History

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Reason of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2011-07-11</td>
<td>Document created</td>
</tr>
<tr>
<td>2</td>
<td>2011-08-15</td>
<td>Report draft transferred from Google document</td>
</tr>
<tr>
<td>3</td>
<td>2011-08-26</td>
<td>Amendments made according to internal review comments</td>
</tr>
<tr>
<td>4</td>
<td>2011-08-31</td>
<td>Inclusion of CBS' content</td>
</tr>
<tr>
<td>5</td>
<td>2011-08-31</td>
<td>Final version</td>
</tr>
<tr>
<td>6</td>
<td>2011-08-31</td>
<td>Some minor corrections</td>
</tr>
<tr>
<td>7</td>
<td>2011-08-31</td>
<td>Inclusion of previously omitted screen captures – final version for submission</td>
</tr>
</tbody>
</table>

Impressum

Full project title: Next Generation Teaching, Education and Learning for Life
Grant Agreement No: 285114
Workpackage Leader: Susan Bull, BHAM
Project Co-ordinator: Harald Mayer, JRS
Scientific Project Leader: Peter Reimann, MTO

Acknowledgement: The research leading to these results has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 258114.

Disclaimer: This document does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of its content.

This document contains material, which is the copyright of certain NEXT-TELL consortium parties, and may not be reproduced or copied without permission. All NEXT-TELL consortium parties have agreed to full publication of this document. The commercial use of any information contained in this document may require a license from the proprietor of that information.

Neither the NEXT-TELL consortium as a whole, nor a certain party of the NEXT-TELL consortium warrant that the information contained in this document is capable of use, nor that use of the information is free from risk, and does not accept any liability for loss or damage suffered by any person using this information.
# Table of Contents

1 Executive Summary .................................................................................................................. 1

2 Introduction................................................................................................................................. 4
   2.1 Purpose of this Document ...................................................................................................... 4
   2.2 Scope of this Document ......................................................................................................... 4
   2.3 Status of this Document ........................................................................................................ 4
   2.4 Related Documents ................................................................................................................ 5

3 OLM Design ................................................................................................................................. 6
   3.1 Open Learner Modelling ....................................................................................................... 6
   3.2 Visualising the Learner Model ............................................................................................... 6
   3.3 Open Learner Model Stakeholders ....................................................................................... 7
   3.4 The OLM as a Web Service .................................................................................................. 8

4 About Release One ......................................................................................................................... 10
   4.1 SMILI specification ............................................................................................................... 10

5 OLM Prototype .......................................................................................................................... 14
   5.1 Information Content ............................................................................................................. 14
      5.1.1 Simple Example ............................................................................................................. 14
      5.1.2 Learner Model Information .......................................................................................... 14
   5.2 Visual Methods ..................................................................................................................... 16
      5.2.1 Default set of visualisations ......................................................................................... 16
      5.2.2 Student ......................................................................................................................... 16
      5.2.3 Teacher ........................................................................................................................ 19
      5.2.4 Rendering Process ........................................................................................................ 20
   5.3 Component Access ............................................................................................................... 21
   5.4 OLM Browser/Filter (Basic) ................................................................................................. 22

5.5 Modelling Process ..................................................................................................................... 24
   5.5.1 Create activity .................................................................................................................. 24
   5.5.2 Define Source Type ......................................................................................................... 25
   5.5.3 Assign Activity to Student ............................................................................................... 25
   5.5.4 Add New Data ................................................................................................................. 26
   5.5.5 Associating Students ....................................................................................................... 26
   5.5.6 Retrieving Data from the Database .................................................................................. 27
   5.6 Summary .............................................................................................................................. 28

6 Evaluation of OLM Mock-Ups Using Eye-Tracking .................................................................... 29
   6.1 Theoretical Framework ........................................................................................................ 29
      6.1.1 Perception and Appropriation of Socio-Technical Affordances ................................... 30
      6.1.2 Representational Guidance ........................................................................................... 30
      6.1.3 Cognitive Dimensions of Notations .............................................................................. 32
   6.2 Participants, Materials and Methods ..................................................................................... 33
      6.2.1 Materials ....................................................................................................................... 34
      6.2.2 Participants .................................................................................................................... 40
D4.2
Student Model Tools R1

6.2.3 Methods ........................................................................................................ 40

6.3 Eye Tracking Outcomes .................................................................................. 41
  6.3.1 Mean View Time .................................................................................... 42
  6.3.2 Mean Emotional Activation .................................................................... 42
  6.3.3 Skill Meters ............................................................................................ 44
  6.3.4 Smiley Metaphor .................................................................................... 45
  6.3.5 Traffic Light Metaphor ........................................................................... 47
  6.3.6 Topic Checkboxes .................................................................................. 48
  6.3.7 Group Histograms .................................................................................. 50
  6.3.8 Word Clouds ............................................................................................ 51
  6.3.9 Textual Descriptions .............................................................................. 52
  6.3.10 Table ..................................................................................................... 54
  6.3.11 Matrix .................................................................................................... 55

6.4 Canonical Abstract Prototypes of Dynamic Visualisations of an OLM .......... 56
  6.4.1 Dynamic Visualisations of Open Learner Models ................................ 57

6.5 Summary ........................................................................................................ 60

7 Repertory Grid Technique: Modelling Student Constructs .......................... 61
  7.1 Repertory Grid Technique ......................................................................... 61
  7.2 Triadic Method of Teaching Analytics (TMTA) .......................................... 61
  7.3 Methodology ............................................................................................... 63
    7.3.1 Classroom Setting ............................................................................... 63
    7.3.2 FARGO: A Facebook Implementation of the Repertory Grid Technique ................................................................. 64
    7.3.3 Study #1: Repertory Grid Classroom Exercise on Consumer Decision-Making .......................................................... 64
    7.3.4 Study #2: Repertory Grid Classroom Exercise on Online Marketing Topics .......................................................... 65
    7.3.5 Study #3: Eye-Tracking Laboratory Study of Repertory Grid Exercise of Online Marketing Topics ........................................... 66
    7.3.6 Study #4: Eye-Tracking Laboratory Study of Multiple Representations of Repertory Grid Data for Consumer Decision-Making ........................................................................ 67

7.4 Results .......................................................................................................... 69
  7.4.1 Study #1: Repertory Grid Classroom Exercise on Consumer Decision-Making .......................................................... 69
  7.4.2 Study #2: Repertory Grid Classroom Exercise on Online Marketing Topics .......................................................... 70
  7.4.3 Study #3: Eye-Tracking Laboratory Study of Repertory Grid Exercise of Online Marketing Topics ........................................... 70
  7.4.4 Study #4: Eye-Tracking Laboratory Study of Multiple Representations of Repertory Grid Data for Consumer Decision-Making ........................................................................ 76

7.5 Discussion ..................................................................................................... 87
  7.5.1 Implications for Teachers ..................................................................... 87
  7.5.2 Implications for Students ..................................................................... 88
  7.5.3 Implications for Researchers ................................................................. 88
  7.5.4 Implications for Design of RGFA R1 ..................................................... 88
  7.5.5 Future Work: TMTA, Repertory Grid and Open Learner Models .......... 89

8 Summary .......................................................................................................... 90

9 References ........................................................................................................ 91

10 Glossary .......................................................................................................... 94

11 Appendix A: Eye Tracker Diagram Interpretation ........................................ 96

12 Appendix B: Repertory Grids for Formative Assessment (RGFA) Application .................................................. 98

© NEXT-TELL consortium: all rights reserved
1 Executive Summary

Learner models (LM) enable educational environments to adapt to the individual learner’s specific and current educational needs (Holt, 1994). They are the system’s representation of educational data pertaining to the learner, such as their mastery, conceptual knowledge, difficulties, learning goals, motivational states, etc. Opening the LM to the user can have benefits such as prompting reflections and collaboration; facilitating navigation; and enhancing user trust. It can also be used by others (e.g. teachers to help their decision making.) Methods for visualising the content of the learner model are varied and often highly graphical and textual.

Application of open learner modelling (OLM) to the needs of NEXT-TELL implies learner model enquiry based on one specific activity or purpose (that may be currently undertaken) or general enquiry into progress, strengths, weaknesses etc. at different levels of abstraction. Access to the learner model is via a web service. This requires:

- **Interface Pages** (e.g. that contain information about specific activities)
- **OLM Visualisation Components** (individual components/views/visualisations that detail a specific element of the OLM, which can be embedded into other NEXT-TELL components e.g. homepage.)
- **OLM Browser.** All information that the user is able/allowed to access is available for inspection on different levels of abstraction, using a filter mechanism, which supports both browse and search methodologies.

The first release of the OLM prototype is a proof of concept piece of technology. Development focuses on the ‘knowledge level information’ facet primarily, as this facet is established in existing OLM systems and first stage of development is to apply this to NEXT-TELL. A full description of how this matches the proposed SMILII specification is given in Section 5.1. The information stack for the prototype is as Figure 1.

![Figure 1: Learner Model Information Stack](image)

Information is held for individual students and modelled at the level of each information source (centre left of Figure 1). Information about other elements of the stack (e.g. activities, groups, subject areas) is derived through combination of information from individual data sources, from each individual student. There are two main entities within the stack: the *information* that is modelled for the student and their learning (left of Figure 1) and information about how the student *relates to other people/stakeholders* (right of Figure 1).

Nine visualisation methods are provided for users of the OLM prototype (Table 1). These are presently a default set.
The visual methods used to externalise the underlying learner model are accessed through the HTTP protocol. The URL used to access the content is meaningful, composed of the parameters required to retrieve the information from the learner model database. For example, the URL may need to identify the person and the context, identify the type of information to which access is requested and specify additional parameters. In release 1 the order of URL components is as follows (all constituents of the URL path are optional for inclusion) 
/stakeholder-type/user_id/institution/group/subject/module/topic/concept/activity/source/visualisation_type

The OLM browser allows the content of the learner model to be inspected and browsed/searched using a filter mechanism. This is particularly aimed at supporting enquiry into learning (whether it is performed by the student or teacher), and also aimed at supporting navigation to a specific part of the model.

The LM is a weighted model. Modelling takes place at the level of each constituent information source. Figure 2 shows the steps required to configure an activity and to add data. This is further discussed in Section 5.5.

Figure 2: Configuring and Updating the Learner Model
Section 6 details an evaluation of interface elements in an educational setting using eye tracking equipment. The evaluation focuses on elements of interpretation and emotional response and has yielded a series of recommendations for the implementation of simple mocked up interface components. Analysis is conducted using heat maps and ‘areas of interest’ analysis (e.g. Figure 3.) A series of recommendations for OLM interface components are made. We apply these recommendations to the development of a canonical prototype (“DV-OLM”) that is currently undergoing evaluation.

Section 7 details the use of the repertory grid technique as a data source for the learner model. We describe the technique in the context of the project and ways in which the technique may be used to capture students’ constructs about knowledge and evaluate this in a learning scenario (Section 7.3). Through the use of eye tracking equipment we evaluate students’ visual attention to a deployment of the repertory grid technique through Facebook (Figure 3c), and also students’ visual attention to several simple visualisations of their repertory grid data (Section 7.4).

The progress detailed in this report is a milestone in the development of the NEXT-TELL OLM service. The design, architecture and evaluation we have detailed will allow is to move forward into the next phase of development and integration of the OLM.
2 Introduction

2.1 Purpose of this Document

This document focuses on workpackage 4 of the NEXT-TELL project. This, the month 12 deliverable, reports on the first version of the open learner model prototype. We use the term 'learner model' rather than 'student model' because workpackage 4 focuses on learning both inside and outside the school setting (learners may undertake activities that are not primarily part of their 'student' role, but where the outcomes still provide input to their model). It presents an overview of the current stage in development together with design information for the architecture and interface, and evaluation of interface elements using two eye-tracking studies.

Work is conducted in the context of the following three components of the workpackage:

Task 4.1 Open learner model architecture: what specific learner model data should be represented and from what sources of evidence should it be collated. The approach taken should be evidence based (both computerised and human information sources). Information should be collated and made available as is appropriate for each stakeholder. The architecture needs to be flexible and should be able to encompass information formats that do not yet exist. The initial focus is on knowledge, skills and abilities (KSAs), expanding to epistemic beliefs and finally information about knowledge building, as the project progresses.

Task 4.2 Representing and visualising learner models: how open learner model information is presented (including information that is non KSA based), according to each stakeholder type (student, teacher, parent, peer, school administrators etc.).

Task 4.3 Communicating and negotiating learner models: how HCI, usability and learnability of open learner models are affected in the metrics of reflection, planning (student and teacher), peer comparisons, negotiation and the ECAAD methodology. Stakeholder analysis and participatory design workshops are important sources of information to influence design. Later in the project this part of the workpackage will focus on scenario-based design and evaluation of communication and negotiation tool prototypes.

2.2 Scope of this Document

This document covers the workpackage 4, month 12 deliverable:

- The open learner model (OLM) prototype in the context of the NEXT-TELL project
- Basic LM and OLM prototype architecture
- Basic OLM prototype learner model visualisation methods
- Evaluation of the default set of visualisation methods
- Repertory grid analysis

2.3 Status of this Document

This is the final version of D4.2.
2.4 Related Documents

The content of this report complements that which is contained in the following documents, as part of the month twelve deliverable:

- D2.2 ECAAD Tools R1
- D3.2 Activity Capturing Tools R1
- D5.2 TISL Components R1

The reader should be familiar with the following documents prior to the reading of this report:

- D4.1 Methods and Specification for Student Model V1
3 OLM Design

3.1 Open Learner Modelling

Learner models enable educational environments to adapt to the individual learner’s specific and current educational needs (Holt, 1994). They are the system’s representation of educational data pertaining to the learner, such as their mastery, conceptual knowledge, difficulties, learning goals, motivational states, etc.

Open Learner Model is the term commonly used for learner models that are accessible to the user (Bull and Kay, 2010). This accessibility to the learner model includes visualisation of the model contents to the user and allows learner access to the LM’s content in a meaningful way, and in many cases at any point they choose. A visualisation is the externalised representation of the underlying learner model, such as skill meters indicating strength of knowledge of topics (Mitrovic and Martin, 2007); or more complex representations portraying conceptual relationships (Mabbott and Bull, 2006) (Perez-Marin et al., 2010)). Learner responsibility, awareness and independence in learning are argued as benefits of viewing an OLM, and metacognitive activities such as self-assessment, planning and reflection may be promoted (Bull and Kay, 2010) (Van Labeke et al., 2008) (Mabbott and Bull, 2007).

3.2 Visualising the Learner Model

Possible methods for visualising the learner model are diverse, as shown in Figure 4. Information may originate from the model of one learner, or may be aggregated from the learner models of many students. Information presented may also contain varied levels of granularity ranging from knowledge level information to specific beliefs, misconceptions and interrelationships between knowledge. Different stakeholders in the learning process require different aspects of OLM presentations. For example, students and parents may be more concerned with finely grained information from a single learner model (top right); teachers may in addition be interested in aggregated models of the whole class (centre) – though in some cases this may also be relevant for students and parents; whilst school administrators and policy makers may be more concerned with information at a national or institutional level (bottom left), rather than specific beliefs learners hold.

There is a clear diagonal trend in information that may be presented with sufficient clarity. Information that is very fine-grained may be easily represented for single and small groups of students (top right), for use in the classroom or at home. However, it is more difficult to visualise large numbers of beliefs, which for the most part may be pseudo-unique and domain-specific (bottom right). Information that draws on such a large number of learner models may be presented clearly with very coarse granularity, for example at a national level, using geographic information (bottom left). Information this coarse requires many learner models to allow meaningful inferences to be made: for example, presenting information about the progress of different class groups in a school. To date, most work on open learner modelling has focussed on opening the learner model to individual or relatively small groups of students, using knowledge level and belief information (top middle/right), and so emerging open learner model presentations are those that visualise data pertaining to greater numbers of students. In NEXT-TELL, stakeholders are to use OLM information in new contexts (e.g., in real time, to influence classroom activities; to see how student progress compares to other students at a national level), which mandates state-of-the-art visualisation methods be used to present information clearly, in alignment with current practices and pedagogical strategies. Methods such as tag clouds, network maps and sparklines will be important in aggregating information that may be interpreted ‘at a glance’. 
3.3 Open Learner Model Stakeholders

To illustrate the uses of NEXT-TELL OLMs by the various stakeholders, we offer the following examples:

- **Student**: Using an adaptive learning environment as part of a classroom activity; planning future learning based on information presented in their OLM.
- **Parent**: Providing support to the student; monitoring student progress; providing additional information to the system, about the student.
- **Peer**: A student helps another student who is struggling; students collaborate to comprehend a problem—centred on inspection of their respective learner models.
- **Teacher**: Just-in-time feedback on a classroom activity; planning future learning activities.
- **School Administrators**: Monitoring school educational targets; identification of extra support required.
- **Policy Maker**: Budget setting; making a decision as to whether a current strategy is working.
- **Researcher**: Evaluation of pedagogical strategies; evaluation of the use of software tools.

In terms of other aspects of the project, the OLM is required to support student enquiry into their learning and the learning outcomes of specified activities, such as those created using the Evidence Centred Activity and Appraisal Design tool (ECAAD), whether STEM or language based. This enquiry may be made in a classroom or home scenario, and multiple requests for feedback may be made in quick succession on a specific activity that is...
being undertaken, or the enquiry may form more general browsing of the model’s contents, and tendering information not linked to any ECAAD activity. Similarly teacher enquiry into student learning (TISL) must be supported asynchronously to classroom activity. In Section 3.4 we elaborate on these points to consider how the OLM may support these different elements of the project in terms of release 1 of the OLM prototype.

3.4 The OLM as a Web Service

In the context of NEXT-TELL, the OLM web service (summarised in Figure 5) is a software system which supports machine-machine interaction over a network. Using special HTML interfaces, machine-human interaction is also supported, with the content being displayed in a web browser. The HTTP protocol is used to access the content of the underlying learner model. Access falls into two categories: (i) input – updating the content of the learner model, with new inferences and configuration settings; and (ii) output – conducting enquiry into the learner model content. The external representation of the learner model (LM) is referred to as the open learner model (OLM).

Application of LM enquiry to the needs of NEXT-TELL implies two modes of interaction:

- Enquiry based on one specific activity or purpose (that may be currently undertaken). This user making the enquiry may already know which part of the model they require information from; they may make the same enquiry multiple times in quick succession, for example during the completion of an activity that is facilitated through use of the ECAAD planner.
- General enquiry into progress, strengths, weaknesses etc. at different levels of abstraction. This may be unrelated to any specific activity or learning episode. For example enquiry may be undertaken to gain a general overview of understanding as part of an episode of reflection.

Enquiry may take place not only by humans, but also by other pieces of software. Elements of the OLM may also be embedded into other NEXT-TELL components, such as the homepage or an interface designed to support defined classroom activities. Figure 2 breaks down LM enquiry into three types of OLM resources: (i) OLM browser; (ii) OLM interface pages; and (iii) individual visual components/representations of the underlying LM:

(i) OLM Browser. All information that the user is able/allowed to access is available for inspection on different levels of abstraction, using a filter mechanism, which supports both browse and search methodologies. Filtering is a dynamic search method, where results are updated each time a parameter is changed, this allows for browsing and supports serendipity (finding answers by chance that the user did not expect to find).

(ii) Interface Pages. These contain information about specific activities (e.g. pages produced to give real-time feedback in a classroom setting.) These may be embedded into other activity facilitators, or may be located by
browsing the OLM. Page content may be configured by the teacher to provide the students with an appropriate means of feedback for this activity.

(iii) Interface OLM Visualisations. These are individual components/views/visualisations that detail a specific element of the LM, which can be embedded into other NEXT-TELL components, for example the homepage.

[Diagram of OLM as a Web Service]

Elaborating upon the input-output information flow shown in Figure 5, the two main aspects are shown in Figure 3. Firstly, as described above, is the means by which information may be visualised or accessed, using webpages (OLM, right of Figure 7). The second aspect is the ability to update the content of the learner model with new inferences (inferences, left of Figure 7). Information may be linked to a specific activity (e.g., it is expected; solicited) or may be tendered separately from a planned event (unsolicited). Inferences that are modelled also have context and supporting evidence in addition to their content.

[Diagram of OLM as a Web Service]

In Sections 4 and 5 we further consider the OLM as a web service in terms of release one of the OLM prototype. Section 4 details which aspects are implemented and Section 5 describes aspects of the architecture and implementation.
4 About Release One

The first release of the OLM prototype is a proof of concept piece of technology. Development focusses on the ‘knowledge level information’ facet primarily, as this facet is established in existing OLM systems and the first stage of development is to apply this to NEXT-TELL. In subsequent releases of the OLM this will be extended to include broader aspects of learning. This first release focusses mainly on the needs of two of the seven stakeholders: students and teachers.

Visualisation mechanisms included are a static default set, which may present numerical facets of domain content (e.g. knowledge level) whilst remaining domain independent and granularity independent. Methods are available to display group/individual content, and also current/historical content. Ultimately the available set will be able to be configured by the user and will encompass a wider selection of options of finer granularity and embedded domain/facet content. The current visual mechanisms selected are based on previous implementations of OLMs and other simple visual methods. The set is small and suited to the purpose of a ‘proof of concept’ design. As integration with STEM, TESL and TISL components is further completed, along with the baseline studies, future inclusions may be further tailored to specific needs of these uses and their stakeholders in the NEXT-TELL context. The initial set of OLM views are being evaluated with end users in terms of interpretation and emotional response (see Section 6).

The OLM is not yet integrated with the following components, however facilities are provided to prepare for the integration:

1. **ECAAD layer.** Activities can be created and webpages viewed to visualise the modelled activity. (An evaluation of this facility is included in Section 6) A graphical user interface (GUI) together with a machine interface is implemented for this facility as an interim solution (see Section 5.5.)
2. **STEM and TESL elements.** A facility currently exists to generate mock data. The system is also linked to other information sources for the purpose of ‘proof of concept’, such as existing OLM systems that are deployed in higher education at the University of Birmingham, UK.
3. **TISL.** A filter mechanism is being designed, so users (i.e. teachers mainly at this stage) may inspect mainly knowledge level information at different levels of abstraction using the default set of visualisations. Using the filter mechanism, the GUI supports methods of browsing, searching and a hybrid of these two.

4.1 SMILI specification

With increasing use of OLMs, the SMILI (Student Models that Invite the Learner In) OLM Framework was developed to help authors to describe and analyse their OLMs; compare the features of a range of OLMs; and identify new areas to explore [Bull, 2007]. Table 1 considers how learner model information may be opened to each of our stakeholders. Table 1 places the stakeholders identified for NEXT-TELL into columns 2-8, with reference to the SMILI Framework [Bull, 2007] elements (columns 1). See D4.1 for more information.

The first release of the prototype covers only a portion of the planned development work over the four years of the project. Table 2 shows aspects of the specification that are implemented using a green tick.

---

**Key:** √ = aspect of this implemented  * = proposed  ? = still to be determined

© NEXT-TELL consortium: all rights reserved
## SMILI Elements

### 1. Extent of model accessible

<table>
<thead>
<tr>
<th>Complete</th>
<th>Partial</th>
<th>Knowledge level</th>
<th>Knowledge</th>
<th>Difficulties</th>
<th>Misconceptions</th>
<th>Learning issues</th>
<th>Social issues</th>
<th>Preferences</th>
<th>Other users’ LM (ind)</th>
<th>Other users’ LM (gp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔</td>
<td>*</td>
<td>✔</td>
<td>✔</td>
<td>*</td>
<td>*</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>√</td>
<td>*</td>
</tr>
</tbody>
</table>

### 2. Presentation

<table>
<thead>
<tr>
<th>Textual (i.e...)</th>
<th>Graphical (i.e...)</th>
<th>Other (i.e....)</th>
<th>Overview</th>
<th>Targeted Details</th>
<th>All Details</th>
<th>Support to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔</td>
<td>✔</td>
<td>*</td>
<td>✔</td>
<td>*</td>
<td>?</td>
<td>*</td>
</tr>
</tbody>
</table>

### 3. Similarity to underlying representation

| Identical | Similar | Different | ✔       | *       | ✔       | ✔       | *       | *       | ✔       | *       |

### 4. Access to uncertainty

| Complete | Partial | None | ✔       | *       | ✔       | *       | *       | ✔       | *       |

### 5. Role of time

| Previous | Current | Future | ✔       | *       | ✔       | *       | *       | ✔       | *       |

© NEXT-TELL consortium: all rights reserved
### SMILI Elements Table

<table>
<thead>
<tr>
<th>SMILI Elements</th>
<th>Student</th>
<th>Parent</th>
<th>Students’ Peers</th>
<th>Teacher</th>
<th>School Admin</th>
<th>Policy Makers</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Access method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspectable/view</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Co-operative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sys persuade user</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User persuade sys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User add evidence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negotiated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Editable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Access initiative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System initiated</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Self-initiated</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Other initiated (stu)</td>
<td>n/a</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>n/a</td>
</tr>
<tr>
<td>Other initiated (peer)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>n/a</td>
<td>*</td>
<td>*</td>
<td>n/a</td>
</tr>
<tr>
<td>Other initiated (tea)</td>
<td>*</td>
<td>?</td>
<td>n/a</td>
<td>*</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Other initiated (par)</td>
<td>*</td>
<td>n/a</td>
<td>*</td>
<td>n/a</td>
<td>*</td>
<td>*</td>
<td>n/a</td>
</tr>
<tr>
<td>Other initiated (res)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>?</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>8. Access to sources of input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial</td>
<td>*</td>
<td>*</td>
<td>?</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td>✓</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Student</td>
<td>*</td>
<td>*</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Peer</td>
<td>*</td>
<td>*</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Teacher</td>
<td>*</td>
<td>*</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Parent</td>
<td>*</td>
<td>*</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Other program</td>
<td>✓</td>
<td>*</td>
<td>?</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>9. Control over accessibility (to others)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student</td>
<td>n/a</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer</td>
<td></td>
<td>*</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instructor</td>
<td>?</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parent</td>
<td>?</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other program</td>
<td>?</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### SMILI Elements

<table>
<thead>
<tr>
<th>SMILI Elements</th>
<th>Student</th>
<th>Parent</th>
<th>Students' Peers</th>
<th>Teacher</th>
<th>School Admin</th>
<th>Policy Makers</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Partial</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>None</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

#### 10. Awareness of effect of model on personalisation

<table>
<thead>
<tr>
<th></th>
<th>Student</th>
<th>Parent</th>
<th>Students’ Peers</th>
<th>Teacher</th>
<th>School Admin</th>
<th>Policy Makers</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Partial</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>None</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

#### 11. Flexibility of access

<table>
<thead>
<tr>
<th></th>
<th>Student</th>
<th>Parent</th>
<th>Students’ Peers</th>
<th>Teacher</th>
<th>School Admin</th>
<th>Policy Makers</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Partial</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>None</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

### I. Centrality of OLM

<table>
<thead>
<tr>
<th>Can be used as central focus or additional support</th>
<th>Student</th>
<th>Parent</th>
<th>Students’ Peers</th>
<th>Teacher</th>
<th>School Admin</th>
<th>Policy Makers</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

### II. Evaluation (evidence)

<table>
<thead>
<tr>
<th>Deployment in real settings</th>
<th>Student</th>
<th>Parent</th>
<th>Students’ Peers</th>
<th>Teacher</th>
<th>School Admin</th>
<th>Policy Makers</th>
<th>Researchers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Table 2: SMILI Specification.
5 OLM Prototype

This section presents information on design and technical aspects relating to the learner model, its external (open) representation and the first prototype release. We consider in turn the information content of the LM, a default set of methods for visualising this information with the example facet of ‘knowledge level’, ways in the information may be accessed, and an outline for the method by which the information is maintained. We begin with a simple example and a brief description of the information content of the learner model.

5.1 Information Content

5.1.1 Simple Example

A teacher teaches groups of students. Students may be members of multiple groups for each teacher, and are also taught by different teachers. As a member of each group the student works alongside other students, who may be considered the student’s peers. A teacher may design an activity for students to complete, which is tailored to the current learning needs of a group of students, in alignment with a syllabus. This activity is likely to contain different elements of information, on which the student may be (formatively) assessed.

For example for a writing-based activity the student may be assessed on spelling, grammar, presentation, argument construction or fluency etc., each of which may be considered different sources of information. Information sources could also be defined using the curriculum base of the subject content, for example in an algebra-based mathematics activity there may be questions containing elements relating to the manipulation of brackets, indices, fractions, inequalities or simultaneous equations. Depending on the design of the activity, some elements/sources may be considered more influential than others in the evaluation of the activity, for example if there are a greater number of questions containing content of one curriculum base, or if the activity was designed to assess a student’s understanding of grammar, primarily.

A student may be assigned to multiple activities by the teacher as part of a specific grouping of students. In evaluating the overall understanding of a student or group of students, different activities may have different levels of influence when they are considered together. For example a test taken in the classroom may be defined by a teacher as more important than a short homework exercise, both of which are activities in their own right.

Through consideration of the above example context of use, we define the following key elements and attributes for the design of the information structure of the learner model and the OLM presentation:

- Teacher
- Student
- Group
- Peers
- Activity
- Information source
- Curriculum base

5.1.2 Learner Model Information

In order to make sense of, and contextualise information held about students, the information falls into a hierarchy or stack. Conceptually, information is held about individual students only, and modelled at the level
of each information source (centre left of Figure 8). Information about other elements of the stack (e.g. activities, groups, subject areas) is derived through combination of information from individual data sources, from each individual student. There are two main entities within the stack: the *information* that is modelled about the student and their learning (left of Figure 8) and information about how the student *relates to other people/stakeholders* (right of Figure 8).

![Figure 8: LM Information Stack](image)

**Sources** are the fundamental elements of the model that model an attribute (model facet) of the student (e.g. knowledge level, specific beliefs, appraisal, epistemic belief, 21st century skill). The source may be very fine grained (e.g. about a specific concept) or coarse grained (e.g. information related to a whole module). Each source is linked to a curriculum base, which specifies the subject content. Each source is also linked to a single activity. In release one, sources are configured to model, primarily, the ‘knowledge level’ facet. Each source also has an influence weighting that specifies its relative importance when it is combined with other sources. This should be able to be configured by either the teacher or another piece of software.

**Curriculum bases** are used to contextualise the source with reference to syllabi and subject content. At present it has four granularities of specification (subject, module, topic and concept). The curriculum base is of particular use when information is aggregated and displayed in the OLM browser for enquiry into learning (whether student or teacher based). Each source within an activity may have a unique curriculum base (e.g. if the activity is modelling competency of different concepts within a topic) or a common curriculum base (e.g. if modelling different facets of the same concept.)

**Activities** group together sources (i.e. sets of modelled inferences of a common type for a common purpose.) An activity may contain one or many sources, depending on the different aspects of it to be modelled, and may contain different model facets and different elements of a curriculum base. An activity can be used flexibly to group together information from:

- a solicited data source (i.e. an anticipated set of student actions) such as those that may be specified using the ECAAD planner.
- a tertiary solicited data source, such as the teacher requesting feedback or appraisal from a parent about a student, or the teacher inputting a CEFR assessment of student work.
- an unsolicited data source, such as a student tendering information about their progress or a self assessment without being requested to do so, or uploading unanticipated content to the e-portfolio that may be automatically analysed.
Like the sources forming the activity, the activity itself has an influence weighting, which specifies its relative importance when it is combined with other activities. The teacher should have ultimate control of this.

Groups collect together students. The group could be a specific tuition group, as formally recognised by an educational institution, or may be a subset of students, working towards an educational goal. Each group should have an associated teacher and the other students in the group are recognised as peers. When information is combined for multiple students, each student is given equal influence; no one student is more important or influential than another. The teacher may not change this.

The LM stack is the basis for specifying how information should be combined, configured, updated and managed. In the following sections we look at how some of the information may be visualised using a default set of OLM presentations (Section 5.2), and how information is accessed (Section 5.3), filtered (Section 5.4) and modelled (Section 5.5).

5.2 Visual Methods

5.2.1 Default set of visualisations

The first release implements the following visual mechanisms for externalising the content of the learner model’s ‘knowledge level’ facet (shown in Table 3). Representations suitable for student, teacher and parent are included. These representations show a mixture of current and historical information, and some draw on a single learner model, whilst others show positions within a group or multiple learner models. Where information from multiple learner models is presented to the student, the information is aggregated and anonymous. For the learner to inspect specific content in a peer’s model, this requires the explicit and volunteered permission of the peer involved. A mechanism by which learners may ‘release’ their model to others will form part of release two.

<table>
<thead>
<tr>
<th>Knowledge Level</th>
<th>Student</th>
<th>Teacher</th>
<th>Current</th>
<th>Historical</th>
<th>Single LM+</th>
<th>Many LMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Skill Meter</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>2. Smiley Metaphor</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>3. Traffic Light Metaphor</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>4. Sparkline</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>5. Graph (Student and Group)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>6. Table</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>7. Histogram (Student Position in Class)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>8. Histogram (All Students Named)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>9. Ranked List (All Students Named)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Implemented LM Representations.

5.2.2 Student

Seven visual representations of the learner model are provided for the student stakeholder (Table 4). The OLM prototype is a proof of concept piece of technology and so these visualisations are a very small subset of what is possible and what is planned. Further analysis of results from the baseline studies will yield more requirements for stakeholders, allowing the choice of visualisation to be substantially extended and refined.
1. Skill Meters

The width of the block represents the extent to which each knowledge type is present in the current learner model.

Green = correct/confirmed understanding  
Grey = problematic understanding  
Red = misconception (systematically problematic understanding)

2. Smiley Metaphor

The emoticon expressed on the icon’s face is a metaphor for the state of the learner model. The happier the face, the stronger the understanding, and vice versa

3. Traffic Light Metaphor

The state of the traffic light is a metaphor for the state of the learner model. In this OLM presentation red indicates insufficient understanding and green a strong understanding.
4. Sparkline

This is historical information about the level of correct understanding in the learner model. Left to right indicates time (right is the most recent) and top to bottom indicates the state of the LM (top: strong understanding, bottom: weak understanding.) The LM is a weighted model of student understanding, where more recent information is given greater weighting. The information shown at all points is the result of the weighted model. The sparkline therefore has potential to show increases and decreases in learner understanding, as new evidence is available (this may come from different sources over time.)

5. Graph (Student and Group)

This is historical information about the level of correct understanding in the learner model. Left to right indicates real time (right is the most recent) and top to bottom indicates the state of the LM (top: strong understanding, bottom: weak understanding) Both the group average (yellow) and student (blue) are represented together.

6. Table

The table categorises each topic by identifying the strength of the learner’s understanding. A blue square indicates the category/column that understanding comes under. Columns are arranged from negative to positive.
### 7. Histogram

Each student’s learner model is graded from weak to strong, quantised into 5 categories. The histogram shows the frequency/distribution of students in the group that fall into each category. The dark blue square identifies which category the current student falls into.

**Table 4: Simple Visual Representations of the Learner Model**

<table>
<thead>
<tr>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7. Histogram</strong></td>
<td><img src="image" alt="Histogram" /></td>
</tr>
</tbody>
</table>

5.2.3 Teacher

Two further visual representations of the learner model are provided specifically for the teacher stakeholder (Table 5), in addition to methods described in Section 5.2.2. Namely methods 1 (skill meter), 4/5 (sparkline) and 6 (table) from Table 4 may be used to display information to the teacher for individual students, or individual curriculum bases. The OLM prototype is a *proof of concept* piece of technology and so both the visualisations of the teacher and student are a very small subset of what is possible and what is planned. Further analysis of results from the baseline studies will yield more requirements for stakeholders, allowing the choice of visualisation to be substantially extended and refined.

**8. Histogram**

Each block on the diagram is a student in the current group. Each student’s learner model is graded from weak to strong and placed on the histogram to show the distribution of student ability within the group. Each student is identified by their first name, and the initial of their surname.
9. Ranking

Students are ranked according to the level of correct understanding in their learner model. 1 is the highest ranking. The score (which ranges 0 to 1) is given together with the student’s name. The background colour duplicates this information: green = strong, grey = medium, red = of concern.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wolfgang H</td>
</tr>
<tr>
<td>2</td>
<td>Chris T</td>
</tr>
<tr>
<td>3</td>
<td>Susan B</td>
</tr>
<tr>
<td>4</td>
<td>David J</td>
</tr>
<tr>
<td>5</td>
<td>Matthew J</td>
</tr>
<tr>
<td>6</td>
<td>Robert G</td>
</tr>
<tr>
<td>7</td>
<td>Julia J</td>
</tr>
<tr>
<td>8</td>
<td>Michael J</td>
</tr>
</tbody>
</table>

Table 5: Simple Visual Representations of the Learner Model (Teacher Specific)

5.2.4 Rendering Process

LM information is dynamically displayed. Images and HTML are generated based on the underlying learner model, each time they are requested. Most visual representations at present are images, these are redrawn and rendered each time they are accessed, and so the information is always current. LM content is accessed using the HTTP protocol, and may also take the forms of HTML or XML.

Figure 9 shows the process followed from request (left) to rendering (right), for individual OLM components/visualisations. Firstly the context of the information is determined. If the request is for the OLM browser or a page with a pre-filtered content, these parameters provide the starting point for the context. The HTTP session also contains information about the identity of the authenticated user and information that they are authorised to access. Information in the URL (both the path and the parameters) will override the information in the HTTP session variable. The context is used to determine what information should be rendered, in preparation for searching the database and processing the results. The context may typically contain parameters from a selection of {student_id, teacher_id, activity_id, source_id, group_id, subject_id, concept_id, module_id, topid_id, facet_type, information_is_historical etc.} These parameters are then used to dynamically generate SQL to retrieve the information in a database search. As information is modelled at a very fine level...
(see Figure 8: LM Information Stack) information may need to be combined to provide aggregated values for depicting the model at more coarsely grained levels in the stack. Once the information is collated the render function selects the visualisation type and returns the information as a component that may be rendered in a web browser (namely as an image or HTML) or as information that may be passed to another piece of software (e.g. as XML.) HTTP requests need not always be from a browser, but from any other entity that requires access the data in the learner model and has permission to do so.

5.3 Component Access

The visual methods used to externalise the underlying learner model are accessed through the HTTP protocol. Whether the information to be rendered is a webpage, part of the OLM Browser, or simply an individual visual component (e.g. a skill meter), the URL used to access the content should be meaningful and be composed of the parameters required to retrieve the information from the learner model database. Thus the URL may need to:

- Identify the person and the context (stakeholder-type, institution, person ID (if applicable) etc.)
- Identify the type of information to which access is requested (facet, relationship, artefact etc.)
- Specify additional parameters (names, dates, references etc.)

It is important to identify the scope/granularity of the information in the naming schema, particularly for LM facets, as information for a given belief may be presented and accessed in different levels of detail, depending on the use scenario. If this information can be embedded into the naming schema, this reduces the need for parameters such as these to be specified. For example, information may be required for grain sizes including (but not limited to) the following (Table 6):

<table>
<thead>
<tr>
<th>Scope</th>
<th>Example URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>an institution</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/">http://www.next-tell.eu/students/bergen-high/</a></td>
</tr>
<tr>
<td>a group</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/group3A">http://www.next-tell.eu/students/bergen-high/group3A</a></td>
</tr>
<tr>
<td>a specific student’s progress</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/id/">http://www.next-tell.eu/students/bergen-high/id/</a></td>
</tr>
<tr>
<td>a student’s progress in a specific group</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/id/group3A">http://www.next-tell.eu/students/bergen-high/id/group3A</a></td>
</tr>
<tr>
<td>a student’s progress on a specific topic</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/id/group3A/%7Btopic_name%7D">http://www.next-tell.eu/students/bergen-high/id/group3A/{topic_name}</a></td>
</tr>
<tr>
<td>specific beliefs held by the student</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/id/group3A/%7Btopic_name%7D/misconceptions">http://www.next-tell.eu/students/bergen-high/id/group3A/{topic_name}/misconceptions</a></td>
</tr>
<tr>
<td>evidence for why a specific belief is held by a student</td>
<td><a href="http://www.next-tell.eu/students/bergen-high/id/group3A/%7Btopic_name%7D/misconceptions/justification">http://www.next-tell.eu/students/bergen-high/id/group3A/{topic_name}/misconceptions/justification</a></td>
</tr>
</tbody>
</table>

Table 6: Embedding granularity into the URL – examples of potential URLs.

The same information may also be expressed in multiple forms. This will most likely need to be a parameter or extension to the URL. For example if dealing with an end user request, the following potential URLs may be appropriate:

- http://www.next-tell.eu/students/bergen-high/id/group3A/{topic_name}/SkillMeter
- http://www.next-tell.eu/students/bergen-high/id/group3A/{topic_name}/TrafficLightMetaphor
- http://www.next-tell.eu/students/bergen-high/id/group3A/{topic_name}/Sparkline
If the information is being requested by another piece of software, an .xml file might be more appropriate:

- http://www.NEXT-TELL.eu/students/bergen-high/(id)/class3A/(topic_name)/xml

This will allow machines and humans to access information using the same naming schema. (For the purposes of database access a machine is just another end user stereotype)

The following (Table 7) is the proposed order of information in the URL naming schema in the first release of the prototype. If a specified piece of information is not relevant to the information request, it should be omitted; all constituents of the URL path are optional for inclusion. (e.g. if the request is for information about a specific activity, it is not necessary to specify the curriculum base; if the request is about a group, it is not necessary to specify student IDs)

http://www.nexttell.eu/stakeholder-type/user_id/institution/group/subject/module/topic/concept/activity/source/visualisation_type

<table>
<thead>
<tr>
<th>Information Type (to be accessed)</th>
<th>URL Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td><a href="http://www.nexttell.eu/">http://www.nexttell.eu/</a></td>
</tr>
<tr>
<td>1. About the user</td>
<td>/stakeholder-type/user_id/</td>
</tr>
<tr>
<td>2. About a group</td>
<td>/institution/group/</td>
</tr>
<tr>
<td>3. Curriculum base</td>
<td>/subject/module/topic/concept/</td>
</tr>
<tr>
<td>4. Links to specific information deposits</td>
<td>/activity/source/</td>
</tr>
<tr>
<td>5. Specification of information presentation</td>
<td>/visualisation_type/</td>
</tr>
</tbody>
</table>

Table 7: URL path order

5.4 OLM Browser/Filter (Basic)

The OLM browser allows the content of the learner model to be inspected and browsed/searched using a filter mechanism. This is particularly aimed at supporting enquiry into learning (whether it is performed by the student or teacher), and also aimed at supporting navigation to a specific part of the model. Two behaviours should be supported: searching (know what you want, but do not always know the process of acquiring the information) and browsing (do not know what you’re looking for specifically). It is therefore proposed to use a filter mechanism, which implements a hybrid of these two activities. The GUI is shown in Figure 10.
mechanism at present does not provide the facility to break down information by its curriculum base - this will be included in release two. A screen shot of the teacher’s OLM browser interface is shown in Figure 11.

![Teacher OLM Browser](image)

**Figure 11: Teacher - OLM Browser**

The student may filter LM content by pre-configured activity (see Section 5.1). Again this is very basic and this will be extended in release two to cover other parameters including curriculum base. Release two will also implement a mechanism through which students may grant each other access to view each other’s OLM, and these search parameters will be added to the information filter. The present implementation may be used in a classroom/home setting for specific activities. Release two will support enquiry into learning. A screen shot of the filter mechanism is shown in Figure 12, and the current interface in Figure 13.

![Student Filter Mechanism](image)

**Figure 12: Student - Filter Mechanism**
5.5 Modelling Process

The LM is a weighted model. Modelling takes place at the level of each constituent information source (see LM stack in Figure 8). In this section we overview how the information in the learner model is configured, modelled and aggregated. Figure 14 provides an overview. Prior to accepting data (Section 5.5.4), the model must first be configured (Sections 5.5.1, 5.5.2 and 5.5.3)

![Figure 13: Student - OLM Browser (Screen Shot)](image)

--- CONFIGURATION ---

A. Create Activity
   [activity influence]

B. Define Source Type
   [source influence]
   [modelling parameters e.g. depreciation factor]
   [facet type]

C. Assign Activity to Student

--- UPDATE ---

D. Add New Data

![Figure 14: Configuring and Updating the Learner Model](image)

5.5.1 Create activity

Firstly, as shown in Figure 14, the activity needs to be specified (see also Section 5.1). Its definition and influence may be specified by the teacher (administrator of the learning process) using either a GUI, such as is shown in Figure 15. Alternatively another piece of software can configure the activity, using a URL - this is a back end machine interface. (e.g. [http://www.nexttell.eu/OLM/Ext_AddActivity?activityname=homework-8-11&activityinfluence=5](http://www.nexttell.eu/OLM/Ext_AddActivity?activityname=homework-8-11&activityinfluence=5)) A template is created for the activity, which specifies how the modelling should be carried out.
5.5.2 Define Source Type

Sources are defined and added to the activity template. Each source can be of a different curriculum base, model facet and level of influence. Weighted modelling happens at source level. Each source definition is added to the template for the activity. The learner model is only configured to model information for the source once the student has been allocated to the activity. Sources may be defined using the GUI (Figure 15) or using a URL (e.g. http://www.nexttell.eu/OLM/Ext_AddSourceToActivity?sourcename=source1&sourceinfluence=5&activityid=109&weighting=0.4)

5.5.3 Assign Activity to Student

The final stage of the configuration is to add students to the activity. This allows the learner model to be configured to accept data. This assignation may be manual (e.g. using the interface in Figure 15) or automated using a URL (e.g. http://www.nexttell.eu/OLM/Ext_AddStudentToActivity?studid=3&activityid=109) Potentially the teacher should have admin privileges to revise the activity template post creation, to remove students from the activity, and to approve whether the ‘activity’ remains part of the student’s model in cases where it is automatically configured by software.
5.5.4 Add New Data

The update process is outlined in the bottom right of Figure 14. Modelling happens for each source using a simple weighted algorithm:

\[
\text{new LM value} = \text{old LM value} \times (1 - \text{depreciation factor}) + \text{incoming data value} \times \text{depreciation factor}
\]

The update process is triggered by accessing a URL (e.g. http://www.NEXT-TELL.eu/OLM/UpdateSource?klcorr=0.9&activitysourcetemplateid=106&studid=3)

Information may also be manually entered using interfaces similar to the one shown in Figure 16.

5.5.5 Associating Students

Each student and activity are in turn linked to groups of students. At present this is done using a further intermediate interface (shown in Figure 17). This allows teachers to specify the more social aspects and context of students’ learning - namely who teaches the student and which students are grouped.
5.5.6 Retrieving Data from the Database

Data and values for individual sources may be directly accessed (e.g. bottom row, Figure 18), however if aggregation is to take place of sources, influence weights are used to specify how information is combined to give a picture of understanding. Influence weightings are specified when the activity template is created (see Section 5.5.2 and 5.5.3). Figure 18 is a worked example showing how values at each level of abstraction are derived, for the example of the knowledge level facet. A value of 0.672 is the weighted combination of 0.8, 0.7, 0.6 and 0.4. The specific elements of the model that are to be combined depend on the parameters specified as part of the context of the database search (see Section 5.4.2)

**activity value = sum of ( source value * source influence/total source influence )**

Figure 18: Example Information Combining.
5.6 Summary

This Section has presented an overall architecture for the version one OLM prototype, and has detailed its current implementation. The section focused on issues surrounding interface elements, the modelling process, and information management, in terms of how information is accepted, modelled, stored and retrieved.

In the next two sections we move forward to describe the evaluation of OLM visual methods using eye tracking equipment (Section 6) and to outline a method by which learner model data may be captured that describes student knowledge constructs, using the repertory grid technique (Section 7).
Open learner models are representations of learning that are made accessible and actionable to the individual or group learners.

“The underlying learner model (representation of learner knowledge, understanding, skills, etc.) is inferred by a system based on what has happened during an interaction with a learner or a group of learners (e.g. from problem-solving tasks and specific questions, to more open-ended interaction). This allows a system to further adapt the interaction to suit individual learners, collaborating pairs or groups.” (Bronn & Vrioni, 2001)

One of the central issues in open learner models research is the design, development and evaluation of representations. Since learners perceive and act upon representations of their learning in OLM systems, the notational, emotional, informational and interactive aspects of representations must be considered in the design and development of OLM systems. This report presents the study of notational, emotional, and informational aspects of nine different kinds of OLM representations. The representations are referred to as “static representations” as they only present snapshot views of three knowledge states (weak, average and strong) without offering any interactive capabilities to the student participants. Findings from the eye-tracking study reported here helped the design of dynamic visualizations of the OLM system for the NEXT-TELL project and the dynamic-visualizations of open learner models (DV-OLM) research prototype.

The remainder of the section is organized as follows. The Theoretical Framework (Section 6.1) presents and discusses three lines of conceptual and empirical work relevant to the design and evaluation of representations for the OLMs in particular and the NEXT-TELL “communication and negotiation layer” in general. The methodology section (Section 6.2) presents details on the experimental study design, participant recruitment, sampling and assignment, materials, task, and the protocol. The results and discussion section (Section 6.3) presents the eye-tracking findings and qualitative observations from the exit interviews.

6.1 Theoretical Framework

Representation as a proxy to information plays a crucial role in design in general. The nature of representations, their structures and interactions is one of the central concerns of cognitive science (Winn, 2004). Philosophically speaking, the function of representation is to “re-present”. Representation, in the philosophy of mind sense of the term, “is something that stands for something else”.

For the purposes of the NEXT-TELL project in general and the “modelling student learning” work package (WP4) in particular, OLM representations “re-present” the ongoing learning of the individual student and/or group of students. The technological and pedagogical aspects of representations have received significant conceptual and empirical attention in the fields of human computer interaction and learning sciences. Three following lines of conceptual and empirical work are particularly relevant for the design, development, and evaluation of the communications and negotiation layer of the NEXT-TELL project:

- perception and appropriation of socio-technical affordances (Vatrapu, 2009, 2010)
- representational guidance (Suthers, 1999; Suthers & Hundhausen, 2003; Suthers, Vatrapu, Medina, Joseph, & Dwyer, 2008)
- cognitive dimensions of notations (Blackwell & Green, 2003; Green, 1989)

http://rgfa.cbs.dk/DV-OLM
6.1.1 Perception and Appropriation of Socio-Technical Affordances

The notion of affordance was introduced by J. J. Gibson (1979). Gibson was primarily concerned with providing an ecologically grounded explanation to visual perception. Affordance is a deceptively simple concept that hides a very radical hypothesis. Norman’s introduction of the concept of “perceived affordance” (Norman, 1990) brought the notion of affordance into human computer interaction. Relevant literature includes: Gaver’s seminal articles on technology affordance (Gaver, 1991), affordances of media spaces (Gaver, 1992), affordances for interaction (Gaver, 1996); Bradner’s notion of social affordance (Bradner, 2001); Hartson’s (2003) taxonomy of affordances into physical, sensory, functional and cognitive affordances; McGrenere and Ho’s (2000) critical review of the notion of affordance and a structuration theoretical interpretation of affordances (Vyas, Chisalita, & van der Veer, 2006). Affordances in HCI have largely been misunderstood as widgets, features and functionalities (Torenvliet, 2003), despite a crucial intervention by Norman (1999) himself.

Definition of Socio-Technical Affordance: By drawing upon ecological psychology research, Vatrapu (2010) defined a socio-technical affordance as:

“action-taking possibilities and meaning-making opportunities in a socio-technical system relative to actor competencies and system capabilities.”

With regard to OLM representations, perception of affordances (PoA) refers to the action-taking possibilities and meaning-making opportunities that become available (that is, perceivable) to students in a given situation. Appropriation of affordances (AoA) refers to the intentional utilization of the affordances. AoA refers to the enactment of an interactional practice (generative or creative). The experimental study reported here focused on the perception of affordances aspect of the phenomena. As such, the key issues of study were to what extent were the nine different kinds of OLM representations meaningful and actionable to the students.

6.1.2 Representational Guidance

The system of mental representations “consists not of individual concepts, but of different ways of organizing, clustering, arranging and classifying concepts and of establishing complex relations between them” (Hall, 1997, p. 17).

From a cultural studies perspective, Stuart Hall (1997) argues that representations connect meaning and language to culture and distinguishes two systems of representations: concepts or mental representations and language. From a cognitive science perspective, Zhang (1997) presented a functional model for the problem solving with external representations. The internalist representational view in cognitive sciences posits an internal representational model of every feature of the external world. Zhang rejects this internalist representational view. Instead, Zhang (1997, p. 181) argues that the internal representations and external representations are cognitively processed “in an interwoven, integrative, and dynamic manner”. Zhang’s definitions for internal and external representations are provided next.

Definition of Internal Representations. We define internal representations as:

“Internal representations are the knowledge and structure in memory, as propositions, productions, schemas, neural networks, or other forms” (Zhang, 1997, p. 180).

From a cognitive science perspective, during learning activities information inherent in internal representations is retrieved from long-term memory and working memory.
Definition of External Representations. We define external representations as:

“external representations are defined as the knowledge and structure in the environment, as physical symbols, objects, or dimensions (e.g., written symbols, beads of abacuses, dimensions of a graph, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layouts of diagrams, physical constraints in abacuses, etc.)” Zhang (1997, p. 180)

External representations embody environmental information, and this information can be “directly picked up” by the human perceptual systems in the Gibsonian ecological approach (Gibson, 1979).

The NEXT-TELL open learner model involves external representations. Representational salience and constraints of these OLM external representations can influence the cognitive processes of information retrieval from and subsequent information storage. Suthers’ (1999) conceptual and empirical work on “representational guidance” is highly relevant to the design of the NEXT-TELL OLM and Communication and Negotiation layer.

The Representational Guidance research program was pioneered by Suthers (n.d) “to improve our understanding of how collaborative learning is facilitated by computer software with which learners construct and manipulate visual representations of their emerging knowledge” (The Representational Guidance Project).

The central premise of the representational guidance line of work is articulated by Suthers (2001) as:

“The major hypothesis of this work is that variation in features of representational tools used by learners working in small groups can have a significant effect on the learners’ knowledge-building discourse and on learning outcomes. The claim is not merely that learners will talk about features of the software tool being used. Rather, with proper design of representational tools, this effect will be observable in terms of learners’ talk about and use of subject matter concepts and skills.”

The above hypothesis follows from two lines of reasoning. First, the guiding ontological dimensions of representations—constraint and salience—prompt a user for what is missing as well for what is present (Suthers, 2001). The ontological dimensions of representations are not intrinsically social. Second, external representations play a role in guiding collaborative learning by amplifying certain kind of social interactions (Suthers & Hundhausen, 2003) and knowledge building interactions (Suthers, et al., 2008).

Definition of Representational Guidance. We define representation guidance as:

“Representational guidance” refers to how these software environments facilitate the expression and inspection of different kinds of information.” (Suthers, n.d)

Figure 19 is taken from Suthers (2001) indicates that representational guidance has tripartite origins in the (a) affordances of a representational notation, (b) in how that notation is realized in a representational tool such as software, and (c) in the actual configuration of representational artefacts created by users of that tool. The SR-OLM study reported here primarily deals with the affordances of the nine different kinds of representational notations for OLMs. How the representational notations (such as smiley metaphors, word clouds, and traffic lights metaphors etc.) are realised in the software and the actual configuration of representational artefacts are issues of concern for the design and evaluation of the DV-OLM application7.

7 http://rgfa.cbs.dk/DV-OLM
6.1.3 Cognitive Dimensions of Notations

The cognitive dimensions framework (Blackwell & Green, 2003; Green, 1989) is highly relevant to understanding the notational aspects of the OLM representations. The cognitive dimensions of representations deal with the cognitive affordances of notations with respect to users engaged in activities. Gibson's ecological optics (Gibson, 1979) and Green and Blackwell's cognitive dimensions (Blackwell & Green, 2003) share conceptual terms such as medium and environment. Cognitive dimensions of representations, like affordances, are about the action-taking possibilities and meaning-making opportunities given actor competencies and system capabilities. The next section presents key concepts in the cognitive dimensions framework and discusses their relevance to the NEXT-TELL project. The following definitions are taken from Green and Blackwell (1998):

- **Information Artefacts**: "the tools we use to store, manipulate, and display information" (p.5)
  Information artefacts are further classified as "non-interactive artefacts" and "interactive artefacts". The OLM representations are information artefacts and the static representations studied here are an example of "non-interactive artefacts".

- **Environment**: "The environment contains the operations or tools for manipulating those marks" (p.8). The environments in the NEXT-TELL context are the various "dashboards" of the Communication and Negotiation Layer, ECAAD and such for the different stakeholders.

- **Medium**: "The notation is imposed upon a medium, which may be persistent, like paper, or evanescent, like sound"(p.8). In the case of the OLM, the medium is persistent and dynamically changed.

In summary, the static representations are non-interactive artefacts of the OLM medium in the NEXT-TELL Communication and Negotiation environment.

The cognitive dimensions framework distinguishes four types of user activity.

- **Incrementation**: "adding further information without altering the structure in any way" (p.10)
D4.2
Student Model Tools R1

- **Modification**: "changing an existing structure, possibly without adding new content"(p.10)
- **Transcription**: "copying content from one structure to another structure;"(p.10)
- **Exploratory Design**: "combining incrementation and modification, with the further characteristic that the desired end state is not known in advance"(p.10)

NEXT-TELL user groups of students and teachers will engage in all four kinds of user activity. The nine different kinds of static representations have been designed with Exploratory Design in mind with the student participants engaging in all four activities as detailed in the Methodology section (Section 6.2).

**Definitions of Cognitive Dimensions.** We define cognitive definitions as follows (Green and Blackwell (1998)):

- **Abstraction**: "An abstraction is a class of entities, or a grouping of elements to be treated as one entity, either to lower the viscosity or to make the notation more like the user’s conceptual structure" (p.24)
- **Closeness of Mapping**: "Closeness of representation to domain" (p.39)
- **Consistency**: "similar semantics are expressed in similar syntactic forms"(p.39)
- **Diffuseness**: "verbosity of language" (p.39)
- **Error-Proneness**: "notation invites mistakes" (p.40)
- **Hard Mental Operations**: "high demand on cognitive resources" (p.40)
- **Hidden Dependencies**: "A hidden dependency is a relationship between two components such that one of them is dependent on the other, but that the dependency is not fully visible" (p.17)
- **Premature Commitment**: "Constraints on the order of doing things force the user to make a decision before the proper information is available" (p.21)
- **Progressive Evaluation**: "work-to-date can be checked at any time" (p.40)
- **Provisionality**: "degree of commitment to actions or marks" (p.41)
- **Role-Expressiveness**: "the purpose of a component (or an action or a symbol) is readily inferred" (p.41)
- **Secondary Notation**: "Extra information carried by other means than the official syntax" (p.29)
- **Viscosity**: "Resistance to change: the cost of making small changes"(p.12)
- **Visibility**: "ability to view components easily."(p.34)
- **Juxtaposability**: "ability to place any two components side by side"(p.34)

The nine different kinds of OLM representations (See Section 3.2.1) designed and evaluated for the SR-OLM study embody and exemplify one or many of the above listed cognitive dimensions of notations. For example, the **textual representations** exemplify verbosity of language (diffuseness), the **traffic light and smiley metaphors** are high on abstraction but also high on role-expressiveness, **skill meters** provide progressive evaluation, horizontal and vertical **tables** offer closeness of mapping to the domain of formative assessment, collective **bar chart** representation embodies the juxtaposition dimension.

### 6.2 Participants, Materials and Methods

The experimental study was designed to investigate the notional, informational, and emotional impact of the OLM representations. That is, to investigate how students perceive different kinds of static representations and what if any are the differences in emotional arousals between them. Given the central role that motivation plays in learning (Cordova & Lepper, 1996; Eales, Hall, & Bannon, 2002) and since the primary use of OLM representations is for formative assessment practices, emotional impacts of OLM representations are of interest. The exploratory research question is stated below:
RQ1: What, if any, are the design trade-offs between notational, informational, and emotional aspects of different kinds of static representations of open learner models?

To experimentally answer this exploratory research question, we designed nine different kinds of static representations with varying notational aspects but isomorphic informational aspects. The nine different kinds of representations are presented in the materials section below.

6.2.1 Materials

As mentioned earlier, nine different types of notational systems were used to generate three informational states of the open learner model static representations. The nine notational systems listed below comprise: skill meter, smiley metaphor, traffic light metaphor, topic box, group histogram, word cloud, textual descriptor, table, and matrix representations. For each of the nine notational systems, three isomorphic representations were designed to embody the following informational states of the individual’s learning state: weak, average and strong.

Thus, a total of twenty seven (9 notational systems x 3 informational states = 27) different static representations were developed. Further, we developed domain-specific (business and engineering) and domain-generic (nondescript) versions of the 27 representations. The domain-specific representations for Business subject area were used in the study as the study sample consisted of students attending the International Summer University Program (ISUP 2011) of the Copenhagen Business School, Denmark. The images of the static representations are presented below (Figures 20 – 46).

Skill Meter

![Skill Meter – Strong Student](image)

![Skill Meter – Average Student](image)

![Skill Meter – Weak Student](image)
Smiley Metaphor

Figure 23: Smiley Metaphor – Strong Student

Figure 24: Smiley Metaphor – Average Student

Figure 25: Smiley Metaphor – Weak Student

Traffic Light Metaphor

Figure 26: Traffic Light Metaphor – Strong Student

Figure 27: Traffic Light Metaphor – Average Student
Figure 28: Traffic Light Metaphor – Weak Student

Topic Boxes

Figure 29: Topic Boxes – Strong Student

Figure 30: Topic Boxes – Average Student

Figures 31: Topic Boxes – Weak Student
Group Histogram

Figure 32: Group Histogram – Strong Student

Figure 33: Group Histogram – Average Student

Figure 34: Group Histogram – Weak Student

Word Clouds

Figure 35: Word Cloud – Strong Student

Figure 36: Word Cloud – Average Student
Textual Descriptors

Figure 37: Word Cloud – Weak Student

Figure 38: Text – Strong Student

Figure 39: Text – Average Student

Figure 40: Text – Weak Student
### Table

**Figure 41: Table – Strong Student**

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>Accounting</td>
</tr>
<tr>
<td>Good</td>
<td>Finance</td>
</tr>
<tr>
<td></td>
<td>Marketing</td>
</tr>
<tr>
<td></td>
<td>Management</td>
</tr>
<tr>
<td>Ok</td>
<td></td>
</tr>
<tr>
<td>Weak</td>
<td></td>
</tr>
<tr>
<td>Very Weak</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 42: Table – Average Student**

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>Finance</td>
</tr>
<tr>
<td>Good</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marketing</td>
</tr>
<tr>
<td></td>
<td>Management</td>
</tr>
<tr>
<td>Ok</td>
<td>Accounting</td>
</tr>
<tr>
<td>Weak</td>
<td></td>
</tr>
<tr>
<td>Very Weak</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 43: Table – Weak Student**

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>Finance</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marketing</td>
</tr>
<tr>
<td></td>
<td>Management</td>
</tr>
<tr>
<td>Ok</td>
<td>Accounting</td>
</tr>
<tr>
<td>Weak</td>
<td></td>
</tr>
<tr>
<td>Very Weak</td>
<td></td>
</tr>
</tbody>
</table>
6.2.2 Participants

The sampling frame for the SR-OLM study was the student population of the International Summer University Program (ISUP 2011) of the Copenhagen Business School, Denmark. Study recruitment was done by an email solicitation sent by the ISUP secretariat to all enrolled students of ISUP 2011. Participants expressed their interest and indicated their availability on the study registration form. A total of 15 students participated in the study: 6 male and 7 female.

Participants were instructed to talk aloud about what sense they can make of the representations displayed on the screen and their subjective preferences while playing one of the four roles (themselves, a close friend taking the same course, a classmate who is not a close friend and the teacher of the course).

6.2.3 Methods

Pre-Investigative Session:

- Participants were welcomed and seated in the laboratory. They were briefly reminded that they are about to participate in an eye-tracking study and a short interview will be conducted after the study.
- An informed consent form was given. Participants were explicitly informed that it is the software that is being tested and not them. Further, participants were explicitly informed that they may decline to participate in this study or withdraw at any point in time. Participants were informed that they would still be compensated with a movie ticket coupon in case they stop participating before completing the study,
A copy of the informed consent form was given to the participants after they signed the informed consent form. A participant code was then assigned.

A brief interview was conducted on their in-class exercise experiences and reflections on their prior laboratory and/or eye-tracking study experience. This concluded the Pre-Investigative Session.

Investigative Session:

- The participant was seated in front of the eye-tracker and the position was adjusted so that participant eyes were visible in the eye-finder of SMI iView X³ eye-tracker device driver software and iMotions Attention Tool 4.1 study software.
- 9-point eye calibration was then conducted followed by light calibration.
- The study session consisted of a randomized presentation of the 27 static representations.

Post-Investigative Session:

- A brief open-ended interview was conducted about the participants’ study experiences, reflections, and subjective preferences.
- The participant was then given the movie ticket coupon and a signature of receiving the movie ticket coupon obtained. The participant was then thanked and let out of the laboratory. This concluded the study session.

6.3 Eye Tracking Outcomes

Eye-tracking data analysis was conducted at the aggregate level for each of the 27 static representations of open learner models. Three different kinds of analysis of the eye-gaze data were conducted using the iMotions Attention Tool 4.1 software:

(a) **Emotional activation** is calculated based on the changes in participants’ pupil diameters. Emotional activation measures the level of arousal and engagement towards the stimulus image. The higher the emotional activation measure, greater the emotional impact of it.

(b) **Heatmaps** present the spatial distribution of students’ gaze on a particular repertory grid exercise webpage. Heatmaps are composite images that contain an overlay of a gradient colour layer on the stimulus image (in our case, the particular construct elicitation or elements rating webpage) with areas of the webpage that received a greatest allocation of students’ gaze ranging from red to yellow and with areas that received the least gaze allocation ranging from yellow to green. The heatmaps presented below are static images of the aggregate gaze distribution on a particular image for all respondents.

(c) The **Area of Interest (AOI)** analysis was conducted on regions of the images that were of particular importance from the pedagogical and/or user interface design perspectives.

The remainder of this results section is organised as follows. First, findings about mean view time and mean emotional activation are presented (Section 6.3.1 – 6.3.2). Secondly, for each of the 27 stimulus images, descriptive statistics, emotional activation, heatmap, and AOI results are presented and important observations are discussed (Sections 6.3.3 – 6.3.11).

---

4 http://www.imotionsglobal.com/
6.3.1 Mean View Time

Mean view time (shown in Figure 47a) was the highest for the collective histogram notation followed by the skill meter and the word cloud representations.

Figure 47a: Mean View Time for the Nine Notations

Figure 47b presents the average view time for the three information states (weak, average, and strong). View time was highest for the average learning representations compared to the Strong and the Weak learning state representations across all nine notational systems.

6.3.2 Mean Emotional Activation

As mentioned above, emotional activation is calculated based on the changes in participants’ pupil diameters. Emotional activation measures the level of arousal and engagement towards the stimulus image. The higher the emotional activation measure, greater the emotional impact of it.

Figure 47c: Average Emotional Activation across Notational Systems

Figure 47c presents the average emotional activation for the nine notational systems. The least preferred notation of word cloud also received the least emotional activation. The traffic lights representations received the highest emotional activation followed by the collective histogram and smiley notations. Figure 47d presents the average emotional activation for the three information states (weak, average, and strong). Unlike mean view time, no differences in emotional activation were found across the three information states.

Mean view time was the highest for the collective histogram notation followed by the skill meter and the word cloud representations. Figure 47a presents the average view time for the three information states (weak, average, and strong). An analysis of the talk-aloud and post-investigative session interviews shows that participants found the collective histogram to be informative but challenging initially. It was informative
because participants could perceive the individual’s learning within the context of the whole class and it was challenging as it required increased decoding of the representation. Further, word cloud and skill meter were the two representations that participants liked the least and have higher view times. Unlike the collective histogram, the primary reason here is the difficulty of making sense of the representations. The traffic light and smiley metaphors received relatively lower view time than the word cloud, skill meter and collective histogram. Average view time was the lowest for the representations that participants described with phrases such as simple, easy and straightforward during the talk-aloud and post-investigative session interviews.

Mean view time was highest for the average learning representations compared to the strong and the weak learning state representations across all nine notational systems. This could be due to the fact that decoding of the average case representations with a combination of both weak and strong cases is cognitively more demanding than decoding information at the extremes of weak and strong information states.

As presented here, the least preferred notation of word cloud also received the least emotional activation. The traffic lights representations received the highest emotional activation followed by the collective histogram and smiley notations. Many participants felt that traffic lights and smileys were creative and easy to decipher. Traffic lights were also perceived as being simplistic and not depicting the semantic range of learning assessments from very weak to excellent as with other notations. There were little to no differences in emotional activation of static representations across the three information states of weak, average, and strong.

In the following sections (Sections 6.3.3 – 6.3.11) we explore elements of visual attention each of the nine notational systems, using heat maps and AOI analysis. We conclude each section with the implications of these results for the each OLM visual method. Appendix A contains supplementary information on how to interpret each of the types of diagram, which are output from the eye tracking software.
6.3.3 Skill Meters

Figure 48 (a): Heatmap – Skillmeter – Strong

Figure 48 (b): Heatmap – Skillmeter – Average

Figure 48 (c): Heatmap – Skillmeter - Weak

Figure 48 (d): Area of Interest – Skillmeter – Strong

Figure 48 (e): Area of Interest – Skillmeter – Average

Figure 48 (f): Area of Interest – Skillmeter – Weak
Figure 48 a, b and c present heatmaps for the three information states (average, strong, and weak) of the notational system of skill meters. A significant finding is that regions with information variance receive higher aggregate gaze allocation. In the ‘average’ case (Figure 48b), the gaze distribution is between the topic names, the skill meter bars and the legend. In the ‘strong’ case (Figure 48a), the “hotspot” is at the boundary between the green and the white areas of the topic. In the ‘weak’ case (Figure 48c), the aggregate gaze distribution is greater around the region representing misconceptions in the individual student’s current knowledge (the red coloured bar).

Regions and sub-regions corresponding to the topic names, skill meter bars, and the legend were identified for the Area of Interest (AOI). AOI results, shown in Figure 48 d, e and f, show that the legend received an average of 10% aggregate gaze allocation with the labels and the borders between different learning states (green “known”, red “misconceptions”, grey “problematic”, and white “not covered”) also receiving significant gaze allocation.

Results from the think aloud protocol showed that participants like the skill meters notation as it provided nuanced information. Several suggested adding a numeric value to the proportion (10%, 90% and such). The use of white colour for representing uncovered curriculum areas is not clear to some participants.

6.3.4 Smiley Metaphor

![Figure 49 (a): Heatmap – Smiley – Strong](image)

![Figure 49 (d): Area of Interest – Smiley – Strong](image)
Figure 49 (b): Heatmap – Smiley – Average

Figure 49 (c): Heatmap – Smiley – Weak

Figure 49 (e): Area of Interest – Smiley – Average

Figure 49 (f): Area of Interest – Smiley – Weak

Heatmap results (shown in Figure 49 a, b and c) show that the learning representations area receives about 20% aggregate gaze allocation across the three images. Further, gaze allocation for the “average” image is distributed across the four topics and the key. However, for the “strong” and “weak” images, gaze allocation for the region containing the key favours the “excellent” and “very good” for the strong image, and “ok” and “weak” for the weak image.

Regions corresponding to the specific smileys in the main learning representation and the legend were selected for AOI Analysis. The AOI results (Figure 49 d, e and f) show that participants found disambiguation of the “excellent” and “very good” smileys to be an issue. This was confirmed by the analysis of talk-aloud and semi-structured interviews data. Disambiguation of the “ok” and “weak” smileys were also problematic.

Results from the think aloud protocol showed that many participants thought that the use of smileys was creative, however, design inconsistencies should be eliminated (black border for very good and weak vs. lack of black border for excellent and good). Many participants also reported that the white check mark surrounded by the green rectangle representing the knowledge level ok was misleading. It not only breaks the smiley design metaphor but also conveys the wrong sense that the students are doing great and are good to go.
Many participants felt that excellent and very good smileys should be swapped. That is, without the key, they would assume that the toothy smile of very good is more positive than the ear-to-ear grin of the excellent smiley. Another design change is to hold the shade of yellow constant across all of the smileys. In the future, we could consider the possibility of implementing Chernoff faces.

### 6.3.5 Traffic Light Metaphor

![Figure 50 (a): Heatmap – Traffic Light – Strong](http://people.cs.uchicago.edu/~wiseman/chernoff/)

![Figure 50 (b): Heatmap – Traffic Light – Average](http://people.cs.uchicago.edu/~wiseman/chernoff/)

![Figure 50 (d): Area of Interest - Traffic Light - Strong](http://people.cs.uchicago.edu/~wiseman/chernoff/)

![Figure 50 (e): Area of Interest-Traffic Light -Average](http://people.cs.uchicago.edu/~wiseman/chernoff/)
Aggregate gaze distribution (Figures 50 a, b and c) show three attention points for the strong and weak images but only two hotspots for the average image. 34% and 33% of the aggregate gaze was allocated to the main display region for the average and weak images compared to 22% for the strong image. Further, the time to the first fixation was also higher for the strong image.

AOI results (Figures 50 d, e and f) show that the Traffic Lights metaphor was easily to comprehend and that participants’ has higher gaze allocation to the legend in the case of the Average image when compared to the Strong and the Weak images.

Results from the think aloud protocol show participants thought that the use of traffic lights was creative. Negative comments included the decreased range of knowledge level representations (only “strong”, “average” and “weak”). Some participants suggested that the green light should be at the top as it is the best. One participant wanted the topics to be arranged from the strongest to the weakest so that they can know the “bottom” knowledge level.

Adding more colours for the other knowledge levels is an option (“very good” and “very weak”). The design challenge here is to extend but at the same time preserve the metaphor of the traffic lights.
Heatmaps of topic boxes (Figure 51 a, b and c) show that the design choice of using a single colour contrast for representing the different knowledge levels was problematic as evidenced by aggregate gaze distribution to the main representation area and the key region.

AOI analysis (Figures 51 d, e and f) shows that aggregate gaze allocation for the single colour coded topic boxes was high for all three information states of Average, strong, and Weak.

The topic checkboxes (e.g. Figure n) are the second most disliked representation after Word Clouds. The design issue is the low colour contrast between the different knowledge levels. Design implications are to increase the colour contrast or to use multiple colours as in other representations (dark green to dark red).
6.3.7 Group Histograms

**Figure 52 (a): Heatmap – Histogram – Strong**

**Figure 52 (b): Heatmap – Histogram – Average**

**Figure 52 (c): Heatmap – Histogram – Weak**

**Figure 52 (d): Area of Interest – Histogram – Strong**

**Figure 52 (e): Area of Interest – Histogram – Average**

**Figure 52 (f): Area of Interest – Histogram – Weak**
Heatmaps for collective/group histograms (Figure 52 a, b and c) show that participants’ aggregate gaze is allocated to the notational mark that represents their individual knowledge level relative to the entire class.

AOI analysis results (Figure 52 d, e and f) show that the semantic scale of “weak — strong” does receive gaze allocation and that the key region and the notational mark of “star” receive gaze allocations.

The collective/group histogram had the highest mean view time but participants found the absolute information of the individual embedded with the relative information about the whole class to be highly informative. Results of the think aloud protocol show the notational mark “star” needs to be changed to a neutral symbol and the legend should indicate clearly that it is a collective representation.

6.3.8 Word Clouds

Figure 53 (a): Heatmap – Word Cloud – Strong

Figure 53 (b): Heatmap – Word Cloud – Average

Figure 53 (d): Area of Interest – Word Cloud – Strong

Figure 53 (e): Area of Interest – Word Cloud – Average
Heatmap analysis (Figure 53 a, b and c) confirms the observation from the talk aloud and debriefing interviews that the word cloud is the most problematic notational system of the nine tested in this study.

AOI results (Figure 52 d, e and f) show that participants’ aggregate gaze was distributed between both the good understanding and weak understanding word clouds for the same topics.

Word clouds are the most disliked and the most confusing representation. One design implication is not to repeat the topics between good and weak understanding level and to create just one simple word cloud with colour coded topics. For example, green — red colour range indicating positive vs. negative category with topic size also coded for level of understanding.

6.3.9 Textual Descriptions
Heatmap analysis (Figure 54 a, b and c) shows that participants’ gaze distribution was primarily to the topic names and the knowledge level descriptors.

AOI results (Figure 54 d, e and f) confirm that topic names and knowledge level descriptors greater aggregate gaze allocation compared to the rest of the representation.

Most participants said that the textual description representation was not that useful. They found the repetition of the text tedious and the overall representation boring. Unlike other representations, the textual descriptors do not reveal the full scale of the ratings. One design change to explore is to colour code the knowledge level terms.
6.3.10 Table

Figure 55 (a): Heatmap – Table – Strong

Figure 55 (b): Heatmap – Table – Average

Figure 55 (c): Heatmap – Table – Weak

Figure 55 (d): Area of Interest – Table – Strong

Figure 55 (e): Area of Interest – Table – Average

Figure 55 (f): Area of Interest – Table – Weak
Heatmaps (Figure 55 a, b and c) show that aggregate gaze allocation was divided between the two columns of topic names and knowledge levels.

AOI analysis (Figure 55 d, e and f) shows near symmetrical aggregate gaze allocation between the two vertical columns of knowledge levels and topic names.

Many participants liked the table representation and the mean view time was the lowest. Participants made contradictory suggestions during the debriefing interviews. Some participants would like the vertical scale to range from the negative to the positive (unlike the traffic lights case) while other would keep it as it is.

6.3.11 Matrix

Figure 56 (a): Heatmap – Matrix – Strong

Figure 56 (b): Heatmap – Matrix – Average

Figure 56 (d): Area of Interest – Matrix – Strong

Figure 56 (e): Area of Interest - Matrix -Average
Heatmap results (Figure 56 a, b and c) for the three information states of the matrix notational system show greater aggregate gaze distribution for the topic names and the scale names.

AOI analysis (Figure 56 d, e and f) shows that the topic names and the knowledge level scale receive greater aggregate gaze allocation than the matrix cells.

Results from the think aloud protocol show the matrix representation was by far the representation that most participants find as the easiest to interpret and has the lowest mean view time but second lowest emotional activation. Many participants suggested that the scale should be re-organized from the left to the right being negative to positive.

Another scale related suggestion was to add “excellent” and “unacceptable” as anchors (excellent, very good, good, ok, weak, very weak, and unacceptable). For formative assessment purposes, “unacceptable” might be too strong a term and could be counter-productive.

6.4 Canonical Abstract Prototypes of Dynamic Visualisations of an OLM

Based on results of the eye tracking studies with static images report above (Section 6.3) we present an overview of a canonical prototype that builds on these recommendations to provide a facility to embed the OLM into an activity. Initially this is intended for summative assessment.

Canonical abstract prototypes “are an extension to usage-centred design that provides a formal vocabulary for expressing visual and interaction designs without concern for details of appearance and behaviour” (Constantine, 2003). Informed by the empirical findings of the SR-OLM study, four canonical abstract prototypes were created to integrate the modified OLM representations and potential learning activities in the NEXT-TELL project. As Lookwood says:

“Canonical Abstract Prototypes are a model specifically created to support a smooth progression from abstraction toward realisation in user interface design. The impetus for developing them arose from a growing awareness among practitioners of usage centred design regarding the substantial conceptual gap between the task models needed to drive an effective design and the
detailed, realistic prototypes needed for successful implementation. Particularly on large projects, the need for some intermediate form of representation became acutely apparent. Simple content inventories had proved both too abstract and too imprecise for resolving design issues in very complex user interfaces.” (Constantine, 2003)

Table 7 presents the four canonical abstract prototypes for the dynamic visualisations for the open learner model. The learning sciences design consideration was to implement a variation of the “artefact centred discourse” (Suthers & Xu, 2002) insight by embedding the OLM visualizations into the learning activities. The OLM visualisations share half of the screen with the learning activity. The DV-OLM prototype is designed to complement the Repertory Grids for Formative Assessment (RGFA)6 application by providing a summative evaluation option. The four canonical abstract prototypes were then implemented into the four variants of the Dynamic Visualizations of the Open Learner Models (DV-OLM) application7.

6.4.1 Dynamic Visualisations of Open Learner Models

At the time of writing, a prototype version of the DV-OLM application has been developed to be used for summative assessment in introductory computer science programming. The DV-OLM application is deployed at http://rgfa.cbs.dk/DV-OLM6 and will be used for summative evaluation in a pre-test and post-test design in a

---

6 http://rgfa.cbs.dk
7 http://rgfa.cbs.dk/DV-OLM
real world class on mobile application development for the curriculum module on Visual C# programming. This prototype is currently undergoing evaluation and results will be made available in October 2011.

Table 8: Screenshot of DV-OLM Prototype

1. DV-OLM: Vertical Left Orientation

![Diagram of DV-OLM: Vertical Left Orientation]

2. DV-OLM: Vertical Right Orientation

![Diagram of DV-OLM: Vertical Right Orientation]
3. DV-OLM: Horizontal Bottom Orientation

3. DV-OLM: Horizontal Top Orientation
6.5 Summary

This section has detailed an evaluation of interface elements in an educational setting using eye tracking equipment. The evaluation focussed on elements of interpretation and emotional response and has yielded a series of recommendations for the implementation of simple mocked up interface components. The outcomes of this study will be used to influence the future design of the OLM. A future, more in depth analysis of the results may be used to contribute to guidelines about key issues in OLMs from a HCI, visual attention and emotional response viewpoint. We have presented briefly an abstract canonical prototype for a dynamically updated OLM that is juxtaposed to the learning activity. In the near future we will build on this and hope to include such a facility in subsequent releases.
7 Repertory Grid Technique: Modelling Student Constructs

In this section we detail the use of the repertory grid technique as a data source for the learner model. We describe ways in which the technique may be used to capture students’ constructs about knowledge and evaluate this in a learning scenario (Section 7.3). Through the use of eye tracking equipment we evaluate students’ visual attention and emotional response to a deployment of the repertory grid technique through Facebook, and also students’ visual attention and emotional response to several simple visualisations of their repertory grid data (Section 7.4). Firstly we begin by describing the repertory grid technique (Section 7.1) and its role within the project using the triadic method of teaching analytics (Section 7.2).

7.1 Repertory Grid Technique

The repertory grid technique (RGT) is a method for eliciting personal constructs of individuals about elements belonging to the topic of study. RGT is based on the seminal contribution of the personal construct theory of the psychologist George Kelly (Kelly, 1963, 1992) and subsequent theoretical and methodological developments (cf. Adams-Webber, 2006; Fransella, Bell, & Bannister, 2003). RGT has been used by both researchers and practitioners in a wide variety of fields including psychotherapy (Winter, 2003), marketing (Frost & Braine, 1967), education (Bell & Harriaugstein, 1990; Mazhindu, 1992), and information systems (Cho & Wright, 2010; Tan & Hunter, 2002).

RGT consists of a family of methods and variations involving the nature of the personal construct elicitation and the rating or ranking of elements in monadic, dyadic or triadic configurations (Fransella, et al., 2003). Within the NEXT-TELL project, for the purposes of formative assessment, we have decided to start researching RGT with an implementation of the widely adopted method of triadic sorting of elements for personal construct elicitation and subsequent five-point Likert-item rating of the rest of the elements (Fransella, et al., 2003). In short, the triadic sorting method consists of the participants being presented sets of three elements each. For a given set of three elements, the participant is prompted to select the element that is different from the other two and to state how it is different as the “opposite construct”. Then, the participant is to state how the two remaining elements in the triad are similar to each other as the “similarity construct”. The rest of the elements are then rated on a Likert-item scale ranging from the opposite construct (1) to the similarity construct (5). The participants repeat this process until all the triads of elements are sorted into different and similar and the elements for that comparison are rated. The outcome of this exercise is the repertory grid (RG) consisting of rows consisting of triads, columns consisting of elements with the first column being the opposite construct and the last column being the similarity construct, and the cell values consisting of the ratings given for elements.

7.2 Triadic Method of Teaching Analytics (TMTA)

The following discussion is adapted from (Vatrapu, Teplovs, Fujita, & Bull, 2011) and presents the triadic model of teaching analytics (TMTA) developed within the NEXT-TELL project. As the NEXT-TELL project proposal says:

“In order to deal with these [21st century teaching]demands, teachers need to rapidly capture an ever-increasing amount of information about students’ learning, interpret this diverse body of information in the light of students’ development, appraise it in light of curricular goals, and make reasoned decisions about next learning steps. However, in comparison with most other professionals from whom clients expect rapid decisions in a dynamically changing environment, presently teachers often do not get the information they need for decision making in a timely fashion and in an ‘actionable’ format. This is particularly a challenge in technology-rich settings (the school computer lab, the laptop classroom) with high content and communicative density, where students engage with learning software and tools that teachers can only partially follow
at any point in time. However, as technology increasingly is permeating all schools and all classrooms, the challenge is there for all to face.” (Reimann et al., 2010)

Drawing on this, we conceived of RGT as a research and development topic within the emerging field of learning analytics and sought to provide both computational and methodological support for teachers in classroom settings to design, deploy and assess repertory grid exercises. Towards this end, we sought to integrate emerging developments in visual analytics and the established methodological approach of design-based research (DBR) in the learning sciences. The results of this integrative exercise are the approach called “teaching analytics” and a model of teaching analytics, termed “triadic model of teaching analytics (TMTA)”, discussed next.

TMTA seeks to adopt and extend the model of pair programming from the software engineering paradigm of extreme programming. We propose an extensible triadic model. More specifically, teaching analytics adapts the “pair analytics” method (Arias-Hernandez, 2011) in visual analytics (Thomas & Kielman, 2009). The pair analytics method was inspired by the pair programming model in the extreme programming software engineering approach. In pair programming, “all code to be sent into production is created by two people working together at a single computer.” Our vision for the research and development of RGT for technology enhanced formative assessment (TEFA) can be outlined as below.

To empirically explore the effectiveness, efficiency and satisfaction in fundamentally transforming the teaching profession from a “lone ranger” model to the collaborative model where teachers, analysts and researchers with complementary expertise collaboratively leverage their knowledge, skills and aptitudes towards enhancing learning in high-performance/high-bandwidth/ high-density classrooms of the 21st century.

However, the dyadic configuration of “driver” and “navigator” in pair programming and pair analytics creates a bootstrapping problem for learning settings: can we really throw a visual analytics expert (VAE) and teaching expert (TE) together into a classroom setting and expect them to work productively without explicit facilitation, intelligent scaffolding, and guided design? Facilitating interaction is a role that can be fulfilled by a design-based research expert (DBRE). As such, we adapt and extend the dyadic model of pair analytics in visual analytics to a triadic model of teaching analytics (TMTA) as shown in Figure 57:

![Figure 57: Triadic Model of Teaching Analytics (TMTA)](image)

At its core, our model sees collaborative knowledge building between teachers, analysts and researchers. Each has a complementary role in the teaching analytics setting.

---

http://www.extremeprogramming.org/rules/pair.html
http://www.extremeprogramming.org/
Eliciting criteria for teaching analytics involves a collocated collaborative triad of a teaching expert (TE), a visual analytics expert (VAE), and a design-based research expert (DBRE) analysing, interpreting and acting upon data being generated by students’ learning activities by using a range of visual analytics tools.

We think of the relationships between the TE, VAE and DBRE as a dynamic socio-technical system. The design considerations are about creating feedback loops between the three individuals, such that each one drives the other two to higher levels of performance on the positive side (with the cost of anxiety in the negative case). That is, feedback from the teacher inspires the VAE to create new, better visualizations and for the researcher to better understand the on-going teaching and learning processes while feedback from the VAE – perhaps in the form of visualization artefacts – allows the teachers to better understand what is going on in the classroom from a learning activity design perspective and the research to hypothesise, test and predict student learning trajectories and performance outcomes. All in all, these feedback loops should culminate in the teacher providing timely, meaningful actionable, customized and personalized feedback to students. The key point here is that each member of the triumvirate of TE, VAE, and DBRE can gain from the other two, not that each partner’s role is to highlight deficiencies of the other two.

Therefore, TMTA involves a close collaboration between the TE, VAE, and the DBRE. It includes teaching practitioners in the design process and invites them to contribute significantly to the innovation of the visual analytics tools. This allows these learning analytics tools to address pedagogical issues as they arise and evolve in real classrooms. The Methodology section (Section 7.3) details two cycles of iterative research and development of the RGT in a real classroom setting and the subsequent eye-tracking studies in the laboratory setting.

### 7.3 Methodology

There are three interdependent research and development objectives for the use of repertory grid technique for technology enhanced formative assessment.

1. Integration of repertory grid into the curriculum as an in-class learning activity or a take-home exercise.
2. Methodological support for teachers to designing and deploying RGT exercises.
3. Computational support for visualizing the repertory grid data at the individual student and whole classroom level for formative assessment purposes for teachers and self- and collaborative learning purposes for students.

In order to achieve these three interdependent objectives, we employed educational action research methods (Hartley, 2009) in a real classroom. We conducted two cycles of iterative research and development of the RGT in a real classroom setting and the subsequent eye-tracking studies in the laboratory setting. The classroom setting, Facebook implementation of RGT, and the three studies are described below.

#### 7.3.1 Classroom Setting

The classroom setting for the in-class exercises was a course on Internet Marketing\(^{10}\) at the international summer university programme (ISUP) of the Copenhagen Business School (CBS). Internet marketing was taught in two sections of about 42 students for 150 minutes each on Tuesdays and Thursdays for five consecutive weeks. The syllabus and other materials are available from the course portal [http://www.itu.dk/people/rkva/2011-Summer-IM/].

---

7.3.2  FARGO: A Facebook Implementation of the Repertory Grid Technique

The internet marketing class has a strong emphasis on social media and integrated marketing communications using social media. The course is taught at the bachelor’s level at the Copenhagen Business School and at the master level at the IT University of Copenhagen. The course is extremely popular given the increasing influence of social networking sites such as Facebook. The course leverages the social media focus through a Facebook page (http://www.facebook.com/group.php?gid=133258548012). The pedagogical purposes for the Facebook course page\(^\text{11}\) are (a) to provide a social sharing platform for items of interest to the course such as viral videos, interesting articles and such, and (b) to utilize the discussion boards for online discussion exercises on topics such as personal product purchase reflection\(^\text{12}\), decision heuristics simulations\(^\text{13}\), and motivations for social sharing\(^\text{14}\).

Given this tight pedagogical coupling between the course curriculum and Facebook, we decided to start our research and development of RGT for TEFA using the Facebook platform. A Facebook application called “formative assessment using repertory grid online” (FARGO) was developed towards this purpose. The first implementation of FARGO was designed to support formative assessment of students’ prior knowledge of consumer decision-making before the scheduled lecture on consumer psychology. The objective was to adapt the online lecture teacher based on the Repertory Grid data and to link the FARGO exercise on consumer decision making to the decision heuristics simulations exercise designed for students to gain familiarity with behavioural economics. Study #1 below described the content and format of the first study that involved using FARGO for the topic of consumer decision-making.

7.3.3  Study #1: Repertory Grid Classroom Exercise on Consumer Decision-Making

The course module on consumer decision-making covered two different perspectives on the impact of the internet on consumer decision-making: the revolutionary view that the internet has empowered consumers to make better informed decisions and the evolutionary view that the internet has led to information overload and as before consumers rely on shortcuts in decision-making. The module introduced the neoclassical economics model of a rational consumer and Herbert Simon’s critique of the neoclassical model through the notion of “Bounded Rationality”. Product alternatives and attributes are key concepts within the module and the repertory grid in-class exercise on Facebook was designed to elicit the personal constructs of the students with respect to the product attributes and purchasing processes of eight different types of consumer products.

The topic for the repertory grid exercise was consumer decision making. The eight elements were:

- car
- laptop
- beer
- water
- airline tickets
- pair of shoes
- pair of jeans
- movie tickets

\(^{11}\) http://www.facebook.com/group.php?gid=133258548012&ref=ts


\(^{13}\) http://www.facebook.com/topic.php?uid=133258548012&topic=15081

The elements were selected to range from fast moving consumer goods to potentially luxury goods (Veblen goods) and ranging from relatively inexpensive to relatively expensive purchases involving little or great consideration time and personal taste vs. social influences.

With 8 elements there are \( \binom{8}{3} = \frac{8!}{3!(8-3)!} = 56 \) unique combinations of triads possible for comparison. 56 comparisons followed by elements ratings are obviously time-consuming and potentially tiring and boring for the students. So, the teacher made the design decision to select 10 interesting triads to include in the exercise. The 10 triads selected were:

- beer, water, pair of jeans
- pair of jeans, pair of shoes, car
- car, laptop, beer
- pair of shoes, pair of jeans, laptop
- water, airline tickets, pair of shoes
- beer, movie tickets, pair of shoes
- airline tickets, pair of shoes, movie tickets
- laptop, water, pair of jeans
- airline tickets, car, water
- movie tickets, beer, airline tickets

The selection criteria for the triads was that each element (i.e., product) should appear at least once and in different positions in the triad (first, second and third) and with as many different elements as possible. Based on the comparative method (Ragin, 1987), some triads were selected from the most similar systems design (MSSD) and most different systems design (MDSD). The order of presentation of the triads was randomised to control for order effects.

The in-class exercise was administered in class the week before the course module on online consumer psychology lecture and decision heuristics simulations take-home exercise was scheduled. After completing the Facebook exercise in-class, participants were provided with a network diagram visualising the relationship between the elements based on the ratings provided. Participants had the option of sharing their repertory grid network diagram and the repertory grid table with their classmates and other members of the Facebook page for online marketing. Observations of the in-class exercise activity and student feedback afterwards indicated that ten triadic comparisons and ten sets of element ratings were tedious, tiresome and boring for the students. This was the primary design consideration for the second iteration of FARGO, the Facebook implementation of RGT. The Repertory Grid data from the consumer decision-making was utilised in the eye-tracking study of multiple representations to be discussed below. Further observations on Study #1 on consumer decision-making are discussed in the results section (Section 7.4).

7.3.4 Study #2: Repertory Grid Classroom Exercise on Online Marketing Topics

Based on the observations from the consumer decision-making exercise, the second iteration of formative assessment using repertory grid online called FARGO 2 implemented the critical design change of reducing the number of triads to five. The second half of the course was organized into special topics on eight different kinds of online marketing. The purpose of this exercise was (a) to inquire into students’ conceptions about these eight different kinds of online marketing and adapt instructional content and format accordingly, and (b) to familiarise students of the existence of and the relationships between the eight different kinds of online marketing covered as special topics in the course curriculum.

The elements (i.e., online marketing topics) for the second exercise are listed below:

- search engine marketing
As discussed above, the number of triads was reduced from ten to five. The five triads are listed below.

- viral marketing, social media marketing, mobile marketing
- search engine marketing, flash mob marketing, augmented reality marketing
- advergaming, in-game advertising, flash mob marketing
- social media marketing, search engine marketing, mobile marketing
- augmented reality marketing, viral marketing, in-game advertising

As with the consumer decision-making exercise, the selection criteria for the triads was that each element (i.e., online marketing topic) should appear at least once and in different positions in the triad (first, second and third) and with as many different elements as possible. Based on the comparative method (Ragin, 1987), some triads were selected from the most similar systems design (MSSD) and most different systems design (MDSD). The order of presentation of the triads was randomized to control for order effects.

The in-class exercise was administered in class at the midpoint of the course and the week before the special topics were scheduled. Students who didn’t complete the exercise in the class were invited for an eye-tracking study in the laboratory. Students who completed the in-class exercise were invited to participate in the eye-tracking study of multiple representations of the Repertory Grid Data from the Consumer Decision-Making exercise. Further observations from Study #2 on Online Marketing Topics are discussed in Section 7.4.

### 7.3.5 Study #3: Eye-Tracking Laboratory Study of Repertory Grid Exercise of Online Marketing Topics

As mentioned above, all students in the class were invited for an eye-tracking study in the laboratory. Study participation was voluntary and an online study registration form was used to collect students’ demographic data and availability. The laboratory students were then scheduled based on the mutual availability of the student-participants and the teacher-facilitator. Students who didn’t complete the online marketing topics in-class exercise were assigned to participate in the FARGO 2 laboratory study. The laboratory study protocol is listed below:

#### Pre-Investigative Session

1. Participants were welcomed and seated in the laboratory. They were briefly reminded that they are about to participate in an eye-tracking study and a short interview after the study.
2. An informed consent form was given. Participants were explicitly informed that it is the software that is being tested and not them. Further, participants were explicitly informed that they may withdraw from the study at any time. If they stopped participating before completing the study, they were to be compensated with a movie ticket coupon.
3. A copy of the informed consent form was given to the participants after they signed the informed consent form. A participant code was then assigned.

---

25 [https://docs.google.com/spreadsheet/viewform?hl=en_US&formkey=dGxrRGlycUk4VG1ocJZ6M0ZMR2QxQlE6MQ#gid=0](https://docs.google.com/spreadsheet/viewform?hl=en_US&formkey=dGxrRGlycUk4VG1ocJZ6M0ZMR2QxQlE6MQ#gid=0)
4. A brief interview was conducted on their in-class exercise experiences and reflections on the repertory grid technique. This concluded the pre-investigative Session.

Investigative Session

5. The participant was seated in front of the eye-tracker and the position was adjusted so that participant eyes were visible in the eye-finder of SMI IView X\(^1\) eye-tracker device driver software and iMotions Attention Tool 4.1\(^2\) study software.

6. 9-point eye calibration was then conducted followed by light calibration.

7. Participants were then instructed to log on to their Facebook account and request to use FARGO 2 Facebook application.

8. Once the homepage for FARGO 2 loaded in the browser tab, participants were instructed to follow the onscreen instructions for the online marketing topics repertory grid exercise.

9. After participants completed the repertory grid exercise, they were given the option of sharing the network diagram visualisation and the repertory grid table to the Facebook wall. This concluded the investigative session.

Post-Investigative Session

10. A brief open-ended interview was conducted laboratory study experience with and reflections on the repertory grid technique. This concluded the post-investigative session.

11. Participants were then given the movie ticket coupon and a signature of receiving the movie ticket coupon obtained. The participant was then thanked and let out of the laboratory. This concluded the study session.

One observation was that, on average, construct elicitation time was longer than the elements rating time. Further, aggregate eye-tracking heat maps showed an increased distribution of gaze to the triad during construct elicitation and to the middle of the elements during the ratings task. Section 7.4 presents detailed findings from the eye-tracking laboratory study of online marketing topics.

7.3.6 Study #4: Eye-Tracking Laboratory Study of Multiple Representations of Repertory Grid Data for Consumer Decision-Making

As mentioned above, all students in the class were invited for an eye-tracking study in the laboratory. Study participation was voluntary and the same online study registration form as Study #3 was used to collect students’ demographic data and availability. The laboratory students were then scheduled based on the mutual availability of the student-participants and the teacher-facilitator. Students who completed both the consumer decision making and online marketing topics repertory grid exercises in the class were assigned to the study of multiple representations of the repertory grid dataset for consumer decision-making. The laboratory study protocol is listed below:

Pre-Investigative Session

1. Participants were welcomed and seated in the laboratory. They were briefly reminded that they were about to participate in an eye-tracking study and a short interview after the study.

2. An informed consent form was given. Participants were explicitly informed that it is the software that is being tested and not them. Further, participants were explicitly informed that they may


\(^2\) http://www.imotionsglobal.com/
refuse to participate in this study or stop participating at any time. If they stopped participating before completing the study, they were told that they would still be compensated with a movie ticket coupon.

3. A copy of the informed consent form was given to the participants after they signed the informed consent form. A participant code was then assigned.

4. A brief interview was conducted on their in-class exercise experiences and reflections on the repertory grid technique. This concluded the pre-investigative session

Investigative Session

5. The participant was seated in front of the eye-tracker and the position was adjusted so that participant eyes were visible in the eye-finder of SMI iView X\(^{18}\) eye-tracker device driver software and iMotions Attention Tool 4.1\(^{19}\) study software

6. 9-point eye calibration was then conducted followed by light calibration

7. The study session consisted of a randomised presentation of the three tasks.

7.1. One task involved a static image word cloud of the constructs elicited for the entire class (24 students and 1 teacher) for one particular triad (water, beer and pair of jeans.) Participants were then instructed to log on to their Facebook account.

7.2. A second task involved interacting with dynamically generated multiple representations of the repertory grid dataset for consumer decision-making uploaded to the popular visualisation website Many Eyes\(^{20}\). There were four representations that were investigated (word clouds of constructs elicited, line charts and bar graphs of element ratings, and tree maps of the entire dataset providing a dashboard view.)

7.3 The third task was to inspect the repertory grid of a peer. The tasks consisted of identifying the opposite and similar elements for a given row of the table and to agree or disagree with the rating provided for that row and selected columns. This concluded the investigative session.

Post-Investigative Session

8. A brief open-ended interview was conducted laboratory study experience with and reflections on the multiple representations (static word cloud, dynamic visualisations of Many Eyes: word clouds, line charts, bar graphs, tree maps, and a repertory grid table). This concluded the post-investigative session.

9. Participants were then given the movie ticket coupon and a signature of receiving the movie ticket coupon obtained. The participant was then thanked and let out of the laboratory. This concluded the study session.

A major finding was that the repertory grid tables can be used for creating collaborative learning exercises and that they need to augmented for interactivity by providing sorting functionality in a row or a column. Word clouds are useful for presenting a collective map of the constructs. Line charts are useful for testing students’ beliefs and tree maps are somewhat promising for designing dashboards for teachers and students. Aggregate eye-tracking heat maps showed the expected distribution of gaze to the highly salient areas of word clouds for example. Section 7.4 presents detailed findings from the eye-tracking laboratory study of online marketing topics.


\(^{19}\) http://www.imotionsglobal.com/

\(^{20}\) http://www-958.ibm.com/software/data/cognos/manyeyes/visualize/repertory-grid-for-online-consumer/versions/1
7.4 Results

The following subsections present the findings for each of the four studies: two in-class repertory grid exercises and the two eye-tracking lab studies on repertory grid exercise task and the visual analytics task with multiple representations of the repertory grid data.

7.4.1 Study #1: Repertory Grid Classroom Exercise on Consumer Decision-Making

As part of action research the study leader carried out all three roles of the TMTA model: teacher, design-based researcher and visual analytics expert and also functioned as the laboratory study facilitator. A total of 25 grids (24 students and 1 teacher) were completed. Students were instructed to bring their laptops (fully charged and with a power adapter) to class. A few students didn’t bring their laptops to class and a few other experienced technical difficulties with internet connectivity, Facebook log in, application access and such. Students without their own laptops and/or experiencing technical difficulties were advised to pair up with other students and complete the exercise collaboratively. Data collection included the repertory grids for students and the teacher, observation notes during the in-class exercise, plenary discussion after the exercise, and semi-structured interviews before the eye-tracking laboratory studies #3 and #4.

The main finding from the repertory grid classroom exercise on consumer decision-making is that ten comparisons and ratings are repetitive, tedious and boring to students. Many students expressed the opinion that the maximum number of triads for construct elicitation and element ratings should be 5 or 6. Students found the collaborative mode to be interesting and engaging. Regarding the content of the exercise, students who had domain knowledge of consumer psychology through prior courses felt that the exercise was less interesting compared to students without prior knowledge of the exercise topic. Many students said that it is unlikely that their repertory grids might change before and after the course module on online consumer psychology has been taught. The two different kinds of reasons provided for this lack of change in pre- vs. post-lecture repertory grids were that (a) they already have the domain knowledge about consumer psychology from previous courses, and (b) the constructs were highly personal and they don’t expect their personal constructs to change over a short period of time. These are important pedagogical considerations for teachers in designing repertory grid exercises.

With regard to software design, a majority of the students thought that the network diagram showing the relationship between the elements has limited value. The students suggested that their personal constructs and the element ratings should also be displayed after they completed the repertory grid exercise. Sharing of the completed repertory grids on the Facebook wall of the course was optional and a few students chose not to share their grids. Reasons for not sharing ranged from privacy concerns to technical errors with the FARGO Facebook application.

An inspection of the repertory grids of students indicated that a majority of the students viewed consumer decision-making as multi-dimensional. That said, the personal constructs elicited didn’t demonstrate the linkages to the technical content of the course module. It wasn’t clear if the personal constructs were expressed at the level of “folk psychology” or if students employed the terms in a technical sense at the level of “consumer psychology”. Taking of all this into consideration, the teacher emphasised the theoretical assumptions about the rational model in neoclassical economics and the critique of them from Simon’s work on “bounded rationality” and the decision heuristics findings in consumer psychology. It was also decided to present the students with two contrasting perspective on the influence of internet on consumer decision-making to explicitly link the course module content to the second half of the course curriculum covering the different kinds of online marketing.
After the online lecture was delivered, students were shown a word cloud\(^{21}\) of the personal constructs for the triad (beer, water, pair of jeans) and asked to recall their personal constructs and then compare and contrast it to the personal constructs of other students. They were then instructed to draw linkages to the concepts covered in the online consumer psychology lecture.

### 7.4.2 Study #2: Repertory Grid Classroom Exercise on Online Marketing Topics

The pedagogical design of the second repertory grid exercise took into consideration the level of domain knowledge and the extent to which the constructs could be influenced by intuition. As the teacher of the course as well as a design based researcher, the author decided to design a repertory grid exercise with the eight different kinds of online marketing that were taught as special topics in the second half of the course. A diversity of domain knowledge familiarity was to be expected with the eight kinds of online marketing. For example, topics such as search engine marketing and social media marketing could be expected to be familiar to the students whereas emerging topics such as augmented reality marketing and flash mob marketing are expected to be not that familiar to the students. Further, unlike consumer decision-making where students could draw from their own lived experience of being consumers and engaging in purchasing decisions on a regular basis, except for very few students working in marketing departments, the majority of students had to reflect on the action-taking possibilities and meaning-making opportunities (socio-technical affordances) of the different kinds of online marketing.

The software implementation of FARGO 2 incorporated the feedback from the students and the teacher. As mentioned earlier, the number of triads was reduced to five and the students were presented with both the network diagram visualisation as well as the repertory grid table of their constructs and ratings for the elements.

An interesting classroom observation was that some students asked the teacher about the topics they were not familiar with and other students looking on the course portal and/or querying the search engines. During classroom discussions and semi-structured interviews, students said that the online marketing topics exercise was more engaging and challenging and felt that their grids would change before and after the course modules on the special topics have been taught. The researcher/teacher decided to investigate these student perceptions and scheduled a repeat of the repertory grid exercise on the last day of the course. Unfortunately, FARGO 2 wasn’t functional on the last day of class and as such there is no pre-instruction vs. post-instruction repertory grids to compare and contrast. But this will be incorporated into future studies.

The online marketing topics repertory grid exercise data was meaningful and actionable from a formative assessment standpoint. The teacher changed the order of presentation of the curriculum modules and decided to allocate more instructional time to flash mob marketing and mixed reality advertising special topics than was originally planned. The teacher also used the word clouds of the personal constructs elicited for the five triads to emphasise the similarities and differences between the different kinds of online marketing topics from the return of marketing investment (ROMI) perspective.

### 7.4.3 Study #3: Eye-Tracking Laboratory Study of Repertory Grid Exercise of Online Marketing Topics

Six students (3 female and 3 male) participated in the eye-tracking laboratory study of the repertory grid exercise with the eight online marketing topics as elements. The lab study exercise was identical to the in-class exercise. The objectives of the laboratory study were (a) to investigate the time taken for construct elicitation and the subsequent elements rating for each of the five triads, and (b) to investigate the collective gaze behaviour of participants during the construct elicitation phase and the subsequent elements rating phase for each of the five triads.

\(^{21}\) http://www.wordle.net/show/wrdl/3840911/Repertory_Grid_for_Consumer_Decision-Making%7Bbeer%2C_water%2C_a_pair_of_jeans%7D
Task Time: Construct Elicitation vs. Elements Rating

Except for a couple of instances, time taken for construct elicitation was higher than the time taken to rate the elements. In the two instances where the elements rating time was greater than the construct elicitation time, students had to relate opposite and similarity constructs that were specific to the three elements in the triad to the five other elements. One student commented that he would have chosen different constructs if he could go back. Analysis of the talk aloud and the structured interview data indicates that students spent more time on construct elicitation when one or more of the elements in the triad were unfamiliar to them (like advergaming, augmented reality advertising). No order effects were found. Figure 58 presents the average time in seconds for the five construct elicitations and the five elements ratings. Figure 59 presents the overall average times for construct elicitation and elements ratings.

![Figure 58: Time taken for each construct elicitation and elements rating](image-url)
Gaze Behaviour: Construct Elicitation and Elements Rating

Eye-tracking data analysis was conducted at the aggregate level for each of the five construction elicitation and elements rating tasks. Three different kinds of analysis of the eye-gaze data were conducted using the iMotions Attention Tool 4.1 software: (a) Heatmaps and (b) Bee Swarms.

The heatmap presents the spatial distribution of students’ gaze on a particular repertory grid exercise webpage. Heatmaps are composite images that contain an overlay of a gradient colour layer on the stimulus image (in our case, the particular construct elicitation or elements rating webpage) with areas of the webpage that received a greatest allocation of students’ gaze ranging from red to yellow and with areas that received the least gaze allocation ranging from yellow to green. The heatmaps presented below are static images of the aggregate gaze distribution on a particular webpage for all respondents.

The Area of Interest (AOI) analysis was conducted on regions of the webpages that were of particular importance from the pedagogical and/or user interface design perspectives.

The Bee Swarm is a dynamic presentation of the main areas of gaze allocation across all of the respondents for that particular webpage (that is, the construct elicitation or elements ratings tasks). Unlike the heatmaps, bee swarms also present the temporal dynamics of the spatial allocation of gaze for all students of that particular task for that particular webpage.

Appendix A is taken from the Attention Tool Analysis report and presents further information on the heatmaps and bee swarms.
Heatmaps of Construct Elicitations and Elements Ratings
Table 7 below presents thumbnails of the heatmaps for the five construct elicitation tasks and the five elements rating tasks.

Table 9: Composite Heatmaps for Construct Elicitation and Elements Ratings
An analysis of the aggregate heatmaps (Table 8) shows that the gaze distribution pattern is fairly similar across the five construction elicitation tasks. Students’ gaze is primarily allocated to the 3 elements in the triad and the text boxes for the opposite and similarity constructs. For this area of interest (triad radio buttons and construct textboxes), the average time to the first fixation (TTFF) ranges from 0.4 seconds to 1.6 seconds. The average time spent in this area of interest out of the total task time ranges from 24% to 32%.

The elements ratings heatmaps show a greater variation in the gaze distribution on the webpage. There are two areas of interest. The first area of interest is the set of pull down list controls for rating the elements and the second area of interest is the elements names. Gaze is also allocated to the scale of the elicited constructs at the top. For the pull down list controls, the first area of interest, the average time to the first fixation (TTFF) ranges from 0.2 seconds to 0.9 seconds. The average time spent in this area of interest out of the total task time ranges from 28% to 43%.

**Area of Interest (AOI) Analysis of Construct Elicitations and Elements Ratings**

For further analysis, three areas of interest (AOI) were defined on the construct elicitations webpage corresponding to the following student actions:

- Selection of the different element in the triad (three radio button controls followed by the element names)
- Opposite construct elicitation (text box control)
- Similarity construct elicitation (text box control)
Results show that, on average, students’ gaze allocation was higher selection of the different element in the given triad with the opposite and similarity construct text boxes receiving roughly similar gaze allocation.

Three areas of interest (Figures 60 and 61) were defined for further analysis of eye gaze data for the elements ratings webpages. The three AOI were:

- The Likert scale ranging from 1 (opposite construct) to 5 (similarity construct)
- Names of the eight elements
- The ratings region consisting of pull down list controls ranging from 1 (opposite construct) to 5 (similarity construct)

Results show that, on average, only 1% of the gaze for total exposure time was allocated to the Likert scale with the ratings region and the element names receiving 21% to 15% gaze allocation on average. User interface and user experience design implications from the AOI analysis are discussed in the next section.

![Figure 60: Area of Interest (AOI) Results for Construct Elicitation of the First Triad](image-url)
Figure 61: Area of Interest (AOI) Results for Elements Rating of the Fifth Triad

Bee Swarms of Construct Elicitations and Elements Ratings

As expected, bee swarms analysis of the construct elicitation and elements ratings for the first triad shows that participants’ gaze varies over time. The dynamic aggregate gaze behaviour can be divided into three different phases. During the first phase, visual gaze is primarily concentrated on the instructions. During the second phase, gaze is distributed primarily over the three elements in the triads with occasional forays into the instructions and the Facebook ads on the right hand panel. During the third and final phase, gaze is allocated to the text box fields for the opposite and similarity constructs. The Bee Swarm video for the first construct elicitation task can be downloaded from this temporary link[^22].

Bee swarms analysis of the first elements ratings task also showed differential spatial preferences for participants’ gaze over time. The dynamic aggregate gaze behaviour can be divided into two phases. During the first phase, students’ gaze is primarily allocated to the elements. During the second phase, students’ gaze is primarily allocated to drop down list controls. The bee swarm video for the first elements rating task can be downloaded from this temporary link[^23].

7.4.4 Study #4: Eye-Tracking Laboratory Study of Multiple Representations of Repertory Grid Data for Consumer Decision-Making

Four female and four male students participated in the eye-tracking laboratory study. As mentioned earlier, the study consisted of three tasks presented in a random order:

- Static Word Cloud

- Repertory Grid Table generated by FARGO on Facebook
- Dynamic representations of the repertory grid dataset uploaded to Many Eyes
  - Word Cloud
  - Line Graph
  - Bar Chart
  - Tree Map

Analysis of gaze data for each of the above representations is presented below:

**Static Word Cloud of Constructs for a Triad**

As discussed earlier, the image consisted of a word cloud that was created from the similarity and opposite constructs for one particular triad (beer, water, and pair of jeans) of the consumer decision-making repertory grid classroom exercise. The task consisted of initial free range viewing subtask and word finding subtask. Students had to find different words of different sizes located in different regions of the word cloud, the heat map shows a fairly uniform gaze distribution with the region to the left of the largest sized word (“need”) having the highest proportion. The area containing the largest sized words receives the highest proportion of gaze distribution of 17% with an average time to the first fixation (TTFF) of 0.3 seconds. Figure 62 presents the heatmap.

![Figure 62: Heatmap of the Static Word Cloud](image)

Area of Interest analysis shows that horizontal layout with alphabetical ordering of words results in greater gaze distribution to the areas surrounding the larger words. Figure 63 presents the AOI results for a pre-defined template.
Bee swarm analysis shows that students gaze distribution starts at the most salient item (the largest word) and becomes completely disjointed. This is mostly due to fact that the students had to find different words and they scanned the image in different ways. The bee swarm video for the static word cloud task can be downloaded from this temporary link 24.

Emotional activation metrics couldn’t be calculated for this static image unlike the static representations of the open learner model study presented elsewhere as the total number of respondents was less than the minimum required of ten subjects.

**Repertory Grid Table**

The primary purpose of this task was to investigate how students make sense of the repertory grid table consisting of rows of elements ratings anchored with the opposite and similarity constructs. Students were instructed to inspect the pre-selected repertory grid of a classmate. Based on the elicited constructs and the elements’ ratings for the third row, they were asked to figure out the triad of elements involved. Students were asked what their own constructs and ratings would have been and if and how they agreed or disagreed with their peer. Further, they were instructed to inspect pre-selected columns and reflect on the ratings and the constructs. Heatmap analysis (Figure 64) shows that students’ gaze was primarily distributed to the opposite and similarity constructs and in particular to row 3 due to the task instructions. As expected, the columns preselected for inspection also received higher gaze allocation. One observation is that the repertory grid table can be employed in inspection exercises for reflection and collaborative learning in a guided discovery mode.

Four Areas of Interest (AOI) were defined for further analysis and are listed below.

- Element names in the first row
- Opposite constructs in the first column
- Similarity constructs in the last column
- Elements’ ratings in the body of the repertory grid table

Given the task instructions described earlier and the “demand characteristics” (Orne, 1962) of the study setting, AOI analysis confirmed expectations about aggregate gaze distribution to the constructs, the element names and the element ratings. Specifically, 60% of the total exposure time was spent outside the four AOI with the elements rating cells receiving 19% aggregate gaze followed by 10% for opposite constructs column, 6% for the element names row, and 5% for the similarity row. Analysis of the talk-aloud and the semi-structured interviews indicate that students might benefit from interactive repertory grid tables that support sorting and multiple grid comparisons. Figure 65 presents the AOI results for the repertory grid table inspection task.
Figure 65: AOI Results for the Repertory Grid Table Inspection Task

Bee swarm analysis shows the differential distribution of gaze across the four AOI with crisscrossing gaze paths between the opposite and similarity constructs and the elements ratings. The bee swarm video for the repertory grid table task can be downloaded from this temporary link\(^\text{25}\).

**Dynamic Word Cloud of All Constructs Elicited**

The word cloud representation is identical to the static version task above discussed in terms of the horizontal layout and the alphabetical ordering of the words. The differences were that the word cloud had to be composed by the students, supported dynamic interaction and content was exhaustive of the constructs from all the ten triads of the consumer decision making repertory grid exercise for all the students. The task consisted of initial construction of the word cloud, free range viewing subtask followed by word finding subtask.

Heatmap analysis (Figure 66) shows that the aggregate gaze of the participants was distributed around the most salient items (larger sized words). When compared to the heatmap of the static word cloud, the dynamic visualization has more regions with high aggregate gaze.

\(^{25}\) http://www.itu.dk/people/rkva/temp/FARGO RepGrid Table - BEE SWARM (BEES+HMP).wmv
Area of interest analysis shows that the dynamic visualization with the horizontal layout with alphabetical ordering of words results in more even gaze distribution. As it is to be expected, the most frequent word ("decision") which has the largest size receives higher gaze allocation. Figure 63 presents the AOI results for a pre-defined template. Figure 67 presents the AOI results for the dynamic word cloud.
A side-by-side bee swarm analysis of the static word cloud and the dynamic word cloud shows that unlike the static case, the initial gaze allocation of the students in the dynamic case starts at different regions rather than at the largest word. This is mostly due to the fact that the dynamic word cloud had many salient words. The bee swarm video for the dynamic word cloud task can be downloaded from this temporary link[^26].

**Dynamic Line Graph of All Element Ratings**

The static and dynamic word cloud tasks visualized the textual content of first aspect of the repertory grid exercise, construct elicitation. Line graph and bar chart tasks visualized the numeric content of the second aspect of the repertory grid exercise, elements rating. Students were instructed to freely explore and interact with the dynamic visualization and try to find patterns if any in the elements ratings.

Heatmap analysis (Figure 68) shows that the legend for the visualization and the element names on the left hand side next to the vertical axis received 14% of the aggregate gaze with 86% of the aggregate gaze distribution outside this attention point. The line graphs corresponding to elements at the top receive more gaze allocation than the lines in the middle of the chart.

![Figure 68: Heatmap of the Dynamic Line Graph](http://www.itu.dk/people/rkva/temp/Many%20Eyes-CDM-WordCloud%20-%20BEE%20SWARM%20(BEES%20HMP).wmv)

Five areas of interest have been identified corresponding to the main graph area, element names, user identity labels beneath the horizontal axis, the visualization controls for the x-axis and the y-axis. Results show that 74% of the aggregate gaze data was outside the five AOI with the main line graph area accounting for 20% of the aggregate gaze data. Figure 69 presents the AOI results for the Line Graph.

Figure 69: AOI Results for the Dynamic Line Graph

Bee swarm analysis shows that the horizontal axis receives the least gaze allocation and that students’ gaze starts out in different regions of the line graph with the element names region and the peaks of the line graphs emerging as key convergence points. The bee swarm video for the dynamic line graph task can be downloaded from this temporary link\(^27\).

**Dynamic Bar Chart of All Element Ratings**

As mentioned earlier, both line graphs and bar charts visualized the numeric content of the second aspect of the repertory grid exercise, elements rating. As with the line graph task, students were instructed to freely explore and interact with the dynamic visualisation and try to find patterns if any in the elements ratings. Only two out of the total eight students that participated in the laboratory study completed this task as students found the line graph to be a more informative, meaningful, actionable, and interactive visualisation. As such the findings reported for the bar charts are not conclusive.

Heatmap analysis (Figure 70) shows similar aggregate gaze distribution as the line graph with the legend for the visualisation and the element names on the left hand side next to the vertical axis accounting for 7% of the aggregate gaze and the middle of the bar chart are accounting for 2% and with the remaining 91% of the aggregate gaze distribution outside these two regions.

Six areas of interest were defined corresponding to the main chart area, element names, user identity labels beneath the horizontal axis, instructions for the interactive controls on top of the element names, the visualization controls for the x-axis and the y-axis. AOI analysis shows that 85% of the aggregate gaze was outside the six AOI with the main Bar Chart area accounting for 10% of the aggregate gaze. Figure 71 presents the AOI results for the Dynamic Bar Chart.
Figure 71: AOI Results for the Dynamic Bar Chart

Unlike the line graph, the bee swarm analysis shows that the horizontal axis receives some gaze allocation. Gaze lingers on the peaks of the bars in what are speculated as moments of comparisons. The bee swarm video for the dynamic line graph task can be downloaded from this temporary link.28

Dynamic Tree map of All Elicited Constructs and Elements Ratings

Tree map visualizations were designed to provide a “dashboard” view of the entire repertory grid exercise. That is tree map visualisations can provide a comprehensive view of the both the textual data (elicited constructs) and numeric data (element ratings). As with the line graph and bar chart visualizations, students were initially instructed to freely explore and interact with the tree map visualisation with subsequent instructions for guided interaction of the functionality of the tree map visualisation.

Analysis of the talk-aloud and semi-structured interview data shows that students felt that the tree maps were the most difficult visualisations to make sense of. Heatmap analysis (Figure 72) shows that tree map region corresponding to the first triad followed by the regions for the second, third and eighth triads accounted for the majority of the aggregate gaze distribution at 38%.

Figure 72: Heatmap of the Dynamic Tree Map

Nine areas of interest were defined with five AOI corresponding to 5 triads, one AOI each to the tree map hierarchy ordering and the interactive controls for size, colour, and opacity. AOI analysis results show that 76% of the aggregate gaze distribution was outside these nine AOI. The regions corresponding the first, fourth, sixth, eighth and tenth triads accounted for 7%, 5%, 3%, 5%, and 2% of the aggregate gaze. Figure 73 presents the AOI results for the dynamic tree map.

Figure 73: AOI Results for the Dynamic Tree Map
Bee swarm analysis shows that students’ gaze paths have a preference for the left half of the tree map visualisation. Students’ gaze paths start at different points of the tree map visualisation with some coalescing in the middle phase of the task. The bee swarm video for the dynamic tree map task can be downloaded from this temporary link\(^29\).

This concludes the presentation of the results. Substantive interpretations with respect to the triadic model of the teaching analytics (TMTA) and implications for different stakeholders are presented in Section 7.5.

### 7.5 Discussion

The two classroom exercises and the two eye-tracking laboratory sessions were designed and conducted as action research studies exploring the formative assessment potential of repertory grid technique and the triadic model of teaching analytics (TMTA). The author carried out all four roles of teacher, design based researcher, visual analyst, and laboratory study facilitator.

Based on the results reported in the previous section, the preliminary finding is that repertory grid technique with triadic sorting is a promising candidate for technology enhanced formative assessment. A carefully designed repertory grid exercise provides insight into students’ personal constructs on a topic in a subject. An emerging finding from the laboratory study is that time taken for construct elicitation and elements ratings could provide another dimension for pedagogical decision-making. Eye-tracking results show that while aggregate gaze distribution varies for the elements rating phase while remaining fairly uniform for the construct elicitation phase. As for the representations of the repertory grid data, eye-tracking results combined with analysis of the verbal protocols and the semi-structured interviews show that word clouds for constructs (text) and line graphs for element ratings (numbers) are effective visualisations. Interactive tree map visualisations need to be better designed and end-users should be provided with training to comprehend and interact with the dashboard display. Implications for the different stakeholders are presented below.

#### 7.5.1 Implications for Teachers

In designing repertory grid exercises, teachers should pay particular attention to the previous domain knowledge of students and to what extent the elicited constructs are grounded in the personal lived experience of the students compared to the domain knowledge. An ideal repertory grid exercise would involve 6-10 elements and 5-6 triads with each element appearing at least once and in different positions of the triad when a particular element features more than once across the different triads. The repertory grid exercise could be designed for individual students or as a computer supported collaborative learning (CSSL) exercise involving a small group of students. The pre-test and post-test paradigm could be applied to solicit individual or group repertory grids before and after a particular curriculum module has been taught. Further, the teacher can make his or her own repertory grid to the students for reflection and repertory grids of domain experts for benchmarking and guided inquiry. Post repertory grid exercise tasks could include asking the individual students or groups to reflect on their own repertory grids, inspects the repertory grids of their peers or domain experts, and/or inspect the visualisations of the repertory grids for the entire class. An additional implication from the classroom exercises and the eye-tracking laboratory studies is that teachers could also learn about students’ current understanding based on the time take for construct elicitation and element rating.

With regard to formative assessment, teachers can inspect the constructs or the word cloud representations of the individual or collective constructs and discern students’ level of domain knowledge. Similarly, teachers can scrutinize the element ratings to discern students’ ability to distinguish between the different concepts. With

necessary training, teachers can make use of tree map or some other visualisation of the entire repertory grid exercise to adapt the content and didactics for that particular curriculum module.

Apart from the classroom usage scenario, another usage scenario for teachers is to employ the repertory grid exercise as lightweight appraisal method for informal learning tasks. We will research this usage scenario in future work with teachers participating in the NEXT-TELL project.

7.5.2 Implications for Students

Repertory grid exercises on topics not inherently familiar to students either from prior formal learning settings or from personal lived practice seem to be perceived as challenging and engaging. That said, a well-designed repertory grid exercise on the familiar and lived practice would allow students to externalise their implicitly held constructs. Students should then be motivated and guided to reflect on their intuitions and connect their personal constructs to domain concepts.

Students should also be able to co-design repertory grid exercises with peers and teachers. Co-designing a repertory grid exercise would require students to select the topic, the elements, and the number, content and order of triads. This in itself could be pedagogically effective.

Finally, students should be given the option of sharing their repertory grids with their classmates and within their social networks. Students should be able to interact with their visualisations of their individual repertory grids and those of their peers and the classroom level repertory grid. Moreover, students should be able to upload their repertory grid exercises to their e-portfolios and integrate them with their open learner models.

7.5.3 Implications for Researchers

From a learning sciences research standpoint, within the NEXT-TELL project objectives, there are at least two lines of inquiry to pursue. The first line of research is to build on existing work in personal construct psychology in understanding the underlying psychological processes of the repertory grid technique (RGT). The second line of inquiry is into research and development of methodological and computational support for teachers to design and evaluate RGT exercises for formative assessment purposes.

Particular attention should be paid to the time on task for construct elicitation and element ratings phases of the RGT exercise in addition to the personal constructs and the ordering of elements on the bipolar scale of the opposite and similarity constructs. Change over time in the repertory grids of students as they progress through curriculum and acquisition and development of “professional vision” (Goodwin, 1994) for teachers are two important research considerations.

7.5.4 Implications for Design of RGFA R1

The findings from the classroom exercises and the eye-tracking laboratory studies were used in the requirements gathering phase for the design and implementation of the software application, repertory grid for formative assessment (RGFA). Release one (R1) of RGFA is designed to provide a simple interface for teachers to design a repertory grid exercise and deploy it to a group of students. Unlike Rep5 or FARGO, RGFA is designed from the scratch to integrate with the NEXT-TELL technology infrastructure. RGFA also incorporates proper instrumentation for research purposes and interactive visualization functionalities to be developed and deployed in upcoming releases (R2, R3, and R4). Screen shots of the teacher’s workflow in the RGFA system are included as Appendix B.

http://rgfa.cbs.dk
7.5.5 Future Work: TMTA, Repertory Grid and Open Learner Models

An obvious starting point for future developing of the Triadic Model of Teaching TMTA approach with respect to the repertory grid technique (RGT) is to base it around the existing work in artificial intelligence in education, on open learner models. A learner model holds information (usually) about an individual learner, and the model is automatically and dynamically updated during the user’s interaction with a computer-based/online educational environment. The learner model typically includes data about the learner’s knowledge state, which may include specific difficulties and misconceptions; and it can also have data on other aspects of the learning process (e.g. representation, content, teaching style preferences; motivational, social, affective attributes). The learner model is then used by the educational environment to adapt its teaching to the specific needs of the individual learner (the environment ‘understands’ the user’s understanding). An “open learner model” is a learner model that can also be externalised to the user (Bull & Kay, 2007). This externalised (open) learner model may be simple or complex in format using, for example: text, skill meters, concept maps, hierarchical structures, animations (Bull et al., 2010).

Normally the user who accesses the learner model is the learner. Common purposes of externalising the learner model to learners are to promote metacognitive activity such as awareness-raising, reflection, self-assessment and planning (Bull & Kay, 2008). Some learner models have, however, also been made available to teachers (Bull & McKay, 2004; Eyssautier-Bavay, Jean-Daubias, & Pernin, 2009; Zapata-Rivera, Hansen, Shute, Underwood, & Bauer, 2007). Teacher access to the learner models of their students can help them to better understand learners’ needs as individuals and as a group, and can therefore enable teachers to adapt their teaching. Of particular interest in NEXT-TELL is the possibility of open learner models to support the routine but dynamic decision-making that teachers need to perform in the classroom.

While the above describes the typical situation of open learner models, it is easy to envisage this being extended for use in TMTA using the RGT. A range of visualisations or externalisations of the learner model have been explored (e.g. Bull et al., 2010), and these could be further extended to support the synthesis of work between teachers, visual analysts and design-based researchers, as proposed in the TMTA approach (Vatrapu, et al., 2011) and its application to the Repertory Grid Technique (RGT) datasets as reported here.

We conceive of the triadic model of teaching analytics (TMTA) as a socio-technical system. Such systems are characterized by socio-technical interactions. The design considerations are to develop, deploy and evaluate the use and impact of the perception and appropriation of socio-technical affordances in the TMTA socio-technical system. Affordances are action-taking possibilities and meaning-making opportunities in an actor-environment system relative to the competencies of the actor and the capabilities of the system (Vatrapu, 2010). Based on the theory of socio-technical interactions in technology enhanced learning environments developed in (Vatrapu, 2009, 2010), we propose that design dimensions based on affordance classes can help inform realize the integration of TMTA, RGT and OLM.
8 Summary

This report has presented an overview of the application of open learner modelling to the NEXT-TELL project in terms of release one of the OLM prototype, following on from deliverable D4.1 (May 2011).

Building on the generic concept of open learner modelling (Section 3) and its application to the NEXT-TELL project (Sections 3 and 4), Section 5 presents an overall architecture for the prototype, and details its current implementation. This section focuses on issues surrounding interface elements, the modelling process, and information management, in terms of how information is accepted, modelled, stored and retrieved.

Section 6 detailed an evaluation of interface elements in an educational setting using eye tracking equipment. The evaluation focussed on elements of interpretation and emotional response and has yielded a series of recommendations for the implementation of simple mocked up interface components.

Section 7 has explored the potential of using the repertory grid technique as a method for capturing student learning and knowledge based constructs. The potential integration with the open learner model is elaborated.

The progress detailed in this report is a milestone in the development of the NEXT-TELL OLM service. The design, architecture and evaluation we have detailed will allow is to move forward into the next phase of development and integration of the OLM.
9 References


Torenvliet, G. (2003). We can't afford it!: the devaluation of a usability term. *interactions, 10*(4), 12-17.


### 10 Glossary

Terms used within the NEXT-TELL project, sorted alphabetically.

**Partner Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>JRS</td>
<td>JOANNEUM RESEARCH Forschungsgesellschaft mbH, AT</td>
</tr>
<tr>
<td>Uni Research</td>
<td>UNI RESEARCH AS, NO</td>
</tr>
<tr>
<td>KMRC</td>
<td>Medien in der Bildung Stiftung, DE</td>
</tr>
<tr>
<td>TUG</td>
<td>Technische Universität Graz, AT</td>
</tr>
<tr>
<td>CBS</td>
<td>Copenhagen Business School, DK</td>
</tr>
<tr>
<td>BHAM</td>
<td>The University of Birmingham, UK</td>
</tr>
<tr>
<td>IOE</td>
<td>Institute of Education, University of London, UK</td>
</tr>
<tr>
<td>EXACT</td>
<td>eXact Learning Solutions SPA, IT</td>
</tr>
<tr>
<td>TALK</td>
<td>Verein offenes Lernen, AT</td>
</tr>
<tr>
<td>BOC-AT</td>
<td>BOC Asset Management GmbH, AT</td>
</tr>
<tr>
<td>BOC-PL</td>
<td>BOC Information Technologies Consulting SP.Z.O.O., PL</td>
</tr>
<tr>
<td>MTO</td>
<td>MTO Psychologische Forschung und Beratung GmbH, DE</td>
</tr>
</tbody>
</table>

**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>Baseline Study</td>
</tr>
<tr>
<td>CbKST</td>
<td>Competence-based Knowledge Space Theory</td>
</tr>
<tr>
<td>CBT</td>
<td>Computer Based Training</td>
</tr>
<tr>
<td>DBR</td>
<td>Design-Based Research</td>
</tr>
<tr>
<td>ECAAD</td>
<td>Evidence Centered Activity and Appraisal Design (builds on the ECD)</td>
</tr>
<tr>
<td>ECD</td>
<td>Evidence Centered assessment Design (PADI project eg)</td>
</tr>
<tr>
<td>EFL</td>
<td>'English as a Foreign Language'; EFL refers to learning English in a non-English-speaking region, such as studying English in an Asian or Latin American nation. Typically, EFL is learned as part of a student's school curriculum or for career purposes if working for an international corporation.</td>
</tr>
<tr>
<td>ENA</td>
<td>Epistemic Network Analysis</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>ESL</td>
<td>English as a Second Language</td>
</tr>
<tr>
<td>HCI</td>
<td>Human Computer Interaction</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>LEPP</td>
<td>Longitudinal Evaluation of Performance in Psychology (2nd generation e-portfolio)</td>
</tr>
<tr>
<td>LM</td>
<td>Learner Model</td>
</tr>
<tr>
<td>NEXT-TELL</td>
<td>Next Generation Teaching, Education and Learning for Life</td>
</tr>
<tr>
<td>OLM</td>
<td>Open Learner Model</td>
</tr>
<tr>
<td>PADI</td>
<td>The PADI project aims to provide a practical, theory-based approach to developing quality assessments of science inquiry by combining developments in cognitive psychology and research on science inquiry with advances in measurement theory and technology.</td>
</tr>
</tbody>
</table>
STEM fields are collectively considered core technological underpinnings of an advanced society, according to both the National Research Council and the National Science Foundation.

NEXT-TELL partners responsible for generating tools and methods

BOC-AT  ECAAD
BOC-PL  SPICE
EXACT  Moodle
JRS/EXACT  Google Docs and Google Spreadsheet
TALK  OpenSim
CBS  Rep5
JRS  EVE
EXACT  Mahara ePortfolio
BHAM  OLM

Acknowledgement: The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 258114.
Appendix A: Eye Tracker Diagram Interpretation

**Heatmap** shows the distribution of attention with a transparent layer super imposed on the stimuli. Areas which have attracted most attention will be more transparent than those which have attracted less attention – the underlying image will be more visible in areas receiving highest attention. The high attention areas are classified as Attention Points.

- **Hit time** – Average time when the respondents discovered the Attention Point for the first time.
- **First Fixation** – Average time of each respondent's first fixation in the area.
- **Time spend** – Average time spent in an Attention Point out of the total exposure time.
- **Ratio** – Number of respondents who had at least one glance at the Attention Point.
- **Revisitors** – Number of respondents who visited more than once an Attention Point out of those who had at least one visit.
- **Revisits** – How many times respondents revisited an Attention Point on average.

**Labels** display the priority of the Spotlight – based on the Hit time.

**Residual** – How much time the respondents spent looking elsewhere than the attention points.
**EYE TRACKING - AREAS OF INTEREST (AOI)**

AOIs are user-defined selections of one or many areas (Areas Of Interest) – revealing their attention results. This is particularly useful when you need to know whether a specific area like a logo / tag line or other specific parts of a stimulus has attracted attention.

- **Hit time** – Average time when the respondents discovered the Attention Point for the first time
- **First Fixation** – Average time of each respondents first fixation in the area.
- **Time spent** – Average time spent in an Attention Point out of the total exposure time
- **Ratio** – Number of respondents who had at least one glance at the Attention Point
- **Revisitors** – Number of respondents who visited more than once an Attention Point out of those who had at least one visit
- **Revisits** – How many times respondents revisited an Attention Point on average

**Labels** display the priority of the AOI – based on the hit time

**Residual** - How much time the respondents spent looking elsewhere than the AOIs

**EYE TRACKING - BEE SWARM**

Bee Swarm provides a dynamic visualization of a group of respondents gaze for the duration of the stimulus exposure. Color coded dots representing gender are used to mark the center of individual respondents gaze points – while an outline marks areas of the stimuli that attracted a certain percentage of the recorded respondents attention.

- **Male respondent**
- **Female respondent**

**Outline** – color coded depending on how much attention the region has attracted

- **High interest areas** have attracted more than 75% of the respondents
- **Medium interest areas** have attracted between 50 and 75% of the respondents
- **Low interest areas** have attracted between 25 and 50% of the respondents

**Enabled Spotlight** – to obscure regions of the stimuli that received no attention

**Disabled Spotlight** – to display stimuli without attention masking

**Info bar** display the number of respondents, time and playback speed of the Bee Swarm
12 Appendix B: Repertory Grids for Formative Assessment (RGFA) Application

The following figures present the teachers’ workflow with RGFA.\(^\text{31}\)

Figure 1: Login Screen for Teachers & Students

Figure 2: NEXTELL CAS integration for Teachers

\(^{31}\) http://rgfa.cbs.dk
Figure 3: Homepage for Teachers
### Create New Repertory Grid

**Exercise Name:** Mobile Application Development  
**Topic Name:** App Phones  
**Element Name Singular:** phone  
**Element Name Plural:** phones  
**Aspect Name Singular:** app  
**Aspect Name Plural:** apps

![Figure 4: Create New Repertory Grid](image)

### Create New Repertory Grid

**Please choose number of entities for phones**

<table>
<thead>
<tr>
<th>Number of Elements</th>
<th>Prepare elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Element 1:** iPhone 4  
**Element 2:** iPad 2  
**Element 3:** Samsung Galaxy Tab  
**Element 4:** HTC EVJ3D  
**Element 5:** HTC HD7  
**Element 6:** Samsung Omnia 7  
**Element 7:** Nokia N8  
**Element 8:** Sony Ericsson Xperia

![Figure 5: Create Elements](image)
Create new repertory grid

Please choose triads for analysis
Total possible Triads combinations for chosen Elements: 56

Number of Triads to generate: 5

Generate random triads  Generate triads manually

<table>
<thead>
<tr>
<th>Triad1</th>
<th>Triad2</th>
<th>Triad3</th>
<th>Triad4</th>
<th>Triad5</th>
</tr>
</thead>
<tbody>
<tr>
<td>iPhone 4</td>
<td>HTC EVO 3D</td>
<td>HTC HD7</td>
<td>HTC HD7</td>
<td>HTC HD7</td>
</tr>
<tr>
<td>iPad 2</td>
<td>Samsung Galaxy Tab</td>
<td>iPhone 4</td>
<td>iPhone 4</td>
<td>iPhone 4</td>
</tr>
<tr>
<td>Nokia N8</td>
<td>HTC HD7</td>
<td>Samsung Galaxy Tab</td>
<td>Samsung Galaxy Tab</td>
<td>Nokia N8</td>
</tr>
<tr>
<td>Sony Ericsson Xperia</td>
<td>Samsung Omnia 7</td>
<td>Nokia N8</td>
<td>Nokia N8</td>
<td>Nokia N8</td>
</tr>
</tbody>
</table>

Figure 6: Create Triads
The following grid has been created

<table>
<thead>
<tr>
<th>Exercise Name:</th>
<th>Mobile Application Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topic Name:</td>
<td>App Phones</td>
</tr>
<tr>
<td>Element Name Singular:</td>
<td>phone</td>
</tr>
<tr>
<td>Element Name Plural:</td>
<td>phones</td>
</tr>
<tr>
<td>Aspect Name Singular:</td>
<td>app</td>
</tr>
<tr>
<td>Aspect Name Plural:</td>
<td>apps</td>
</tr>
</tbody>
</table>

Elements:

- iPhone 4
- iPad 2
- Samsung Galaxy Tab
- HTC EVO 3D
- HTC HD7
- Samsung Omnia 7
- Nokia N8
- Sony Ericsson Experia

Triads

1. Tried 1: iPhone 4, HTC EVO 3D, HTC HD7
2. Tried 2: iPad 2, Samsung Galaxy Tab, iPhone 4
3. Tried 3: Nokia N8, HTC HD7, iPhone 4
4. Tried 4: Sony Ericsson Experia, Nokia N8, Samsung Galaxy Tab
5. Tried 5: HTC HD7, Samsung Omnia 7, Nokia N8

Link to complete exercise

Figure 7: Confirmation and Overview of the Creation of the New Repertory Grid Exercise

Online Consumer Psychology

Consumer Decision-Making

Please choose which of the following product is different from other products (1 out of 10)

- beer
- water
- pair of jeans

Please describe why one is different: construct1

Please describe why the other two are the same: construct2

Next

Figure 8: Construct Elicitation
Online Consumer Psychology

Consumer Decision-Making

Now rate each of the products on following attribute (1 out of 10)
construct 1 - construct 2

construct 1: (1) -- 2 -- 3 -- 4 -- (5) construct 2

- 2 [ ] car
- 3 [ ] laptop
- 5:construct 2 [ ] beer
- 1:construct 1 [ ] water
- 4 [ ] airline tickets
- 3 [ ] pair of shoes
- 5:construct 2 [ ] pair of jeans
- <select> [ ] movie tickets

construct 1: (1) -- 2 -- 3 -- 4 -- (5) construct 2

Save

Figure 9: Elements Rating
Figure 10: Display of the Completed Repertory Grid Table