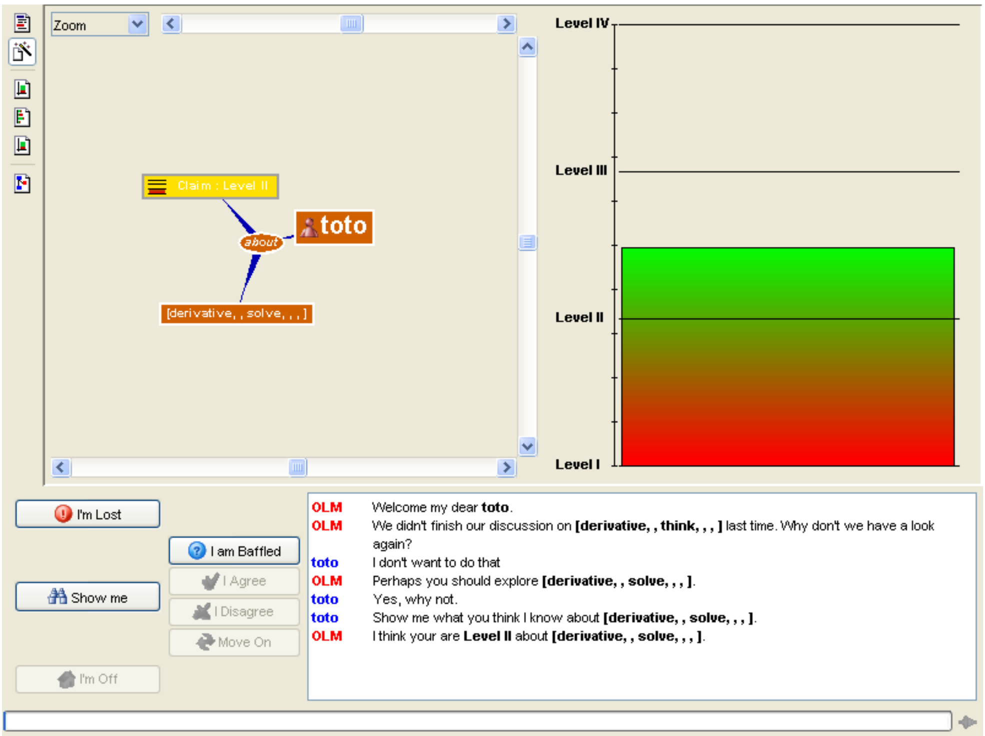
- The summary belief (see Figure 3.3), associated with the `Claim` node of the Toulmin Argumentation Pattern, has been graphically simplified: the ambiguous colour gradient was replaced by a uniform fill with a colour corresponding to one of the four levels, namely `Level I` (red), `Level II` (orange), `Level III` (yellow) and `Level IV` (green).
- The external representations associated with the `Data` node (see Figure 3.4) have been restricted to the pignistic and the (belief) mass distribution; the certainty view, deemed too complex and without significant benefit for helping learners understand judgements, has been removed altogether. Tooltips covering each individual mass in the distributions as well as percentage scales are also now provided in order to ease students' interpretation of the information (Section 3.3).
- To support the introduction of the partitioning of evidence in the Toulmin Argumentation Pattern, a new dedicated graphic has been introduced (Figure 3.5). It consists of a pie chart representing the respective strength of the different sets that the evidence has been separated into (in this figure, the data items are partitioned according to `performance`, dividing the evidence space between `high`, `low` and `others`. (See Section 3.1.2 above.) The strength of each space is computed based on the number of individual pieces of evidence in each as well as on their relative impact factor [6].
- The graph representation associated with the `Evidence` node (Figure 3.6) has been restructured to reflect the fact that it represents the `Backing` and `Warrant` nodes merged together (Section 3.1.1). The upper part of the view (representing the `Warrant`) displays the mass distribution associated with the corresponding piece of evidence. For the `Data` node, the certainty external representation has been removed from the view so that evidence is now solely represented by its mass distribution [7]. The lower part (representing the `Backing`) contains the most important attributes that characterise the interaction associated with this piece of evidence. These attributes are rendered in a table-like fashion, each of them having their own verbalisation in natural language, as well as dedicated widget-based renderers (such as meters, icon-based placeholders, tooltips, etc.) for their externalisation in the GUI.

3.3 Verbalisation

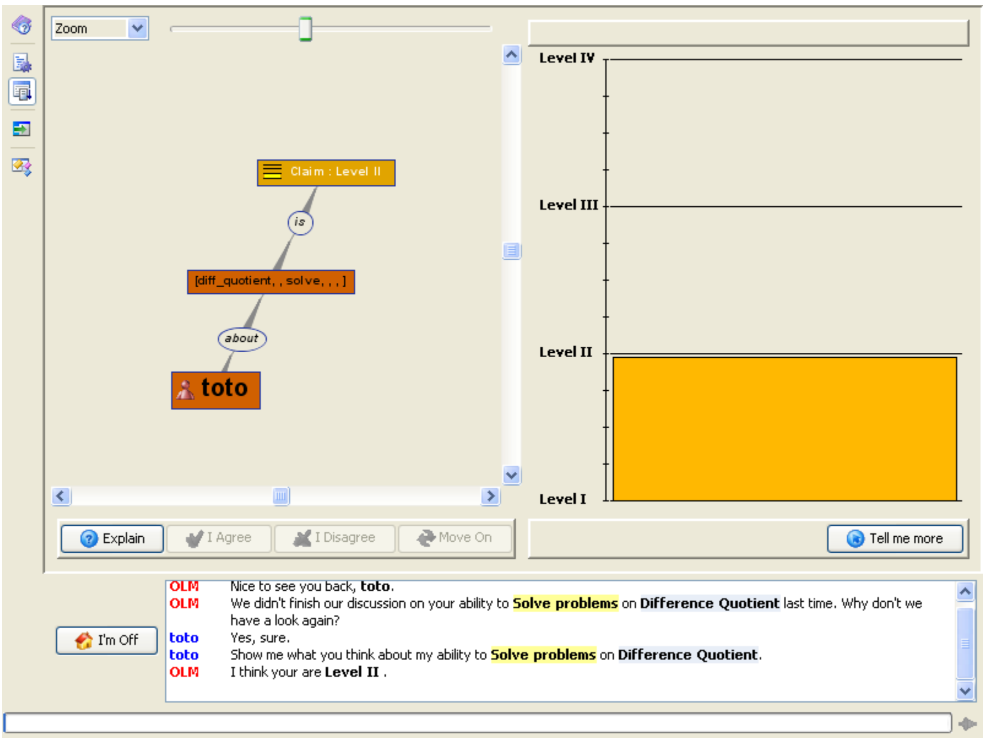
The verbalisation of the interaction between the learner and the OLM has always been considered an important part of the OLM: not as a replacement for the more GUI-based approach utilising direct manipulation, but rather as integral support for GUI actions. In implementing the NL interaction with the OLM, we tried to strike a balance between two conflicting needs: (1) supporting an interactive dialogue that is as close as possible to natural language (in order to avoid a mechanistic look-and-feel), and (2) enabling rapid internationalisation of the system. Maximizing the

[6] The impact factor is a measure of the importance of a given piece of evidence for the current belief on a particular topic. It is calculated by comparing the distance (in terms of mass distribution) between the current belief with that given piece of evidence and the belief without it. The higher the distance is, the more different the mass distributions are and therefore the more important this given piece of evidence is in formulating the current belief.

[7] A **Swap** dialogue move nevertheless allows the learner to switch between the original mass distribution (i.e., representing the internal interpretation of the physical event) and the mass distribution currently considered in the current belief (i.e., reflecting the time-based decay that applies to past evidence).

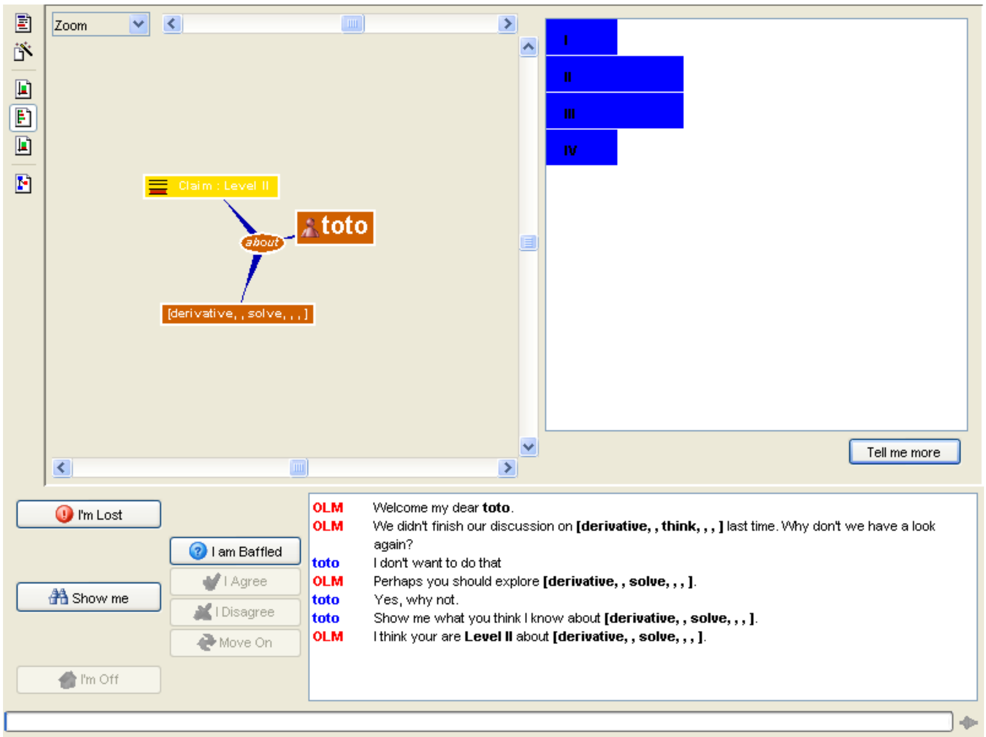


(a) The OLM evidence interface as described in Deliverable D29

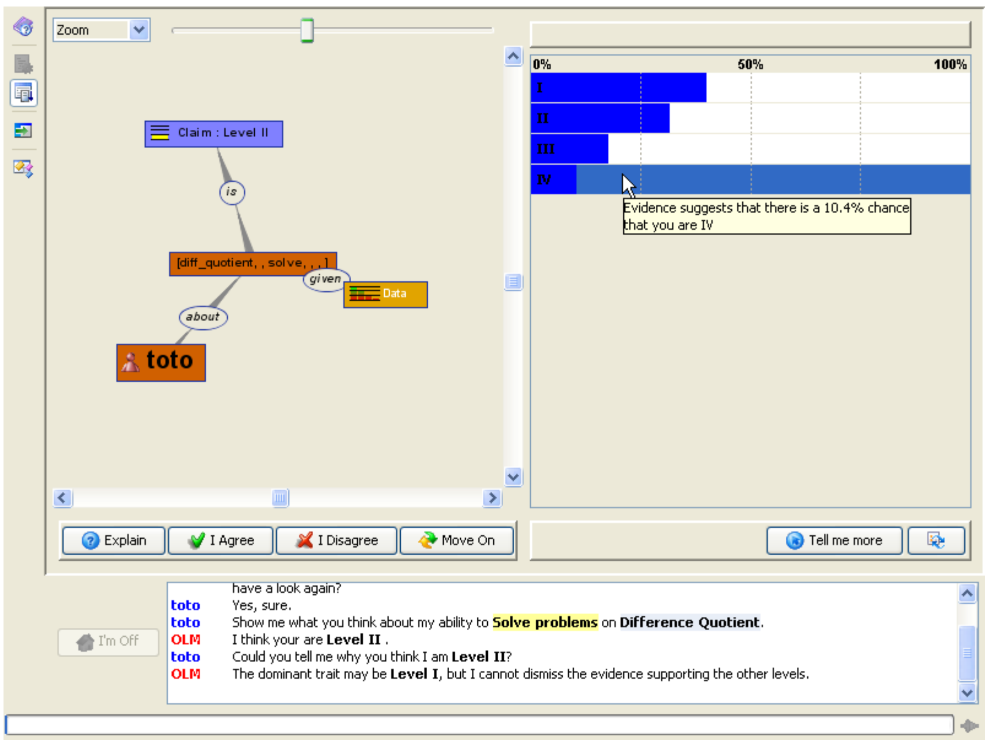


(b) The current release of the OLM interface, with updated topic map, gradient, verbalisation and dialogue widgets.

Figure 3.3. The Claim View.



(a) as described in Deliverable D29



(b) in the current release of the OLM

Figure 3.4. The Data View with the new pignistic distribution graph and tooltips describing the significance of each bar.

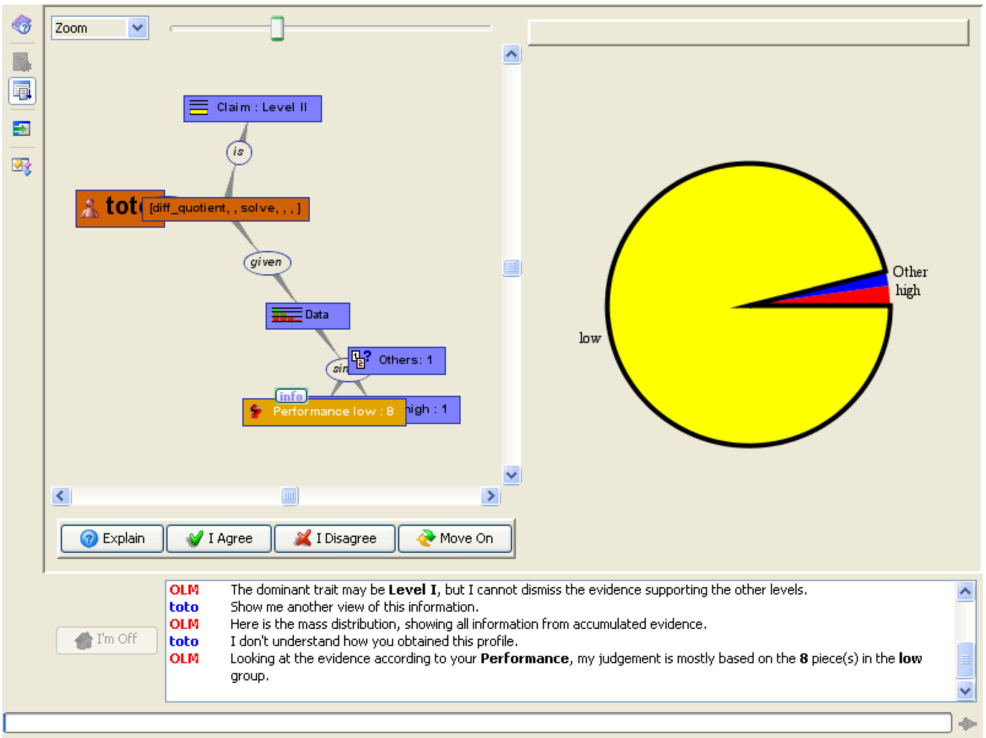


Figure 3.5. The new Partition View.

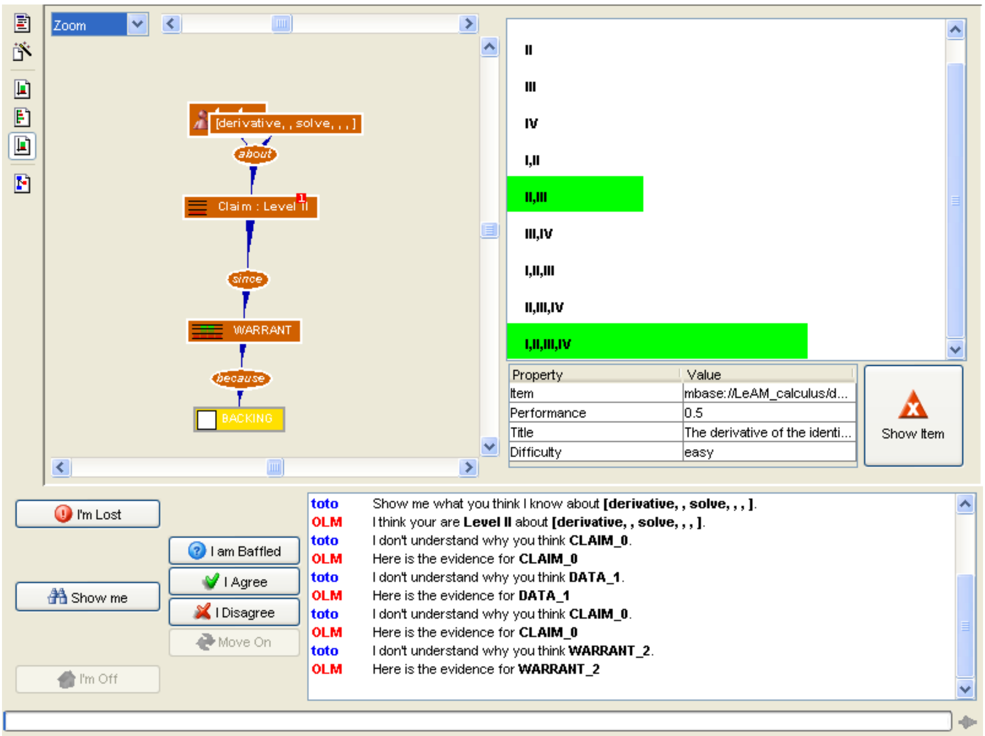
former requires representations of linguistic knowledge that entail extensive resources and effort, whereas internationalisation implies multiplying out that effort for a number of languages.

The solution we chose makes use of: (1) a widget-based interface for the learners' input (where widgets are associated with dialogue moves), and (2) a template-based generation mechanism for the textual output produced by the system. This approach allows for the delivery of natural language interaction with the OLM in multiple languages within the timeframe of the project. More importantly, it is sufficient to support the type of interactions we wished to explore.

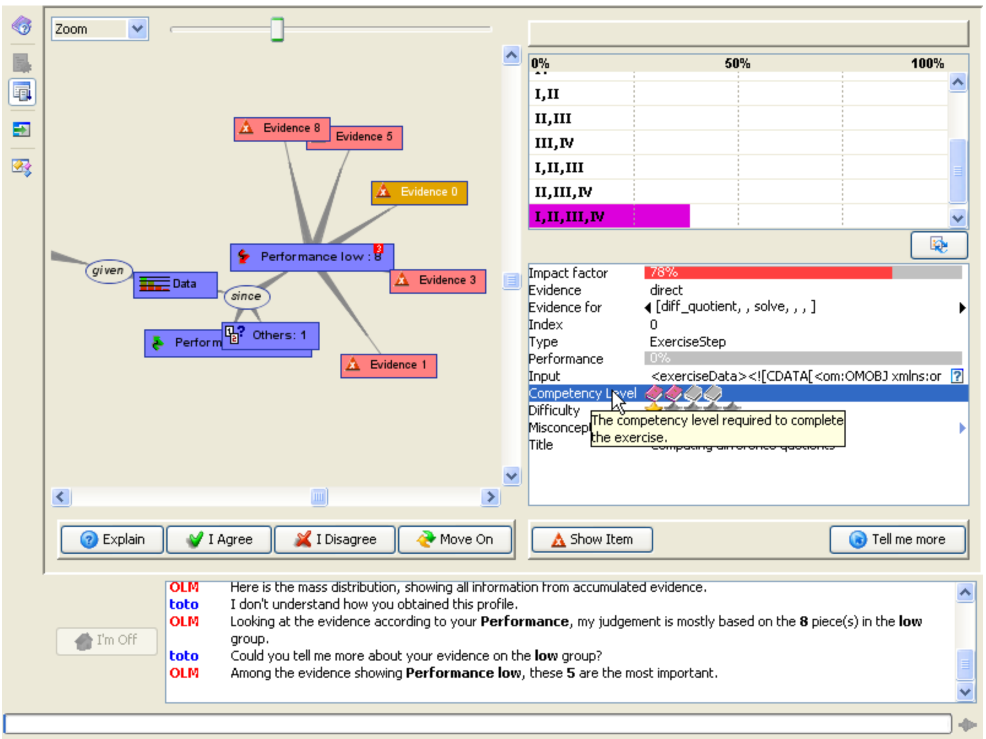
Templates are a method of language production where sentences are broken down into separate strings of text which can then be recombined in multiple ways depending on the current context. For instance, if a learner questions the OLM about why it thinks she is ranked a certain way, the following template can be retrieved: "Because you did this {0} exercise with {1} performance." The template string contains two variables, {0} and {1} which can be filled in with other strings, such as "easy"/"low", and the resulting string can be sent to the dialogue window as the system's output. In Appendix B, listings 2–4 show examples of such template strings with "holes", while listing 1 shows examples of "fillers" for those holes. The main task of the template generator is to map the learner's GUI action (clicking on a widget) and the current context to the appropriate template strings and fillers[8].

Implementing the mapping from the internal representations to the template-based generation mechanism for the verbalisation in the OLM can be challenging. One significant problem when selecting the correct verbalisation for, say, a sentence evaluating a learner's performance, is the nature of the underlying learner model and the complexity of both the information manipulated (mainly probabilistic distributions) and the processes it involves (inferences via Dempster-Shafer

[8] In the OLM, both templates and fillers are implemented using a Java resource file. This allows the system to be internationalised by merely swapping out an English version of the resource file for another version, without the need to even recompile the system.



(a) as described in Deliverable D29



(b) in the current release of the OLM

Figure 3.6. The Evidence View, showing the improved topic map and added information about each evidence node, plus its improved integration with the rest of LeActiveMath.

Theory in the xLM). To illustrate the complexity of one such task, consider the justification of a `Claim` (summary belief) by highlighting the properties reflected in the pignistic distribution of the `Data`. To support such an explanation, three elements must be considered before verbalisation can take place:

- the summary belief (the chart at the top right of Figure 3.3), by looking at the value of the summary on a continuous scale and taking into account its proximity to the discrete thresholds (`Level I`, `Level II`, etc.), where proximity can be considered an indication of the strength of a belief (thresholds basically act as attractors);
- the pignistic (the chart at the top right of Figure 3.4), which summarises the belief by a normalised distribution of the accumulated information over the four named levels and whose relative (i.e., which level is more probable?) and absolute (i.e., how marginal is that probability?) scores are necessary for the decision-making process;
- the decision-making process itself, which extracts the summary belief from the pignistic and, in the current implementation of the learner model, is roughly based on the centre of gravity of the pignistic.

In this case, mapping rules were written that use these values to select an appropriate template string and fillers, and to coordinate the resulting sentence with the external representation to present the relevant evidence both linguistically and graphically. In the following sections we present in more detail the aspects involved in verbalisation, where examples involve a hypothetical learner named "Toto".

3.3.1 A Divide-and-Conquer Approach

The approach in the current release of the OLM is roughly-speaking "divide-and-conquer" in terms of the tasks in the GUI that must support language: instead of trying to combine the verbalisation of every element in a single framework, they are explicitly kept apart in a different – but complementary – framework. In practice, this means that different types of verbalisations for different purposes are deployed through different media in the OLM: verbalisation of dialogue moves appear in the dialogue window, context-dependent tooltips and hints appear at the position of the mouse on the screen, and the OLM Help File can be displayed via a menu command.

Dialogue Moves Each dialogue move put forward by either the learner or the OLM is associated with one or more templates used to verbalise the current actions. These templates are context-dependent: not only is the nature of the dialogue move taken into account (e.g., **Explain**) but also the particular situation in which the move occurs (e.g., **Explain** the `Data` node). This is where the clear separation between dialogue moves for the justification of a judgement (i.e., **Show Me**, **Explain**, **I Agree**, etc.) and for the explanation of particular external representations (i.e., **Tell Me More** and **Swap**) are particularly useful.

The purpose of the first set of dialogue moves is to explore the Toulmin Argumentation Pattern underlying the justification of the judgement. Each move made by the learner is a step further down the chain of arguments; the verbalisation associated with these moves is therefore more centred toward justifying the expansion of the argument. Under this strategy, the verbalisation template relates both issues by emphasising the process involved in the link-up, as in the following exchange:

Toto	Could you tell me more about your evidence on the **low** group?
OLM	Among the evidence showing **low Performance**, these **5** pieces are the most important.

On the other hand, a second set of dialogue moves provides more specific explanations for particular aspects of the information presented to the learner, whether it is (1) the externalisation of a mass distribution:

Toto	I don't understand what this means.
OLM	Since evidence tends to become less certain over time, you can see how the ignorance is increasing, whereas the other masses are decreasing.

or (2) the externalisation of a belief descriptor:

Toto	Could you remind me what this is about?
OLM	You are telling me which ability to judge. Currently, you are looking at your ability to **Think mathematically** on **Difference Quotient**.

Tooltips and Hints In addition to the dialogue moves that provide explanations for particular external representations, most of templates can also be used to provide the learner with tooltips that describe specific items or components. For example, every individual mass in the distributions has specific tooltips, providing contextualised support for this information (see Figure 3.4(b) for the pignisitic distribution); each attribute on the right hand side of Figure 3.6(b) is also associated with a specific tooltip providing a short description of the meaning of the attribute or its values. Tooltips and a help file were requested in order to significantly ease the burden of the evaluation team in their upcoming task, as learners in the formative evaluation had large numbers of repeated questions about elements of the GUI.

Help File Finally, the OLM is also deployed with its own help file, designed and embedded into the general help system of LeActiveMath, see Figure 3.7.

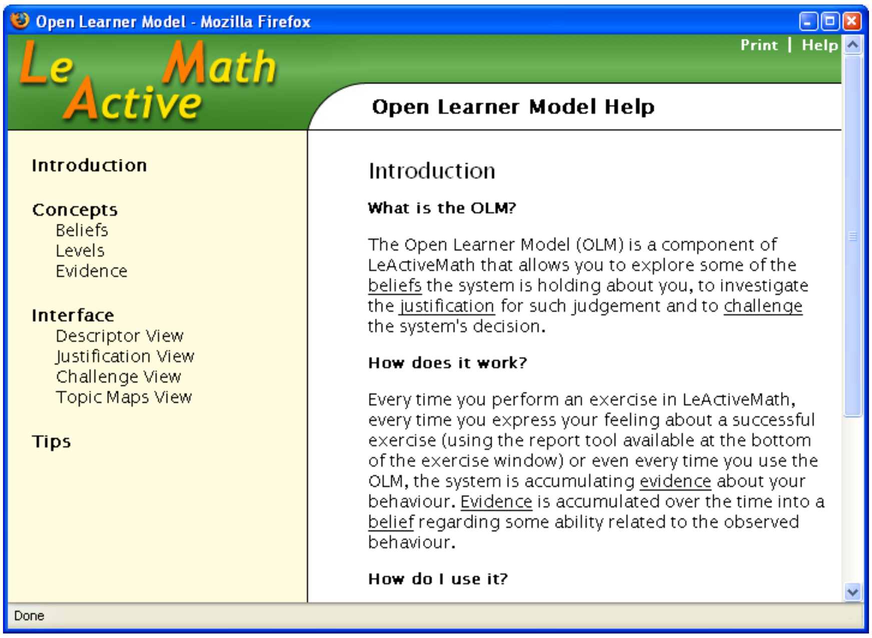


Figure 3.7. The dynamically produced Help File associated with the OLM.

We have grouped the issue of OLM Help with verbalisation because the help files are not static documents, but rather dynamically generated HTML documents using facilities provided by the Maverick-Velocity framework [9], which allows the introduction of variables and placeholders

[9] For Maverick, see http://mav.sourceforge.net/; for Velocity, see http://jakarta.apache.org/velocity/

instantiated at runtime. This means that OLM Help can be tailored to the current learner, using elements coming from their current usage of the OLM (e.g., illustration of key concepts by data extracted from the learner model, explanation of external representations using the actual values from the belief they are exploring, etc.).

3.3.2 Verbilisation of References to OLM elements

For this verbalisation mechanism to work properly, four important aspects of the vocabulary used in the OLM had to be concretely defined: the *belief descriptor*, used to uniquely identify beliefs, the reference to the *ability levels* over which beliefs are expressed, the *topic maps* used to specify the different abilities judged by the OLM, and finally the *events* and their *attributes* used as a source of evidence for a learner's behaviour.

Belief Descriptors Each aspect of the learner model describing one ability of a learner is an interpretation of – or a belief about – the behaviour of the learner along some dimension. This belief is uniquely identified by its *belief descriptor*, internally represented by the 6-tuplet:

`[domain,capes,competency,motivation,affect,metacognition]`

Belief Descriptor Pattern	Verbalisation
capes	
`[domain,capes,,,,]`	the misconception {1} on {0}
competency	
`[domain,,competency,,,]`	your ability to {2} on {0}
motivation	
`[domain,,,motivation,,]`	your {3} on {0}
`[domain,,competency,motivation,,]`	your {3} on your ability to {2} on {0}
affect	
`[domain,,,,affect,]`	your {4} on {0}
`[domain,,competency,,affect,]`	your {4} on your ability to {2} on {0}
metacognition	
`[domain,,competency,,,metacognition]`	your {5} of your ability to {2} on {0}
`[domain,,competency,motivation,,metacognition]`	your {5} of your {3} on your ability to {2} on {0}
`[domain,,competency,,affect,metacognition]`	your {5} of your {4} on your ability to {2} on {0}

Table 3.1. Verbalisation of the belief descriptors, depending on the nature of the belief. The placeholders in the belief descriptor patterns refer to the unique identifier associated with each topic of the relevant layer (i.e., they are types). The placeholders in the verbalisation template refer to the topic in the descriptor, from {0} for the domain topic to {5} for metacognition.

that complies with the rules of composition described in Figure 2.1. The right-most item in the descriptor defines the nature of the ability judged in the belief (i.e., competency, affect, motivation, metacognition or misconception). There are nine well-formed descriptors allowed by the OLM and a proper verbalisation of the descriptor in natural language can be easily mapped (see table 3.1). Combined with the verbalisation of the topics in the various layers, the resulting improvement is appreciable compared to an actual descriptor representation, such as `[derivative,,solve,,,]`:

> OLM Why don't we have a look at your ability to **Solve problems** on **Difference Quotient** again?
> Toto Give me your judgement on my **Effort** on **Difference Quotient**.
> OLM I think your are Level II on your **Monitoring** of your ability to **Think Mathematically** on **chain Rule**.

Not every instance of a belief descriptors needs to be replaced by its verbalisation. In some of the external representations, notably the graphical ones like the topic map, space restrictions force us to keep the bracketed representation for the descriptor. This is the case for example for the Toulmin Argumentation Pattern. In order to maintain the clarity of the representation, hints or tooltips are provided in these particular cases, allowing the learner to see the complete verbalisation of the belief descriptor in natural language (see for example Figure 3.1, which depicts a hint popup window showing the text for the belief descriptor `[diff_quotient,,solve,,,]`).

Ability Levels Every belief in the OLM, whatever the nature of the learner's ability it portrays, is expressed according to a common framework, that of a probabilistic distribution on different levels of ability. Levels were derived from both the PISA framework and the competencies used in the model. Our implementation of the OLM uses four levels, mapping the variation between low and high ability: `Level I`, `Level II`, `Level III` and `Level IV`. Table 3.2 shows the current mapping of the four levels, depending on the nature of the related belief. Although at the time of writing we are still using the `Level I` to `Level IV` terminology, a better – more natural – mapping could easily be instantiated without having to change anything in the OLM; for example, one could use a range from **low** to **high** for the competencies and **occasional** to **persistent** for misconceptions simply by changing the corresponding strings in the Java resource file.

	`Level I`	`Level II`	`Level III`	`Level IV`
`competency`	Level I	Level II	Level III	Level IV
`capes`	Level I	Level II	Level III	Level IV
`affect`	Level I	Level II	Level III	Level IV
`motivation`	Level I	Level II	Level III	Level IV
`metacognition`	Level I	Level II	Level III	Level IV

Table 3.2. Verbalisation of the ability Levels depending on the nature of the belief

Topic Maps, Events and Attributes The final set of elements needing verbalisations in the OLM are the external objects used to specify the context and nature of the learners' abilities.

One subgroup contains the topic maps used for modelling these abilities, i.e., the topics in the domain map, in the competency map, in the affect map, etc.. Each topic is uniquely referred to by an identifier (e.g., `diff_quotient` for the `Difference Quotient` topic in the domain map) and associated with a name and a title, used respectively for their verbalisation (in the belief descriptor) and explanation (as tooltips in the topic map view, as in Figure 4.1). Extracts of the verbalisation of these maps can be found in Appendix C.

Another group includes all the events associated with particular learner interactions in LeActiveMath that are used by the OLM as sources of evidence for establishing a judgement by the learner. This is the concrete information from LeActiveMath that the learner will ultimately deal with in the OLM, so particular care has been taken when constructing their verbalisations.

Table 3.3 schematically outlines a typical LeActiveMath event, `ExerciseFinished`, fired when the learner ends an exercise (either by successfully solving it or by giving up). Attributes characterising this particular instance of the event are extracted by the OLM and formatted in specific ways. For example, the attribute `ITEM` contains the identifier used internally by LeActiveMath to reference the exercise; it is specified as a string that will be rendered as plain text. The attribute `DIFFICULTY` contains the difficulty level associated with the exercise; it is specified as an enumeration, where each of the possible values given are associated with a particular template for verbalisation. The attribute `PERFORMANCE` contains the overall performance of the learner on the exercise, as judged by the LeActiveMath exercise sub-system; it is specified as a double-precision float in the $[0, 1]$ interval and this continuous interval is in turn mapped to discrete ranges, each of which are associated with a particular verbalisation.

This mechanism of specification of both the attribute's internal data structure and its verbalisation (for the attribute itself and its possible values) is generalised to each event used by the OLM. It allows the OLM flexibility for referring (in the dialogue move template, for example) to individual attributes, either by their name (e.g., `Performance`), their value (e.g., 75%) or by their value mapping (e.g., `high`). Widget renderers (such as meters, icons, etc.) are also configurable to display the attribute in the `Evidence` external representation, as shown in Figure 3.6(b).

Attribute	Type	Renderer	Verbalisation
ExerciseFinished			
ITEM	string	string	Object
TITLE	string	string	Title
COMPETLEVEL	enumeration	icons	Competency Level
DIFFICULTY	enumeration	icons	Difficulty
	very_easy		very easy
	easy		easy
	medium		medium
	difficult		difficult
	very_difficult		very difficult
PERFORMANCE	double $[0, 1]$	meter	Performance
	[0.0,0.2]		very low
	[0.2,0.4]		low
	[0.4,0.6]		average
	[0.6,0.8]		high
	[0.8,1.0]		very high

Table 3.3. Configuration and verbalisation of LeActiveMath events

3.3.3 Notes on the Template-based Approach

A couple of points about the template-based approach used for implementing the verbalisation in the OLM are relevant here: variations on the text of the dialogue moves and internationalisation.

Variations via Templates and Arguments The result of linking one template string to each semantic requirement of the interactive dialogue system is that learners quickly notice repetition in the language of the system's responses and begin to ignore it. One way to combat this is to allow multiple semantically identical but linguistically distinct variations for the same dialogue move.

We implemented this type of variation in the verbalisation mechanism by creating multiple templates, one of which is randomly selected by the OLM each time that dialogue move is needed. This mechanism is quite useful for alleviating the mechanistic feeling associated with over-use of a single sentence (though only the template strings vary, not the strings for the arguments themselves). The nature, number and verbalisation of the arguments are hard-coded into the system – only their order of appearance in the template string can be changed, and each is indicated by a numbered placeholder in the resource file (for a complete list, see Appendix B.3).

The following extract of the verbalisation templates is used to describe the set of `Evidence` associated with one of the partitions in the Toulmin Argumentation Pattern in Figure 3.6(b):

```
DlgMove.HereIs.SUBCLAIM   = Here are the most important pieces of evidence showing {3} {2}
DlgMove.HereIs.SUBCLAIM.1 = Amongst the evidence showing {3} {2}, these {1} pieces(s) are the most important.
DlgMove.HereIs.SUBCLAIM.2 = {1} among the {0} pieces of evidence are strong enough to explain {3} {2}.
```

Each alternative template uses the same four arguments: {0} stands for the total number of individual pieces of evidence in the set, {1} stands for the number of important (in terms of impact factor) pieces of evidence, {2} stands for the name of the attribute used for the partition and {3} stands for the value of the attribute describing the given set. The template strings are not required to use all four arguments nor in any particular order. One resulting verbalisation where the OLM has chosen the middle element from above (SUBCLAIM.1) can be seen in the following dialogue extract:

Toto	Could you tell me more about your evidence on the **high** group?
OLM	Amongst the evidence showing **high Performance**, these **2** piece(s) are the most important.

Templates and Internationalisation The verbalisation templates are implemented in the OLM using the Java properties (or resources) mechanism: a set of simple text files containing a list of key/attribute pairs. Every template used in the OLM is therefore uniquely identified by a code; changes in the templates thus do not require changes to the code. This same mechanism also easily supports internationalisation: every language that needs to be supported in the OLM requires only a new set of the template strings shown in Appendix B, where the (human) translation of the templates are associated with the relevant index [10]. When editing an existing set of templates or adding a new language, the OLM code does not need to be recompiled.

The current implementation[11] of the verbalisation scheme in the OLM is based on two sets of the Java properties file: `messages.properties` contains the templates used for the OLM GUI and the internal elements (dialogue moves, events and attributes, etc.); `topicmaps.properties` contains the templates used for verbalising the topics of the various layers of the learner model. These two files are considered the default properties for the OLM, supporting the *English* language. Translations are now under way for *Spanish*, *French* and *German*.

3.3.4 An Example Generated Dialogue

Table 3.4 gives an annotated example of the verbalisation of the interaction between a learner and the OLM. In this example, most of the possible dialogue moves are explored in turn, some several times in order to highlight some of the attempts made to avoid repetition of sentences. For each interaction (i.e., learner requests and the OLM's response), additional notes have been included that allow the dialogue to be visualized in the context of the entire OLM: a description of what can be seen in the GUI, the dialogue moves available to the learner at any moment, and the actual actions undertaken by the learner.

For purposes of comparison, the corresponding generated dialogue from the original version of the OLM in Deliverable D29 is partially reproduced here. We believe the difference is a strong indication of the significant effort we have invested in improving the dialogue capability of the OLM.

[10] The detection of the language used in a properties file is based on its naming convention: if `messages.properties` is the default language set – assumed to be in English – then `messages_es.properties` contains the templates translated in Spanish, `messages_fr.properties` the French version, etc.. The language code should be compliant with the ISO Language Code (see http://ftp.ics.uci.edu/pub/ietf/http/related/iso639.txt).

[11] It should be noted that although we have added the capability for additional languages here, the Description of Work for WP5 specifies that the open learner model dialogue is only required for English. Details can be found in Appendix A.

Table 3.4: Annotated dialogue between the learner and the OLM.

Main screen: Descriptor builder (initialised with `[diff_quotient,,solve,,,]`*)*	
Possible moves: Agree – Disagree	
OLM	Welcome **toto**.
OLM	Why don't we have a look at your ability to **Solve problems** on **Difference Quotient** again?
User action: Agree	
Toto	OK.
Toto	Give me your judgement on my ability to **Solve problems** on **Difference Quotient**.
Left screen: Toulmin graph with `Claim` *node selected*	
Right screen: Summary Belief view	
Possible moves: Explain – Tell Me More	
OLM	I think you are **Level II** on your ability to **Solve problems** on **Difference Quotient**.
User action: Tell Me More	
Toto	Could you remind me what this graph is about?
OLM	This graph represents my judgement of your **Competency**, on a continuous scale between **Level I** and **Level IV**.
OLM	Being very close to the **Level II** indicator, my conviction on my judgement is therefore quite strong.
user action: Explain	
Toto	I don't understand why you think I'm **Level II**.
Left screen: Toulmin graph expanded with `Data` *node selected*	
Right screen: Pignistic view	
Possible moves: Explain – Agree – Disagree – Move On – Tell Me More – Swap	
OLM	The dominant trait for my belief may be **Level I**, but I cannot dismiss the evidence supporting the other levels.
user action: Swap	
Toto	Show me another view of this information.
Right screen: The pignistic view is replaced by the mass distribution	
OLM	On the right, you can see the mass distribution of my belief, showing all information from accumulated evidence.
user action: Tell Me More	
Toto	I don't understand what this means.
OLM	This mass distribution represents my guess about your **Competency**, in terms of the probability for you to be at the various combination of **Competency** levels.
user action: Explain	
Toto	I don't understand how you obtained this profile.
Left screen: Toulmin graph expanded with `Performance` *partition of evidence;* `low` *node selected*	
Right screen: Partition view, with `low` *pie selected*	
Possible moves: Explain – Agree – Disagree – Move On	
OLM	Looking at the evidence according to your **Performance**, my judgement is mostly based on the **8** piece(s) in the **low** group.
user action: Explain	
Toto	Could you tell me more about your evidence on the **low** group?
Left screen: Toulmin graph expanded with `Evidence` *nodes, 5 of them being visible;* `evidence 8` *node selected*	
Right screen: Evidence view, with decayed evidence mass distribution on top, attributes at bottom	
Possible moves: Explain – Agree – Disagree – Swap – Move On – Show Item – Tell Me More	
OLM	Among the evidence showing **Performance low**, these **5** are the most important.

(continued on next page)

Table 3.4: Annotated dialogue between the learner and the OLM (continued).

user action: Swap	
Toto	Show me another view of this information.
Right screen: Evidence view, switch to original evidence mass distribution	
OLM	Here is the complete mass of this piece of evidence, as it was initially generated.
user action: Swap	
Toto	Show me another view of this information.
Right screen: Evidence view, switch back to decayed evidence mass distribution	
OLM	Since evidence tends to be less certain over time, here is the mass as it is now considered in the belief.
user action: Explain	
Toto	Please explain what this interaction was about.
OLM	I concluded this because you did this **very easy** exercise with a **very low** performance.
user action: select `Evidence 0` *on the Toulmin graph*	
Right screen: updated Evidence view, with decayed evidence mass distribution on top, attributes at bottom	
user action: Explain	
Toto	Please explain what this interaction was about.
OLM	I concluded this because you did this **very easy** step with a **very low** performance.
user action: select `Performance high` *partition on the Toulmin graph*	
Right screen: Partition view, with `high` *pie selected*	
Toto	Could you tell me more about your evidence on the **high** group?
OLM	Among the evidence showing **Performance high**, these **1** are the most important.
Toto	I don't understand what this interaction was about.
OLM	I concluded this because you did this **very easy** step with a **very high** performance.
Toto	Could you tell me more about your evidence on the **Other** group?
OLM	Here are the most important pieces of evidence showing **Performance Other**
Toto	Could we talk about something else, please?
OLM	Fine, but we will have to come back to this issue later.
Toto	I don't understand what this means.
OLM	You are telling me which ability to judge. Currently, you are looking at **Difference Quotient**.
Toto	Show me what you think about **Difference Quotient**.
OLM	I don't understand your question. You need to specify at least a competency.
Toto	Could you remind me what this is about?
OLM	You are telling me which ability to judge. Currently, you are looking at your ability to **Think mathematically** on **Difference Quotient**.
Toto	Show me what you think about my ability to **Think mathematically** on **Difference Quotient**.
OLM	I think you are **Level II** on your ability to **Think mathematically** on **Difference Quotient**.
Toto	It was a nice talk but I need to go now.
OLM	Well, see you very soon ...

OLM	Welcome my dear **toto**. What brings you here today?
Toto	I don't know what to do now.
OLM	Perhaps you should explore **[derivative,,think,,,]**.
Toto	Yes, why not.
Toto	Show me what you think I know about **[derivative,,think,,,]**.
OLM	I think your are **Level II** about **[derivative,,think,,,]**.
Toto	I don't understand why you think **Level II**.
OLM	Here is the evidence for **Level II**
Toto	I don't understand why you think **Level II**.
OLM	Here is the evidence for **Level II**
Toto	I don't understand why you think **WARRANT_7**
OLM	Here is the evidence for **WARRANT_7**
Toto	I agree with **WARRANT_7**
OLM	That's OK, I will make sure to take this fact into account.
Toto	Show me what you think I know about **[derivative,,solve,,,]**.
OLM	I think your are **Level III** about **[derivative,,solve,,,]**.
Toto	I don't understand why you think **Level III**.
OLM	Here is the evidence for **Level III**
Toto	I disagree with **Level III**.
OLM	In this case, what is your own judgement about the situation?.
Toto	Let's change the topic of discussion, please.
OLM	Fine, but we will have to come back to this issue later.
Toto	It was a nice talk but I need to go now.
OLM	Well, see you very soon ...

4 Outstanding Issues and Future Work

This section presents several problems encountered during the implementation of the current version of the OLM, suggestions for how to fix them, and ideas for further improving the OLM in the future.

4.1 Alternative Interface for Navigation

As mentioned previously in Deliverable D29, the current interface for navigating amongst the beliefs held by the system (*i.e.*, the descriptor builder, Figure 3.2) was a short-term compromise that should open up the possibility for including more advanced, interactive and intuitive interfaces. One of the possibilities envisaged was to better take advantage of the Topic Maps view of the OLM, found in Figure 4.1.

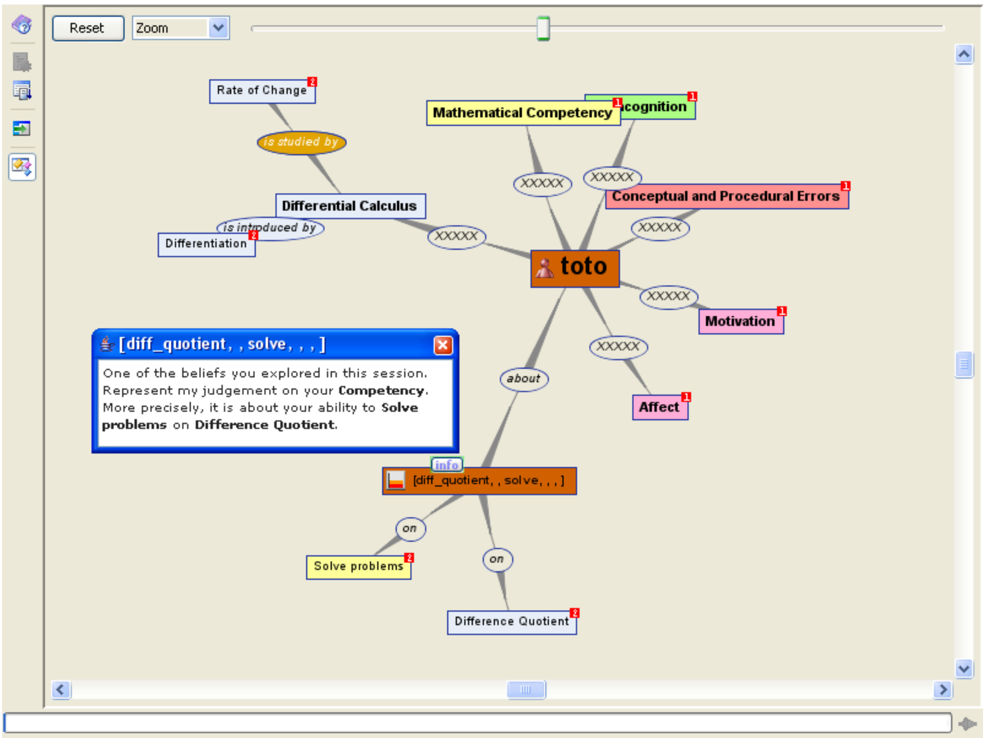


Figure 4.1. The Topic Maps View

Presenting all the topics involved in the multiple dimensions of the learner models as a dynamic graph, this is the only place in the OLM where the structural dependencies between topics could be fully represented and used to justify some of the aspects of the modelling process (most notably the propagation of evidence). It is also a very attractive way of presenting (pedagogical and cognitive) knowledge to the learner, as the comments received from the evaluation of the OLM have highlighted (see Appendix B). Thus further work is highly recommended for investigating a direct-manipulation interface that would allow the learner to interactively build the belief descriptors required by the OLM by merely looking for and selecting the appropriate topics from the map.

4.2 Partitioning Evidence and Multiple Usage of the OLM

As described in Section 3.1, a mechanism for partitioning evidence has been implemented in the current release of the OLM. This mechanism is intended to be fully generic, ensuring that any attributes, and specifying any of the events diagnosed by the XLM, can be used as criteria for partitioning: performance, the presence of a misconception, direct or indirect evidence, impact factors, etc.. Early prototypes of this mechanism allowed the learner, when requiring a judgement on a belief in the OLM, to specify whether a partition of evidence should be used and under what conditions. Informal trials hinted at some potential for this approach, both from an interface perspective (graphical clustering) and from a conceptual point of view (semantic proximity and correlation). But problems also soon became apparent, not because of the mechanism itself but rather because of the current usage of the OLM and its associated verbalisation for *justification of a judgement*.

Indeed, not every aspect of the evidence can be used to justify a belief held by the xLM. As shown in the example dialogue in Table 3.4, it makes sense to present evidence separated out according to performance, because, ultimately, competencies are performance-based: *"I think you are `Level II` because I have 8 pieces of evidence showing low performance"*. On the other hand, it was difficult to use other criteria such as the difficulty of the exercises: *"I think you are `Level II` because I have 8 pieces of evidence on `very easy` exercises"*. What would have made more sense is to use the partition to highlight the (potential) trends and correlations that could exist between the selected criteria and the performance-related aspects of the target ability: *"I have 8 pieces of evidence showing a low performance, all of them on `very easy` exercises"*. But this capability would imply a different fundamental use of the OLM: one that is not based on obtaining a justification for a judgement but instead based on exploring or discovering correlations between observed behaviour.

4.3 Challenging Judgements

The evaluation of the OLM as presented in Deliverable 38 [7] highlighted quite drastically the limitations of the current implementation of the challenge (see Figure 4.2). The main issue mentioned by learners is that the OLM does not "challenge" their challenges: it blindly accepts their alternative statements without trying to counter-argue. This is a weakness that makes the whole process of challenging an OLM judgement seem potentially senseless and needs to be addressed. Several schemes could be used for that purpose, for example by asking the learners to perform a new sequence of exercises in order to judge the relevance of their challenge.

4.4 Re-Contextualising Evidence

As the learner explores the justification of a judgement held by the OLM, individual pieces of evidence are ultimately presented statically via the interface.

In the case of a judgement on mathematical competency, these pieces of evidence are basically interactions with the LeActiveMath front-end, representing every step made by the learner in completing (or giving up on) exercises. In the Evidence view of the OLM, a summary of the interaction (Figure 3.6(b)) is available, presenting some of its most important attributes, among others: the type of the interaction (i.e. complete exercise or exercise step), the performance of the learner in the given interaction, the difficulty of the exercise, etc.

When presented with such evidence, the problem facing the learner is how to *re-contextualise* this information, i.e. how to relocate this particular interaction in the problem-solving sequence performed in LeActiveMath front-end – potentially a long time ago. And the problem for the

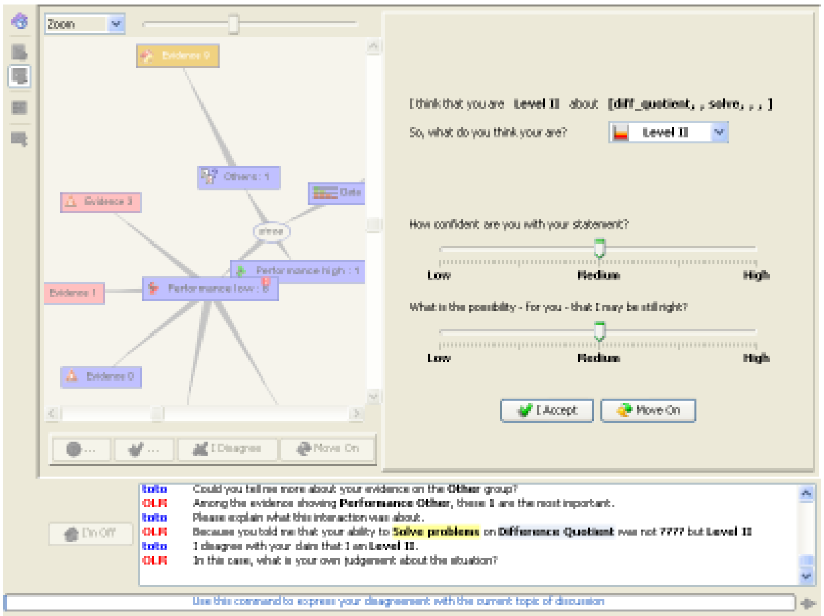


Figure 4.2. Challenging the OLM Judgement

OLM then becomes how to dynamically provide visual support of the learner's actual problem-solving efforts to help such re-contextualisation, namely what tool or mechanism can be used for recreating those previous events.

Figure 4.3(a) represents a snapshot of an exercise run in the LeActiveMath exercise sub-system. It basically shows the outcome of a prior interaction with the learner (i.e. selecting 9 as an answer for the question) and the feedback accordingly provided by LeActiveMath (i.e. *"No, have another look at the sign of* $f(x_0)$*"*).

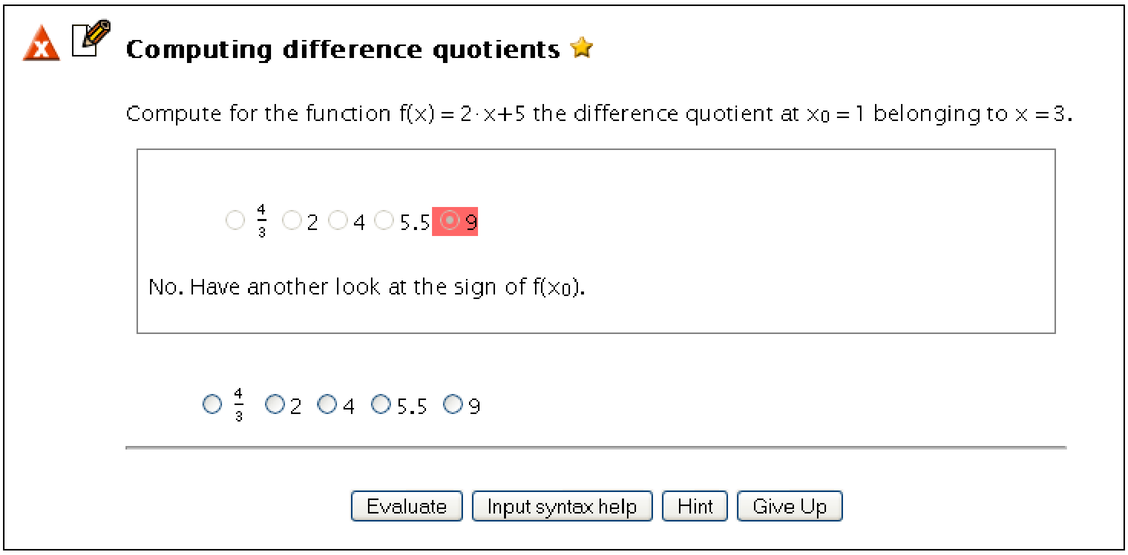
The idea would have been to be able to show a "replay" of that particular step of the exercise, in a form the learner is already familiar with. But as of this writing, this feature is unfortunately not available in LeActiveMath and, because of technical issues that are outside the scope of this document, is unlikely to be implemented in the near future.

As a second choice [1], the currently implemented solution consists of calling the exercise into the search engine associated with LeActiveMath, which allows, as a result of the procedure, the display of the relevant learning object(s) matching the query – albeit in a reduced form, as in Figure 4.3(b). The problem of this approach is that, depending on how the exercise has been authored, it may not provide the learner with sufficient information for remembering the context of the interactions [2]. Moreover, in the case when a piece of evidence is based on the execution of a particular step of an exercise, it is impossible to re-associate that step in the context of the exercise (the situation is even worse for interactive multi-step exercises).

This issue is a serious shortcoming of the integration of the OLM in LeActiveMath and needs to be seriously investigated. Without the possibility of re-contextualising evidence considered by the OLM to establish a judgement on the learners' ability, models of learners will never be able to conduct significant knowledge and skill transfers.

[1] Localised solutions, such as presenting the learner input in the OLM itself – with or without mathematical expression rendering – have also been investigated and ruled out because they did not totally address the importance of the context: for instance, being told *"Your performance on this exercise was low because you typed* $(X-1)^2$*"* is not particularly helpful if you cannot remember the question.

[2] Figure 4.3(b) is an extreme – but unfortunately frequent – case where only the title of the exercise is presented in the LeActiveMath search engine.



(a) in the Exercise sub-system

(b) in the Search Engine

Figure 4.3. Displaying the learning object associated with a piece of evidence in the OLM.

4.5 Bridging LeActiveMath and the OLM

The final issue to address is the question of the learner's introduction to the OLM from the front-end of LeActiveMath. As we already pointed out in D29, both parts of the system use different "languages": the front-end of LeActiveMath speaks in terms of knowledge and content, while the OLM speaks in terms of belief and concepts.

This is not to mean that there is no integration between both parts: the front-end in fact fully uses the learner model to reflect the learner's current beliefs, by way of the coloured indicators associated with every pages and sections in the Table of Content (see figure 4.4).

More generally, there is a problem with the fact that the content in the front-end does not provide the learner with access to their internal information, i.e. the metadata. Only the level of difficulty is externalised (as a list of star icons near their title) but the other information, in particular that used by the xLM and manipulated in the OLM such as the associated competency (or competencies) and the assumed competency level, is not accessible. This issue has also been noted during the evaluation of the Search Engine, where learners had trouble using the search on metadata since these are not externalised anywhere in the front-end.

These questions of metadata externalisation and reference to the concepts used in the OLM need to be addressed to ensure proper integration – in both directions – between LeActiveMath and the OLM.

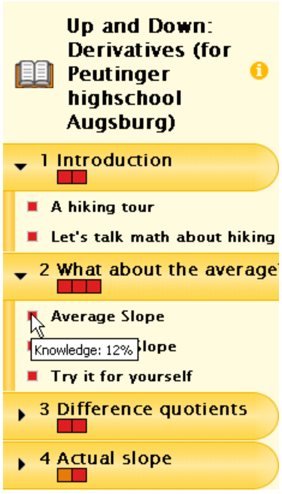


Figure 4.4. LeActiveMath front-end displaying the knowledge level associated with a page

Both the colour and the related tooltips are calculated from the beliefs held by the Extended Learner Model. Without going into detail, the procedure basically computes the average of all the Competency-related beliefs associated with all the exercises found in a given page. But only the end-product of this process is given to the learner. Since there is no one-to-one connection between an exercise in the front-end and a belief in the OLM, the learners have no way to determine why, as in the figure above, their knowledge on "Average Slope" is 12% or "red". Moreover, even if they know about the learner model and its method for computing a model of the learner, they have no way to find out what the corresponding belief is that they should then explore in the OLM.

This point was made very clear in the last evaluation of the OLM. In order to alleviate this problem and offer the learner a better bridge between the LeActiveMath front-end and the OLM, several improvements have been suggested for the front-end. For example, by clicking on the coloured square associated with a page [3], the learner could be presented with a popup window containing all the OLM beliefs that are involved in this page, using the OLM's own vocabulary:

- **Level II** on your ability to **Solve problems** on **Average Slope**
- **Level I** on your ability to **Argue mathematically** on **Average Slope**
- **Level II** on your ability to **on Think mathematically** on **Average Slope**
- etc.

Each of the items in the list could then provide a link to the OLM, initialised with the relevant belief.

[3] This action currently opens the help file "Mastery Colors".

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A Tasks and Deliverables from the DoW

The following are extracts from the updated version of the Description of Work; only the parts that are directly relevant to the Open Learner Model are included here.

Description

WP5 Natural language facilities

This workpackage deals with the development and integration of natural language enhancements of our learning environment.

Natural language technology in LeActiveMath uses two main approaches. One is pre-authored content, including exercises with pre-authored feedback. The other is applying intelligent dialogue system technology to the domain of tutoring problem-solving skills. The function of WP5 is the latter, to provide automated natural language feedback and advice that is adapted to the student and dialogue history. Due to the complexity of student input interpretation, reasoning and diagnosis, and generation of system feedback, the intelligent dialogue system will be necessarily restricted in coverage to a sub-domain of calculus, namely symbolic differentiation.

Beyond the needed internationalization of the system (not including the local tutorial dialogue component and open learner model dialogue component), the intelligent dialogue system enhancements include, for the English language only:

- tutorial dialogue to assist students in problem solving
- *dialogue about the open learner model*
- narrative bridges and summaries

From the outset, the architecture of the tutorial dialogue components will be developed hand in hand with the architecture of the overall system. In particular, the tasks of the tutorial component and the tutorial dialogue component, and communication between them, will be coordinated. The tutorial component will determine which exercises the student will carry out, and will pass this information to the tutorial dialogue component to manage the dialogue with the student. The dialogue will take information in the student model into account when giving advice and feedback to the student, and outcomes of tutorial dialogues will provide input for the student model.

All developed components as well as their integration into the overall system will be software- and user-tested.

Tasks

...

T5.2 Tutorial dialogue management and overall realisation for:

- local tutorial dialogue for support of exercises in symbolic differentiation
- *student model dialogue*

We will devise a dialogue manager (DM), using the flexible Information State Update approach of Trindi/Siridus together with high-level dialogue planning, that supports tutorial dialogue within exercises in symbolic differentiation.

...

This task also includes dialogue about the open student model to help LeActiveMath *present the state of the student's current problem solving abilities (for example, allowing the student both to inspect the evidence for the system's evaluation of their competencies based on their past performance, and to modify the system's evaluation). It involves close cooperation with Glasgow. The student's modifications will be used to update the student model.*

...

Deliverables

...

D5.3 Student model dialogue component *Enable dialogue about the open student model, extending the hypertext-based presentation currently used in ActiveMath. This will be implemented as finite-state machines. Students will provide input using menu selection, and output will be template-based. Note that Glasgow has designed the dialogues with the student model, including a specification of the inputs that should be allowed, and the system responses to these student inputs. Edinburgh's role in this task is to implement the template-based generator to be used for this task.*

...

- *extend the presentation of the open student model with template-based generation of language.*

...

B Details of OLM Interface issues

Below is a list of issues regarding the usability of the Open Learner Model, collected during the evaluation run by Edinburgh University in May this year (see Deliverable D38 [7]). The most salient elements in this list are summarised in Section 2.3.

Whenever possible, every issue has been commented, indicating if it has been fixed (totally or partially), if it is still an open issue that needs further investigation or if it has been decided not to fix it.

Open Learner Model

References Section 3.3.1 and Figure 3.7.

Open. *These issues involve mainly the front-end of* LeActiveMath *and has thus been remanded to WP3. See also section 4 for a discussion on bridging* LeActiveMath *and OLM.*

1. Not initially aware of its existence or what you would use an OLM for.
2. When told there is this thing called a "Learner Model" that they can look at they go straight to it in the My Profile menu.
3. There is no transference of skills from the main LeAM interface to the OLM. Even the concepts have changed so a user who is accomplished at using LeAM should be no better at using the OLM than a novice.

Descriptor View

References Section 3.2.2 and Figure 3.2.

1. Drag of text onto descriptors doesn't work as described in help.

   Fixed. *Description in the status bar has been updated to reflect the real operation (i.e. click and double-click).*

2. Single click of text should put them onto the descriptor.

   Not Fixed. *Single click should be keep for selecting the topic in the list and the transfer to the descriptor should be done deliberately (i.e. by double-click). Otherwise, there are risks of unexpected selection in the descriptor.*

3. Double click to remove the blocks isn't intuitive and the instructions are so separate to the mouse cursor that users don't always see the instruction.

   Open. *Drag-and-Drop could be tried as an alternative but needs a significant re-engineering of the interface. Another alternative for building the descriptors should be envisaged (e.g. by direct manipulation of the topic graph).*

a. Expect to see either a "remove" button or an empty line at the top of each category list which they can select to remove the current item. Some users also tried clicking on the category name at the top of the list to see if this removed the current item.

   Not Fixed. *Adding a button will overload the interface, especially with the dialogue move widgets now relocated.*

b. Why is this name in the list at all?

   Comment. *Because they are part of the topic maps: the topic "metacognition" is itself an element of the metacognition list/layer, acting as a "catch-all" category for the dimension.*

4. Dependencies:

   a. The dependencies between descriptor items are not immediately clear.

      Open. *There is no easy and obvious solution for deciding how to materialise these dependencies at the interface level.*

   b. Users discover the incompatibility between Motivation and Affect but only through experimentation.

   c. Users do not like being told that the system doesn't understand without receiving further explanation. They don't know what to do to fix the question.

      Fixed. *Better explanations are now given – in the dialogue pane – every time the OLM does not understand the question.*

   d. If the dependencies are so important it would be better to constrain the user in their choice of items. All descriptors must begin with a Domain and then build from there. Why not use some kind of step by step construction that first gets them to select a Domain then gives them the choice of which category to look at next and so on. This way the system could enforce the constraints.
      This could be achieved just by hiding or fading out tabs on the category list so that the user can't access them.

      Open. *Implementing such constraints requires the possibility – at a later stage – to release them. The OLM therefore need to be able to switch between a guided and a free, discovery mode. Implementing such a mechanism is a lengthy process as it implies significant refinements of the GUI and the dialogue framework.*

5. Descriptor List

   a. This is useful but only once the user understands what a descriptor and how to read it.

      Fixed. *Their role is now described in the help file and a summary is given with the* **Tell Me More** *dialogue move.*

   b. The order of items in the descriptor is different to the order of the block used in the descriptor view to construct them. This is confusing.

      Comment. *Descriptors read left to right, whereas the descriptor view builds them bottom-up. I tried a left-right construction but it hardly fit in the view: there is more space vertically than horizontally*

   c. If there was someway you could have a descriptor list which has the items added to it as the user adds items to the block view I think this would help users make the transference from the blocks to the list view.

Fixed. *Filtering the descriptor list is based both on selecting topic in the panes (i.e. adding constrains to the filter)and on removing topics from the constructor (i.e. removing constrains).*

d. The user should have the option of either looking at the categories or the existing Domains. Having both in the same group of categories is confusing as they don't symbolise the same thing.

Fixed. *The descriptor list is now used as a filtering of the topic lists and can still be used directly if needed.*

e. Readability of descriptors:

i. Users find it hard to read the descriptors BUT they are able to treat them as entities that the OLM has beliefs about.

ii. If the user is told the question to ask they can decompose it into the right items for the descriptor.

iii. They like the textual interpretation of the descriptors visible in the Topic map.

iv. But some users realise that the full English versions might make the dialogue hard to read and reference. Solution:

- When a user constructs a descriptor using the blocks there could be two interpretations presented underneath the blocks: a list descriptor and a full English version of the descriptor.

  Fixed. *Interpretation of the descriptor is given by using the* **Tell Me More** *dialogue move.*

- Both of these could be constructed as the user selects items from the lists. In fact, having these two views would make the block view redundant. Can you just get rid of this?
- Having an English interpretation would help the user understand the question they were asking. You could also use it to state when a question is poorly formed e.g. a domain on its own would produce the text "Your question is incomplete. Try adding an item from a different category."
- This could also be clarified by having an "Ask" button next to the English version of the descriptor which only becomes active when the question is properly formed.

  Fixed. *The* **Show Me** *dialogue move is now only available if the descriptor is well formed.*

Claim View

References Section 3.2.3 and Figure 3.3.

1. Students find it initially overwhelming.

2. Need introductory tutorial and comprehensive help saying what each bit does and how they are supposed to be used.

   Fixed. *An Help file for the OLM has been added to the system, as well as tool-tips and explanations through the* **Tell Me More** *dialogue move.*

3. Most users focussed their attention on the Toulmin (map) view. A few used the dialogue to confirm their interpretations of the map.

4. Do not initially realise that there is more information behind the claim on the map. Need instruction to know how to explore the map.

5. Instinctively think that the map will expand by double clicking on a node. I think you should activate this function.

   Not Fixed. *Expanding the graph, i.e. gaining access to the next level of justification of the belief, need to be done explicitly – with a dialogue move – rather than by "chance" with a double-click.*

   a. BUG: when the user changes the zoom of the map view and then right clicks on a node the pop-up menu is unreadable. It is like the menu shrinks with the diagram.

      Open. *Cannot recreate the bug.*

6. Is there anyway to make the map automatically scroll to ensure that any expanded sections are visible on the page? The constant dragging of the map currently needed is very frustrating.

   Fixed.

7. When a user switched back to the descriptor view using the top-left view buttons the current question should end. They shouldn't have to click "Move On".

   Fixed. *The* **Move On** *dialogue move is only available when the user starts challenging the judgement (by requesting more justification on the claim). In that case, switching back to the descriptor view is now disabled until a resolution of the challenge is reached (by agreement, disagreement or moving on).*

8. Claim node:

   a. If the red green colours of the overall percentage bar don't mean anything I think you should get rid of them The users try to interpret them which can lead to confusion.

      Fixed. *The percentage bar is now using an uniform colour, selected on the relevant gradient (i.e. red to green mapping the level I to level IV scale).*

   b. The dialogue associated with a claim could encourage the user to explore the claim further to see where the claim comes from.

      Fixed. *The verbalisation of the whole dialogue has been significantly – and hopefully successfully – improved.*

   c. Expand node by double clicking or right clicking and selecting "Expand Node".

      Fixed. *Both double-click and menu selection now expand the selected node.*

   d. "I am Baffled" should be rephrased to something like "Explain".

      Fixed.

9. Data node:

   a. The pignistic is useful for the user to understand how the overall level is an average across probabilities but this needs to be explained.

      Fixed. *Both by the Help file and dynamic verbalisation and comments.*

b. The certainty graph is incomprehensible to users. They do not see the white so they do not realise each bar adds up to 100%. Some users thought it was a sign of how much they needed to do to get up to 100%. Didn't understand distinction between green and red.

Fixed. *The certainty/plausibility view has been completely removed from the OLM.*

c. Mass distribution is better than certainty and may also make idea of using probabilities across levels clearer than pignisitic. Can you not just use mass dist?

Open. *The pignistic view is helpful for trying to understand where the claim comes from. The issue remains on the nuderstanding of the link between the pignitisic and the mass distribution.*

10. Evidence:

a. Skip this level on the graph. Just go straight from Data to backing.

Fixed. *The "warrant" node (representing the sole mass distribution of the evidence) has been removed, only leaving the "backing" node (presenting both the mass and the list of attributes), now renamed "evidence".*

b. Information associated with backing is very good although mass dist needs explanation.

Open. *A limited amount of information is now provided. A more detailed explanation/justification may require the re-introduction of the "warrant" node, as a place-holder for such level of discussion.*

c. Also need key describing what some of the details mean e.g. evidence, index, action.

Fixed. *Tool-tips are now available for that purpose.*

d. Text window needs horizontal scroll bar. Text currently runs off screen.

Not Fixed. *Cannot unfortunately. Will need to redesign the whole attribute interface.*

e. When do show item on exercises it takes the user to a window containing the title of the exercise and any text the author chose to include before the "Start Exercise" button. However, the button is missing so the user can't check what the exercise actually was.

Open. *This is a problem with* LeActiveMath, *see section 4.*

f. They should be able to redo the exercise and then immediately see their knowledge update in the OLM.

Open. *This is difficult to do, as it requires a controlled synchronisation between* LeActiveMath *(for running the exercise) and the OLM (for looking at the impact) that is not available now.*

g. Evidence was the most used part of the claim view. Some way of grouping evidence would be very useful. Speeding up users progress from claim to evidence is also important.

11. Dialogue

a. Mixed usage. Some users used it a lot to explain what was going on, others didn't use it at all.

b. The repetition of sentences and lack of indication when it has updated meant that some users ignored it.

Fixed. *The verbalisation of the whole dialogue has been significantly – and hopefully successfully – improved.*

c. Need to highlight most recent lines of text as users sometimes don't see the dialogue update as they're looking at the map.

Open. *The feature of the dialogue view does not allow such manipulation. It will have to be redesigned significantly.*

d. "I am Baffled" should be rephrased to something like "Explain". baffled is too negative.

Fixed.

e. Most users said they would prefer textual descriptors instead of the lists but some realised this might make the dialogue to crowded. Maybe keep lists but have textual info tab on descriptor in Toulmin like you do in the Topic map.

Fixed. *Done, although the use of the pop-up window in such a limited space may be overwhelming.*

f. Some users initially tried to type into the dialogue. I think accepting typed sentences would be the only way the OLM would become dialogue centred. As it is the dialogue is just a expanded tooltip. I think it would be better to remember this and use the dialogue to help and instruct the user more.

Open. *The use of full-scale natural-language typing is a complex and long-term issue.*

Challenge

References Section 4.3.

Open. *Due to time constraints and complexity of the issue, the current shallow implementation of the challenge will have to be accepted as it is. If too detrimental, it may be a good idea to ban it altogether for the evaluation.*

1. Users were surprised how easy it was to change the OLM's belief and how little argument was given.

2. Expected a negotiation process during which the OLM made its case for why it had a certain belief.

3. Or, a challenge could be taken as a request by the user for the system to test their knowledge to check they are at the level they say they are. The OLM should tell them to attempt certain exercises. I guess this is probably the job of the tutorial component but from what I understand of the Tut Comp it isn't going to do this.

4. The certainty and intransigence scales seem redundant. Don't they ask the same thing? One user also noted that if they were going to be bothered to challenge a belief they would want the system to take their challenge seriously so they would always choose the extremes.

5. Once challenge has been accepted the user should be taken back to the same belief but updated to show how their challenge has affected it.

Topic Map

References Section 4.1 and Figure 4.1.

1. Rated the best bit of the OLM.
2. Remove dialogue from screen when switch to topic. This will give more space.

   Fixed. *The topic map is now standing alone in the GUI, using all the space available.*

3. Users instinctively want to double click a node to expand it. The centring that currently happens on a double click confuses the user. Should possible have expand on double click and have a "make centre" option on the right-click menu.

   Fixed. *Expansion/collapse now occurs when double-click on one node. Centring option added to the node menu.*

4. Same menu problem as Toulmin happens when view is zoomed.

   Open. *Cannot recreate the bug.*

5. Is there anyway this map could be used to construct descriptors? Connections could be dragged between Domain, Motivation, Competency etc items to create descriptors and then these could be asked to the OLM. This would be a great way of exposing the user to the connections between beliefs.

   Open. *A very good idea I've been thinking of for a long time – but difficult to implement! Will be considered for future improvements of the OLM.*

6. Need a RESET button to put the user back the centre of the map. My users kept losing it.

   Fixed. *The reset put the user node back in the centre of the map but alos reset the various parameters of the graph (such as locality, zoom, rotation).*

7. Need instructions telling the user how to read the map e.g. which direction do the arrows go, what the nodes represent, etc.

   Fixed. *In the help document.*

8. What happens when the Domain gets too large. Is there someway to group domain items.

   Comment. *Only by manually building the domain the map with its presentation in the OLM in mind, i.e. by ensuring an appropriate spread of the topics (nodes). It will be difficult to implement some kind of automatic procedure, as the semantic of the map will be unknown to the system.*

C Extracts of the Verbalisation Templates

The following listings give an overview of the various templates used in the verbalisation of the dialogue moves used by the OLM. Additional templates not shown here are used for internationalization of the graphical user interface (widgets, text labels, etc.).

The templates below are organised by category: attributes specifying the various events used as sources of evidence (listing C.1), plain-text descriptions of the belief descriptors (listing C.2), transcriptions for the OLM and learners' dialogue moves (listing C.3), explanations for the different probability distributions used in the OLM (listing C.4) and references for the learner model's dimensions and ability levels (listing C.5).

Also given are the templates used for the verbalisation of the topics of the learner model's dimensions: the competencies (C.6 [1]), the affective (C.7) and motivational (C.8) factors, the metacognitive abilities (C.9) and, finally, an extract of the domain map (C.10). Misconceptions are not supported in this scheme, as they are automatically extracted from the LeActiveMath content.

Listings C.2, C.3 and C.4 are parameterizable, with additional strings passed in as arguments and inserted in order in the numbered braces seen in the strings in these listings. Due to restrictions on Java string types, single apostrophe marks must be entered twice in the template, but only one is seen onscreen.

Listing C.1. Verbalisation of the event attributes

```
# Labels for the metadata and events properties, as well as for their value (if available).
# The template ATTRIBUTE.XXX.YYY means the verbalisation for attribute XXX and its value YYY.
# The ATTRIBUTE.XXX.description template is used for tooltips in the attributes list.

ATTRIBUTE.ACTION                            = Action
ATTRIBUTE.ACTION.16                         = ignore
ATTRIBUTE.ACTION.32                         = replace
ATTRIBUTE.ACTION.8                          = add
ATTRIBUTE.APTITUDE                          = Aptitude
ATTRIBUTE.APTITUDE.description              = My estimate of your ability to solve the problem correctly.
ATTRIBUTE.BDESCRIPT                         = Descriptor
ATTRIBUTE.BDESCRIPT.description             = The target of your interaction with me.
ATTRIBUTE.CHLGCONFID                        = Confidence
ATTRIBUTE.CHLGCONFID.description            = The amount of trust you  put in your own claim.
ATTRIBUTE.CHLGCONFID.high                   = certain
ATTRIBUTE.CHLGCONFID.low                    = fairly sure
ATTRIBUTE.CHLGCONFID.medium                 = quite sure
ATTRIBUTE.CHLGINTRAN                        = Intransigence
ATTRIBUTE.CHLGINTRAN.description            = The amount of trust you put in my judgement.
ATTRIBUTE.CHLGLEVEL                         = Your claim
ATTRIBUTE.CHLGLEVEL.description             = The ability level you claimed to be.
ATTRIBUTE.CHLGOLDLEVEL                      = My claim
ATTRIBUTE.CHLGOLDLEVEL.description          = The ability level I believed you were when you challenged me.
ATTRIBUTE.COMPETENCY                        = Competency
ATTRIBUTE.COMPETENCY.description            = The mathematical competency this exercise trains.
ATTRIBUTE.COMPETLEVEL                       = Competency Level
ATTRIBUTE.COMPETLEVEL.complex               = Level IV
ATTRIBUTE.COMPETLEVEL.description           = The competency level required to complete the exercise.
ATTRIBUTE.COMPETLEVEL.elementary            = Level I
ATTRIBUTE.COMPETLEVEL.multi_step            = Level III
ATTRIBUTE.COMPETLEVEL.simple_conceptual     = Level II
ATTRIBUTE.CONFIDENCE                        = Confidence
ATTRIBUTE.CONFIDENCE.description            = My estimate of your positive self-belief in your ability to tackle and to solve
                                              the problem.
ATTRIBUTE.DEPTH                             = Tenacity
ATTRIBUTE.DEPTH.description                 = Your determination - as I perceived it - in interacting with me.
ATTRIBUTE.DIFFICULTY                        = Difficulty
ATTRIBUTE.DIFFICULTY.description            = The assumed difficulty of this exercise.
ATTRIBUTE.DIFFICULTY.difficult              = difficult
ATTRIBUTE.DIFFICULTY.easy                   = easy
ATTRIBUTE.DIFFICULTY.medium                 = medium
ATTRIBUTE.DIFFICULTY.very_difficult         = very difficult
ATTRIBUTE.DIFFICULTY.very_easy              = very easy
ATTRIBUTE.DIRECT                            = Evidence
ATTRIBUTE.DIRECT.1                          = direct
ATTRIBUTE.DIRECT.2                          = indirect
ATTRIBUTE.DIRECT.description                = Whether this piece of evidence is directly supporting my belief or comes from
                                              related sources.
ATTRIBUTE.DLGMOVE                           = Move
ATTRIBUTE.DLGMOVE.AGREE                     = agreement
ATTRIBUTE.DLGMOVE.DISAGREE                  = disagreement
```

[1] On top of the eight PISA competencies described in the list, a couple of sub-competencies have also been added to the competency layer of the learner model, for diagnosis purpose.

```
ATTRIBUTE.DLGMOVE.SHOWME                  = exploring
ATTRIBUTE.DLGMOVE.WINDUP                  = challenging
ATTRIBUTE.DLGMOVE.description             = The nature of your interaction with me.
ATTRIBUTE.EFFORT                          = Effort
ATTRIBUTE.EFFORT.description              = My estimate of the amount of work you used to complete the exercise.
ATTRIBUTE.FOCUS                           = Evidence for
ATTRIBUTE.FOCUS.description               = All the beliefs that this piece of evidence is supporting.
ATTRIBUTE.INDEX                           = Index
ATTRIBUTE.INDEX.description               = The relative position of this piece of evidence in the chain when establishing my
                                            judgement.
ATTRIBUTE.INITIATIVE                      = Initiative
ATTRIBUTE.INITIATIVE.description          = Whether you pursued the interaction with me under your own will or under my
                                            guidance.
ATTRIBUTE.INTEREST                        = Interest
ATTRIBUTE.INTEREST.description            = My estimate of your positive attitude towards the problem.
ATTRIBUTE.ITEM                            = Item
ATTRIBUTE.ITEM.description                = The URL of the problem associated with this piece of evidence.
ATTRIBUTE.LEVELSET.0                      = 0
ATTRIBUTE.LEVELSET.I                      = I
ATTRIBUTE.LEVELSET.I2II                   = I,II
ATTRIBUTE.LEVELSET.I2III                  = I,II,III
ATTRIBUTE.LEVELSET.I2IV                   = I,II,III,IV
ATTRIBUTE.LEVELSET.II                     = II
ATTRIBUTE.LEVELSET.II2III                 = II,III
ATTRIBUTE.LEVELSET.II2IV                  = II,III,IV
ATTRIBUTE.LEVELSET.III                    = III
ATTRIBUTE.LEVELSET.III2IV                 = III,IV
ATTRIBUTE.LEVELSET.IV                     = IV
ATTRIBUTE.LIKING                          = Liking
ATTRIBUTE.LIKING.description              = The level of attraction you said you felt toward the problem.
ATTRIBUTE.MISCONCEPTION                   = Misconception
ATTRIBUTE.MISCONCEPTION.description       = All the misconceptions I have associated with your performance in the problem.
ATTRIBUTE.OTHERS                          = Other
ATTRIBUTE.PERFORMANCE                     = Performance
ATTRIBUTE.PERFORMANCE.100                 = very high
ATTRIBUTE.PERFORMANCE.20                  = very low
ATTRIBUTE.PERFORMANCE.40                  = low
ATTRIBUTE.PERFORMANCE.60                  = medium
ATTRIBUTE.PERFORMANCE.80                  = high
ATTRIBUTE.PERFORMANCE.description         = Your performance on this exercise, as evaluated by LeActiveMath.
ATTRIBUTE.PRIDE                           = Pride
ATTRIBUTE.PRIDE.description               = The level of attribution you said arose from your actions with the problem.
ATTRIBUTE.RELEVANCE                       = Impact factor
ATTRIBUTE.RELEVANCE.description           = The relative impact of this piece of evidence in supporting my judgement.
ATTRIBUTE.REPRESENTATION                  = Representation
ATTRIBUTE.REPRESENTATION.numeric          = Numeric
ATTRIBUTE.REPRESENTATION.symbolic         = Symbolic
ATTRIBUTE.REPRESENTATION.verbal           = Verbal
ATTRIBUTE.REPRESENTATION.visual           = visual
ATTRIBUTE.SATISFACTION                    = satisfaction
ATTRIBUTE.SATISFACTION.description        = The level of prospect you said arose from your results with the problem.
ATTRIBUTE.TITLE                           = Title
ATTRIBUTE.TITLE.description               = The title of the problem you interacted with.
ATTRIBUTE.TRUSTABILITY                    = Trustability
ATTRIBUTE.TRUSTABILITY.description        = An estimate of the trust I put in assessing your answers.
ATTRIBUTE.TYPE                            = Type
ATTRIBUTE.TYPE.description                = The nature of this piece of evidence.
ATTRIBUTE.USERINPUT                       = Input
ATTRIBUTE.USERINPUT.description           = What you typed or selected in this particular step in the problem.
ATTRIBUTE._UNKNOWN                        = ????
ATTRIBUTE._UNKNOWN.description            = There is a problem with this attribute.
```

Listing C.2. Verbalisation of the belief descriptor

```
# The argument numbers correspond to the layer in the belief descriptor (ie {0} is DOMAIN, {1} is COMPETENCY, etc.).
# The various templates below are combined, depending on the layers involved in the belief descriptor.
# The possible (ie well-formed) patterns are :
#      CAPES + DOMAIN
#      COMPET + DOMAIN
#      AFFECT + DOMAIN
#      AFFECT + COMPET + DOMAIN
#      MOTIV + DOMAIN
#      MOTIV + COMPET + DOMAIN
#      METACOG + AFFECT + DOMAIN
#      METACOG + AFFECT + COMPET + DOMAIN
#      METACOG + MOTIV + DOMAIN
#      METACOG + MOTIV + COMPET + DOMAIN
#
# It may be not to do this combination in other languages. In that case, it may be necessary to have a specific
# template for each of the possible pattern.

DESCRIPTOR.AFFECT     = your {3} of
DESCRIPTOR.CAPES      = the buggy-rule {5}
DESCRIPTOR.CASE.OLM   = your
DESCRIPTOR.CASE.USER  = my
DESCRIPTOR.COMPET     = your ability to {1}
DESCRIPTOR.DOMAIN     = on {0}
DESCRIPTOR.METACOG    = your {4} of
DESCRIPTOR.MOTIV      = your {2} in
```

Listing C.3. Verbalisation of dialogue moves

```
# Alternatives to similar template are materialised by CONTINUOUS index added to the key
# (ie DlgMove.Agree.Accept and DlgMove.Agree.Accept.1 are two variants of the same template).
# For all alternative templates, the arguments NEED to be the same and in the same order.
# Note that the main template (ie default) is mandatory but not the others.
# Every language can also have their own list of variants (eg 2 variants in english but only 1 in Spanish), as long
# as the default template is translated in ALL languages.
# Index are used by the OLM to randomly pick one of the templates.
# Nature and order of arguments of templates depends on each specific dialogue move and its application context.
```

```
DlgMove.Agree.Accept                                  = Yes, why not.
DlgMove.Agree.Accept.1                                = Yes, sure.
DlgMove.Agree.Accept.2                                = OK.
DlgMove.Agree.Agree                                   = I agree with your claim.
DlgMove.Agree.Agree.1                                 = I agree with you.
DlgMove.Agree.Disagree                                = I disagree with your claim that I am {0}.
DlgMove.Agree.Disagree.1                              = I disagree with you, I am not {0}.
DlgMove.Agree.Disagree.2                              = I disagree with you.
DlgMove.Agree.MoveOn                                  = Let''s change the topic of discussion, please.
DlgMove.Agree.MoveOn.1                                = Could we talk about something else, please?
DlgMove.Agree.Reject                                  = I don''t want to do that.
DlgMove.Agree.Reject.1                                = I don''t want to do that.
DlgMove.Baffled.BACKING                               = Please explain what this interaction was about.
DlgMove.Baffled.BACKING.1                             = I don''t understand what this interaction was about.
DlgMove.Baffled.CLAIM                                 = I don''t understand why you think I''m {0}.
DlgMove.Baffled.CLAIM.1                               = Could you tell me why you think I am {0}?
DlgMove.Baffled.DATA                                  = I don''t understand how you obtained this profile.
DlgMove.Baffled.SUBCLAIM                              = Could you tell me more about your evidence on the {0} group?
DlgMove.Baffled.WARRANT                               = I don''t understand how you devised this piece of evidence
DlgMove.Baffled.What                                  = I don''t know what to do now.
DlgMove.Baffled.What.1                                = What should I do now?
DlgMove.HereIs.BACKING                                = Here is what I know about evidence {0}
DlgMove.HereIs.BACKING.ExerciseFinished               = Because you did this {0} exercise with a {1} performance.
DlgMove.HereIs.BACKING.ExerciseStep                   = Because you did this {0} step with a {1} performance.
DlgMove.HereIs.BACKING.OLMChallenge                   = Because you told me that {0} was not {1} but {2}
DlgMove.HereIs.BACKING.OLMChallenge.AGREE             = Because you agreed with me that {0} was {1}
DlgMove.HereIs.BACKING.OLMChallenge.DISAGREE          = Because you told me that {0} was not {1} but {2}
DlgMove.HereIs.BACKING.OLMMetacog                     = Because you showed a {0} tenacity in {1} {2}.
DlgMove.HereIs.BACKING.SelfReport                     = Because you told me that your {0} was {1} on this exercise.
DlgMove.HereIs.BACKING.SituationFactorChanged         = Because your {0} on this exercise changed to {1}
DlgMove.HereIs.CLAIM                                  = Here is the evidence for me to think you are {0}
DlgMove.HereIs.CLAIM.flat                             = Evidence is ambivalent about your ability so I can only make a safe guess.
DlgMove.HereIs.CLAIM.highagainst                      = Even if the most likely justification would be to say {0}, I still have
                                                        to take into account the other levels.
DlgMove.HereIs.CLAIM.highfor                          = Because most of the collected evidence strongly supports you to be {0}.
DlgMove.HereIs.CLAIM.lowagainst                       = The dominant trait may be {0}, but I cannot dismiss the evidence supporting
                                                        the other levels.
DlgMove.HereIs.CLAIM.lowfor                           = Because there is a marginal amount of evidence supporting my claim for {0}.
DlgMove.HereIs.DATA                                   = Here are all the individual pieces of evidence for me to think you are {2}
DlgMove.HereIs.DATA.NOCLUSTER                         = Here are all the individual pieces of evidence for me to think you are {2}
DlgMove.HereIs.DATA.NOCLUSTER.1                       = On all the pieces of evidence I can use to justify you being {2}, these {1}
                                                        are the most important.
DlgMove.HereIs.DATA.NOCLUSTER.2                       = There are the {0} pieces of evidence I can use to justify you being {2}.
                                                        Let''s have a look at the most important.
DlgMove.HereIs.DATA.PERFORMANCE                       = Looking at the evidence according to your {1}, my judgement is mostly based
                                                        on the {0} piece(s) in the {2} group.
DlgMove.HereIs.DATA.PERFORMANCE.1                     = Looking at the evidence according to your {1}, my judgement is mostly based
                                                        on the {0} piece(s) in the {2} group.
DlgMove.HereIs.DATA.PERFORMANCE.2                     = Looking at the evidence according to your {1}, my judgement is mostly based
                                                        on the {0} piece(s) in the {2} group.
DlgMove.HereIs.Evidence                               = Here is the evidence for {0}
DlgMove.HereIs.SUBCLAIM                               = Here are the most important pieces of evidence showing {2} {3}
DlgMove.HereIs.SUBCLAIM.1                             = Among the evidence showing {2} {3}, these {1} are the most important.
DlgMove.HereIs.SUBCLAIM.2                             = {1} among the {0} pieces of evidence are strong enough to explain {2} {3}.
DlgMove.Perhaps.Error                                 = I don't understand your question.
DlgMove.Perhaps.Ignore                                = I''m afraid I know nothing on {0}.
DlgMove.Perhaps.Ignore.1                              = I''m afraid I have no evidence on {0}.
DlgMove.Perhaps.Judgment                              = I think you are {0} on {1}.
DlgMove.Perhaps.Judgment.1                            = {1} seems to be at {0}.
DlgMove.Perhaps.Judgment.2                            = I think you are {0} .
DlgMove.Quit.Bye                                      = Well, see you very soon ...
DlgMove.Quit.Prompt                                   = It was a nice talk but I need to go now.
DlgMove.ShowMe.Think                                  = Show me what you think about {0}.
DlgMove.ShowMe.Think.1                                = Give me your judgement on {0}.
DlgMove.Startup.LeAM                                  = Welcome my dear {0}. Why don''t you have a look at {1}?
DlgMove.Startup.LeAM.1                                = {0}, can I suggest to have a look at {1}?
DlgMove.Startup.OLM                                   = Welcome {0}.
DlgMove.Startup.OLM.1                                 = Nice to see you back, {0}.
DlgMove.Startup.User                                  = Welcome my dear {0}. What brings you here today?
DlgMove.Startup.User.1                                = Ready for a journey into yourself, {0}?
DlgMove.Swap.BELIEF.MASSDISTRIB                       = Here is the mass distribution, showing all information from accumulated
                                                        evidence.
DlgMove.Swap.BELIEF.PIGNISTIC                         = Here is the pignistic distribution, spreading all information from
                                                        accumulated evidence on each of the ability levels.
DlgMove.Swap.EVIDENCE.DECAYED                         = Since evidence tends to be less certain over time, here is the mass as it is
                                                        now considered in the belief.
DlgMove.Swap.EVIDENCE.EVIDENCE                        = Here is the complete mass of this piece of evidence, as it was initially
                                                        generated.
DlgMove.Swap.Prompt                                   = Show me another view of this information.
DlgMove.Swap.Prompt.1                                 = Show me another view of this information.
DlgMove.Swap.Prompt.2                                 = Show me another view of this information.
DlgMove.TellMeMore.BELIEF                             = Represent my guesses of your ability, in term of the probability for you to
                                                        be at the various levels.
DlgMove.TellMeMore.DESCRIPTOR                         = You are telling me which ability to judge. Currently, you are looking at {0}.
DlgMove.TellMeMore.DESCRIPTOR.Empty                   = You need to tell me which ability to judge by selecting and combining topics
                                                        from the domain list, the competency list and the others.
DlgMove.TellMeMore.EVIDENCE                           = Each individual interaction is considered as a piece of evidence in my
                                                        judgement.
DlgMove.TellMeMore.Prompt                             = I don''t understand what this means.
DlgMove.TellMeMore.Prompt.1                           = Could you remind me what this is about?
DlgMove.TellMeMore.SUMMARY                            = This graph represents my judgement of your {0}, on a continuous scale
                                                        between {1} and {2}.
DlgMove.TellMeMore.SUMMARY.ABOVE                      = Being very close to the {0} indicator, my conviction on my judgement is
                                                        therefore quite strong.
DlgMove.TellMeMore.SUMMARY.ABOVE.AWAY                 = Since your ability level is quite distant from the {0} indicator, my
                                                        conviction is not very strong, as you could as well be {1}.
DlgMove.TellMeMore.SUMMARY.BELOW                      = Being very close to the {0} indicator, my conviction on my judgement is
                                                        therefore quite strong.
DlgMove.TellMeMore.SUMMARY.BELOW.AWAY                 = Since your ability level is quite distant from the {0} indicator, my
                                                        conviction is not very strong, as you could as well be {1}.
DlgMove.Unravel.NoIdea                                = I can only advise you to explore the topics you are more familiar with.
DlgMove.Unravel.NoIdea.1                              = I don''t have any suggestion for you, feel free to explore whatever you want.
DlgMove.Unravel.Suggest                               = Perhaps you should explore {1}.
DlgMove.Unravel.Suggest.1                             = Why not having a look at {1}?
```

```
DlgMove.Unravel.Suggest.2           = I will suggest to look at {1}.
DlgMove.Unravel.Urge                = We didn''t finish our discussion on {1} last time. Why don''t we have a
                                      look again?
DlgMove.Unravel.Urge.1              = Why don''t we have a look at {1} again?
DlgMove.WindUp.Accept               = I am {0} to be {1} on {2}.
DlgMove.WindUp.Challenge            = In this case, what is your own judgement about the situation?
DlgMove.WindUp.Moveon               = Let''s change the topic of discussion, please.
DlgMove.WindUp.Resolved             = That''s OK, I will make sure to take this fact into account.
DlgMove.WindUp.Unresolved           = Fine, but we will have to come back to this issue later.
```

Listing C.4. Verbalisation of the mass distributions

```
# Templates for the description of the various probability distributions (ie belief and evidence mass distributions,
# pignistic and summary).
# Special cases (such as empty set, ignorance and conflict) are treated by specialisation of the generic template.
# In all the following templates, {0} stands for the percentage and {1} for the set (eg I, I-II, I-II-III, etc) associated.

MASS.DECAYED.description              = This interaction suggest a {0} chance that you are {1}
MASS.DECAYED.description.I2IV         = Ignorance related to this interaction amount to {0}
MASS.DECAYED.description.empty        = This interaction does not suggest you are {1}
MASS.DECAYED.name                     = Mass Distribution
MASS.EVIDENCE.description             = This interaction initially suggested a {0} chance that you were at {1}
MASS.MASSDISTRIB.description          = {0} of all collected information suggest you are {1}
MASS.MASSDISTRIB.description.0        = {0} of all collected information are conflicting evidence
MASS.MASSDISTRIB.description.I2IV     = {0} of all collected information amount to ignorance
MASS.MASSDISTRIB.description.empty    = no evidence for {1}
MASS.MASSDISTRIB.name                 = Mass Distribution
MASS.PIGNISTIC.description            = Evidence suggests that there is a {0} chance that you are {1}
MASS.PIGNISTIC.name                   = Pignistic
```

Listing C.5. Verbalisation of the topic maps

```
# Layer description and levels verbalisation for the different topic maps
# Note that the topics contained in each map are verbalised in a different package.

OLMTopicConfig.AFFECT.Level1          = Level I
OLMTopicConfig.AFFECT.Level2          = Level II
OLMTopicConfig.AFFECT.Level3          = Level III
OLMTopicConfig.AFFECT.Level4          = Level IV
OLMTopicConfig.AFFECT.Name            = Affect
OLMTopicConfig.CAPES.Level1           = Level I
OLMTopicConfig.CAPES.Level2           = Level II
OLMTopicConfig.CAPES.Level3           = Level III
OLMTopicConfig.CAPES.Level4           = Level IV
OLMTopicConfig.CAPES.Name             = CAPEs
OLMTopicConfig.COMPET.Level1          = Level I
OLMTopicConfig.COMPET.Level2          = Level II
OLMTopicConfig.COMPET.Level3          = Level III
OLMTopicConfig.COMPET.Level4          = Level IV
OLMTopicConfig.COMPET.Name            = Competency
OLMTopicConfig.DOMAIN.Level1          = Level I
OLMTopicConfig.DOMAIN.Level2          = Level II
OLMTopicConfig.DOMAIN.Level3          = Level III
OLMTopicConfig.DOMAIN.Level4          = Level IV
OLMTopicConfig.DOMAIN.Name            = Domain
OLMTopicConfig.METACOG.Level1         = Level I
OLMTopicConfig.METACOG.Level2         = Level II
OLMTopicConfig.METACOG.Level3         = Level III
OLMTopicConfig.METACOG.Level4         = Level IV
OLMTopicConfig.METACOG.Name           = Metacognition
OLMTopicConfig.MOTIV.Level1           = Level I
OLMTopicConfig.MOTIV.Level2           = Level II
OLMTopicConfig.MOTIV.Level3           = Level III
OLMTopicConfig.MOTIV.Level4           = Level IV
OLMTopicConfig.MOTIV.Name             = Motivation
```

Listing C.6. Verbalisation of the competency topics (Extract)

```
# Templates used for the TITLE and DESCRIPTION (eg tooltips) of the COMPETENCY topics

COMPET.competency.description       = Mathematical competencies represent your cognitive abilities to deal with learning material
                                      presented to you.
COMPET.competency.title             = Mathematical Competency
COMPET.think.description            = Includes the ability to pose questions that are characteristic for mathematics, understand
                                      and handle the scope and limitations of a given concept, make assumptions, distinguish
                                      between different kinds of mathematical statements.
COMPET.think.title                  = Think mathematically
COMPET.model.description            = includes the ability to identify, pose and specify problems, self-constitute problems,
                                      monitor and reflect on the process of problem solving, endue strategies / heuristics, solve
                                      different kinds of problems (with various contexts outside of mathematics, open-ended
                                      exercises).
COMPET.model.title                  = Model mathematically
COMPET.represent.description        = includes the ability to understand and utilize (decode, interpret, distinguish between)
                                      different sorts of representation (e.g., diagrams and tables) of mathematical objects,
                                      phenomena, and situations, find relations between different kinds of representation,
                                      choose the appropriate representation for the special purpose
COMPET.represent.title              = Use mathematical representations.
COMPET.communicate.description      = includes the ability to explain solutions, use a special terminology, work in groups,
                                      including to explain at the adequate level, understand and verify mathematical statements
                                      of others.
COMPET.communicate.title            = Communicate
COMPET.argue.description            = includes the ability to develop and assess chains of arguments (explanations, reasons,
                                      proofs), know what a mathematical proof is and what not, describe solutions and give reasons
                                      for their correctness or incorrectness, uncover the basic ideas in a given line of
                                      arguments, understand reasoning and proof as fundamental aspects of mathematics.
COMPET.argue.title                  = Argue mathematically
COMPET.tools.description            = includes the ability to know about the existence of various tools and aids for mathematical
                                      activities, and their range and limitations, to reflectively use such tools and aids.
```

```
COMPET.tools.title               = Use tools
COMPET.language.description      = includes the ability to use parameters, terms, equations and functions to model and
                                   interpret, translate from symbolic and formal language into natural language and the other
                                   way round, decode and interpret symbolic and formal mathematical language and understand
                                   its relations to natural language.
COMPET.language.title            = Deal with symbolic elements
COMPET.solve.description         = includes the ability to translate special areas and contents into mathematical terms, work
                                   in the model, interpret and verify the results in the situational context, point out the
                                   difference between the situation and the model.
COMPET.solve.title               = Solve problems
```

Listing C.7. Verbalisation of the affect topics

```
# Templates used for the TITLE and DESCRIPTION (eg tooltips) of the AFFECT topics

AFFECT.affect.description       =
AFFECT.affect.title             = Affect
AFFECT.anxiety.description      = The feelings of tension that interfere with the manipulation of mathematical numbers
                                  and the solving of mathematical problems in a wide variety of ordinary life and academic
                                  situations.
AFFECT.anxiety.title            = Mathematical Anxiety
AFFECT.liking.description       = The level of attraction arising from the current object of attention.
AFFECT.liking.title             = Liking/Disliking
AFFECT.pride.description        = The level of attribution arising form the current action(s).
AFFECT.pride.title              = Pride/Shame
AFFECT.satisfaction.description = The Level of prospect arising from the consequences of the current events.
AFFECT.satisfaction.title       = Satisfaction/Disapointment
```

Listing C.8. Verbalisation of the motivation topics

```
# Templates used for the TITLE and DESCRIPTION (eg tooltips) of the MOTIVATION topics

MOTIV.confidence.description = The level of positive self-belief in relation to your ability to tackle and solve problems.
MOTIV.confidence.title       = Confidence
MOTIV.effort.description     = The amount of work done on completed task(s).
MOTIV.effort.title           = Effort
MOTIV.interest.description   = The level of positive attitude towards completed task(s).
MOTIV.interest.title         = Interest
MOTIV.motivation.description =
MOTIV.motivation.title       = Motivation
```

Listing C.9. Verbalisation of the metacognition topics

```
# Templates used for the TITLE and DESCRIPTION (eg tooltips) of the METACOGNITION topics

METACOG.control.description         = The ability to consciously and deliberately regulate your own cognitive and affective
                                      processes and states.
METACOG.control.title               = Control
METACOG.metacognition.description   =
METACOG.metacognition.title         = Metacognition
METACOG.monitoring.description      = The ability to actively becoming conscious of your own cognitive and affective processes
                                      and states.
METACOG.monitoring.title            = Monitoring
```

Listing C.10. Verbalisation of the domain topics (Extract)

```
# Templates used for the TITLE and DESCRIPTION (eg tooltips) of the DOMAIN topics

DOMAIN.diff_calculus.description      = The part of calculus that deals with the variation of a function with respect to
                                        changes in the independent variable (or variables) by means of the concepts of
                                        derivative and differential
DOMAIN.diff_calculus.title            = Differential Calculus
DOMAIN.diff_quotient.description      = The difference of the change of a function over a given interval.
DOMAIN.diff_quotient.title            = Difference Quotient
DOMAIN.rules_basic.description        = Governs the differentiation of basic functions
DOMAIN.rules_basic.title              = Basic Function Rules
DOMAIN.rules_chain.description        = Governs the differentiation of the composition of two functions.
DOMAIN.rules_chain.title              = Chain Rule
DOMAIN.rules_cst.description          = Governs the differentiation of a constant
DOMAIN.rules_cst.title                = Constant Rule
DOMAIN.rules_diff.description         = Governs the differentiation of the difference of two differentiable functions.
DOMAIN.rules_diff.title               = Difference Rule
DOMAIN.rules_invfunct.description     = Governs the differentiation of the inverse of a differnetial function
DOMAIN.rules_invfunct.title           = Inverse Function Rule
DOMAIN.rules_power.description        = Governs the differentiation of the power function.
DOMAIN.rules_power.title              = Power Rule
DOMAIN.rules_product.description      = Governs the differentiation of products of differentiable functions.
DOMAIN.rules_product.title            = Product Rule
DOMAIN.rules_quotient.description     = Governs the differentiation of a function which is the quotient of two
                                        differentiable functions.
DOMAIN.rules_quotient.title           = Quotient Rule
DOMAIN.rules_sum.description          = Governs the differentiation of the sum of two differentiable functions.
[...]
```