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Deliverable 3.2

Requirements and technical state-of-the-art on intuitive interaction interfaces for robust learning

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Executive Summary

Work Package 3 (WP3) envisions to provide the technical means by which more exploratory, conceptually-oriented learning activities can be integrated with the rest of the platform and enable research on the role of the different modalities of speech and direct manipulation as well as multiple and alternative representations in learning elementary mathematics (and particularly the domain of fractions as selected by the consortium).

To support the significant amount of design and development effort required, this deliverable reviews the state-of-the-art for exploratory learning environments (ELEs) and voice user interfaces (VUIs) and serves as a means of developing a common understanding between the partners about the possibilities afforded by the corresponding technologies. The deliverable simultaneously raises requirements and our design options for subsequent development.

The structure of this deliverable is as follows:

Section 1 introduces intuitive interaction in the context of iTalk2Learn and refers particularly to opportunities provided by the interaction with the ELE and the VUI designed under WP3. In brief, the ELE will provide familiar, interactive representations of fractions that capitalize on students' prior knowledge or experience and are simple and easy to use. The VUI should enable a more natural means of interaction compared to just keyboard and mouse interaction. Section 1 also outlines the relationship of this deliverable with other deliverables in the project.

Section 2 reviews the state-of-the-art in ELEs through the lens of a framework for a principled approach to ELE design. In particular, the deliverable derives design conjectures that arise from critical analysis and experience of existing related educational software and raises requirements with respect to the design. These are complimented by design drivers that arise from the literature and motivate the design of the iTalk2Learn ELE, the current status of which is also provided for reference in Appendix A.

Section 3 reviews the state-of-the-art in VUIs and particularly automatic speech recognition (ASR) and speech synthesis (SS), identifying their potential to learning and provides possibilities for their integration in the context of iTalk2learn.

Section 4 provides a summary and high-level requirements emerging from the deliverable.

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List of Abbreviations

UHI	University of Hildesheim
IOE	Institute of Education, University of London
TL	Testaluna SRL
RUB	Ruhr-Universitaet Bochum
BBK	Birkbeck College - University of London
Whizz	WHIZZ Education Limited
SAIL	SAIL Labs Technology AG
WP	Work Package
ELE	Exploratory Learning Environment
ELA	Exploratory Learning Activities
VUI	Voice User Interfaces
UI	User Interface
HCI	Human-Computer Interaction
ASR	Automatic Speech Recognition
SS	Speech Synthesis

1. Introduction

The iTalk2Learn is a research project implemented in the context of the 7th EU framework programme. The project will perform interdisciplinary, cutting-edge research in a multidisciplinary team with members from fields as diverse as artificial intelligence/machine learning, user modelling, intelligent tutoring systems, and natural language processing, as well as educational psychology and mathematics education. The specific objectives of italk2learn are:

1. Provide an open-source platform for intelligent support systems integrating structured practice and exploratory, conceptually-oriented learning
2. Provide state-of-the-art and highly innovative reference implementations of plugins for the platform that could be used in a wide range of application domains
3. Promote our understanding of the role of the different modalities of speech and direct manipulation of multiple or alternative representations in learning elementary mathematics through digital technologies
4. A summative evaluation of activities and support features generated by our intelligent learning support platform

The implementation of these blocks of activities is distributed in Work Packages (WP) which are listed below:

WP number	WP name	Lead beneficiary
1	Robust Learning in Elementary Mathematics	IOE
2	Adaptive Intelligence for Robust Learning Support	UHi
3	Intuitive Interaction Interfaces for Elementary Mathematics	TL/SAIL
4	Deployment and Integration	BBK
5	Data Collection and Evaluation	RUB
6	Dissemination and Exploitation	Whizz
7	Project Management	UHi

In reference to the objectives of the iTalk2Learn project, WP3 envisions to provide the technical means by which more exploratory, conceptually-oriented learning activities can be integrated with the rest of the project (c.f. Objective 1) and enable research on the role of the different modalities of speech and direct manipulation as well as multiple and alternative representations in learning elementary mathematics (c.f. Objective 2). This will occur in the mathematical domain of fractions. The project selected fractions as the target domain because of the widely acknowledged difficulty that students have in learning fractions and the richness fractions afford with respect to different representations and interpretations.

In particular, WP3 promises to make progress with regard to intuitive interaction for learners undertaking activities in an exploratory learning environment (ELE), and to design and implement a voice user interface (VUI). Before we define these two areas in more detail in subsequent sections, it is worth referring explicitly to the term 'intuitive interaction' that is somewhat of a 'buzzword' that comes mostly from the field of Human-Computer Interaction (HCI) and only recently researchers have attempted to define it more precisely. The term is reviewed in detail in relevant literature (c.f. Blackler & Hurtienne, 2007) and therefore we do not replicate this work here. For this deliverable it suffices to say that 'intuitive interaction' refers mostly to user experience and is often used interchangeably with terms such as 'ease of use' (Preece et al., 1994) or 'familiarity' (Raskin, 1994). In the case of educational technology users refer to learners, but the term is rarely used, apart from a few notable exceptions such as (Chuang, 2009) and (Haipeng, Krzywinski, Fujita, & Sugimoto, 2012) who associate intuitive with tangible and virtual reality interfaces. However, these are not relevant to iTalk2learn, since the overarching goal here is to create a web-based platform (as outlined in D4.1) where students focus on learning activities supported by direct manipulation user interfaces (UIs), voice interaction and intelligent components for providing feedback and recommendations. Therefore, in iTalk2Learn 'intuitive interaction' refers particularly to

a. the opportunities afforded by the ELE through familiar, interactive representations of fractions that capitalize on students' prior knowledge or experience and are simple and easy to use;
b. the VUI that should, in principle, enable a more natural means of interaction compared to just keyboard and mouse interaction.

To achieve this objective, a significant amount of effort is directed towards design, development, harmonisation and enhancement of UIs across all user facing parts of the platform, from the overall look & feel of the web-based environment (under WP4), to the ELE and VUI (under WP3). To facilitate this design and development effort, this deliverable reviews the state-of-the-art for ELEs and VUIs and serves as a means of developing a common understanding between the partners about the possibilities afforded by the corresponding technologies, simultaneously raising requirements for subsequent development.

The structure of this deliverable and its relationship to other deliverables is as follows: Section 2 reviews the state-of-the-art in ELEs and deduces requirements for the design of the iTalk2Learn ELE (the current status of which is also provided for reference in Appendix A). The emphasis here is on interactivity, usability and UIs, as these are the main concern of WP3. Although, unavoidably, we also discuss epistemological aspects of the ELEs, this is mainly objective of WP1 (which has been feeding information to WP3). More specifically, D1.1 provides more detailed reviews on intelligent tutoring systems and ELEs with respect to the learning of mathematics and in particular fractions, and D1.2 focuses on the activities developed as part of our project that exploit both the ELE and VUI. These aspects, therefore, are not discussed here.

Section 3 reviews the state-of-the-art in automatic speech recognition (ASR) and speech synthesis (SS) (the two aspects of the iTalk2Learn VUI). Since D3.1 provides the corresponding technical state-of-the-art, the emphasis here is again on interactivity and usability, and on our understanding as of M9 of the role of the VUI in iTalk2Learn. Section 4 provides a summary and high-level requirements emerging from the deliverable.

2. State-of-the-art in exploratory learning environments and requirements for iTalk2Learn

2.1 Exploratory learning environments and activities - Definition and scope

Exploratory Learning Environments (ELEs) are virtual environments that provide learners with opportunities to engage with a domain and explore a range of possibilities that would otherwise be difficult to experience directly. Such environments vary on the amount of exploration they afford and how they contextualize learning by means of tasks. The possible student interaction in learning environments, in general, can be perceived as a continuum with the extremes comprising either very structured interaction usually with direct feedback and limited options and answers to a task or very open and unguided interaction with open-ended tasks. These reflect the pedagogical approach that designers take when developing an interactive learning environment (see Figure 1). ELEs also vary in the range of activities they can provide and the extent of the knowledge domain they cover. Some ELEs provide a particular activity usually limited in a specific subset of the knowledge domain, while some others are designed to allow students a range of activities sometimes covering a larger domain.

Structured	Open
- Aims at fostering procedural knowledge - Adopts an atomistic approach - Activity is computer directed (therefore low level of student control) - Provides explanation to student(s) - Adopts a behavioural stance to learning - Assumes student has minor/passive role for student	- Aims at fostering conceptual knowledge - Adopts an holistic approach - Activity is student directed (therefore high level of student control) - Enables student experience - Adopts a constructivist stance to learning - Assumes major/active role for student

Figure 1 *Structured-Open ELE continuum showing how ELEs reflect different pedagogical approaches*

For iTalk2Learn we envisage developing an ELE that can be configured (by the project team) and parameterized (automatically by the system) appropriately to present different activities. In our efforts to combine procedural and conceptual knowledge, students' interaction will be towards the right end of the continuum in Figure 1, aiming to encourage exploration and conceptual understanding. ELEs to the right of the continuum typically emphasise learning by interaction and exploration of the environment via its interface (Ben-Naim, Marcus, & Bain, 2008). The ELE we are developing contributes to improving intuitive interaction by its exploratory nature in general and by the exploratory activities that students will be asked to undertake within it. During design trials, students' intuitive interaction will be observed and these will be built upon in the design of the ELE configurations and interfaces. Of course the tasks that students will be asked to undertake (reported in D1.2) have a key role to play here since they are the ones that provide context and enable or constrain the range of interaction.

2.2 Designing ELEs

It is well documented that the majority of software designers use their own intuition or experience to design multimedia resources (Boyle, 2002; Deubel, 2003; Kalyuga, Chandler, & Sweller, 1999). However, there is more than simply using intuition or experience to design multimedia learning resources (Boyle, 2002). Because educational designers have an extensive knowledge of the contextual factors which influence learning, they can 'engineer' or promote learning by incorporating such contextual factors in the design (Boyle, 2002). Context in the case of ELE varies from the formulation of conditions for usage to task description and from the content of the environment to its associated interactivity (ibid). Indeed, some argue that it is not possible to formulate general statements about computer-based tools because of the wide variances in context to consider (Huk, 2002; Illera, 2004). With respect to interactivity in particular, Mavrikis et al. (2012), refer to '*epistemic affordances*' i.e. design features related to the expected or potential ways that a particular environment can be used to support learning.

We believe that having a good knowledge of the factors that afford learning is not, in itself, a satisfactory approach. In order to make progress in the design of ELEs it is essential to follow a principled design approach. To do this we structure our approach building on previous work by (Hansen, 2008) who established a framework which utilises three elements for a principled approach to designing ELEs.: design conjectures that arise from experience with related software, design drivers that arise from literature, and design assumptions that arise from the developers' pedagogical approach. This is presented schematically in Figure 2. Table 1 provides more detailed explanation of the design elements and how they are utilized in iTalk2learn.

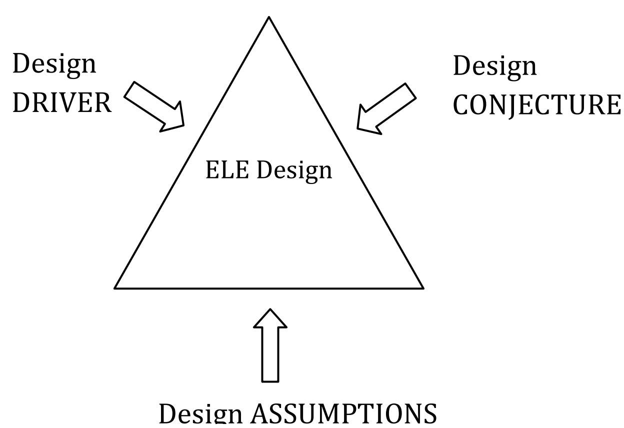


Figure 2 *The elements of task design that feed into a principled approach to ELE design (Hansen, 2008)*

Design element	Explanation of the term	How the element is utilized in iTalk2Learn
Design conjecture	Generic and specific conjectures about the design of the environment and its effectiveness, which arise from the critical analysis of previous experience (direct or indirect through the literature) with related educational software or from evidence from trials with previous software or early prototypes during the design process.	Section 2.5 presents design conjectures for iTalk2Learn in relation to student interactivity and software feedback based on our previous experience and the review of the state-of-the-art in the field (Section 2.3). Through a bootstrapping process we have trialled some existing ELEs with students from the target age range. More detailed findings from the bootstrapping process that developed further design conjectures will be discussed in D1.2 as they relate to the domain rather than interactivity and UIs.
Design driver	Design drivers act as principles that guide the design of the environment. They arise directly from the literature and are initially permitted within the design because of their supporting literature base. Drivers are not a specific focus of the research and therefore they are not evaluated in the same way that design conjectures are. However, design drivers may be supported or challenged by data analysis and they may then transform into design conjectures for the next iteration.	A literature search has been undertaken and this is reported in Section 2.4 that also provides an introduction to and justification of the design drivers as they relate to iTalk2Learn. These are summarised in Section 2.5
Design assumption	Design assumptions arise from personal knowledge and understanding. Schön (1983) refers to this as “professional artistry”. Unlike the other two elements, design assumptions are not explicitly discussed in the design experiment phase. However, like the design drivers, it is possible for a design assumption to be supported or challenged by data analysis and they may then transform into design conjectures for the next iteration.	Design assumptions affect what designers create. The focus on student interactivity and software feedback reflects our assumptions here. As iTalk2Learn is currently in the design experiment phase, the design assumptions are not necessarily explicit. In addition, several design assumptions relate to the domain. As a result the design assumptions will become clearer through the design of activities in the context of D1.2.

Table 1 *Elements for designing ELEs (based on Hansen, 2008) and how they are utilised in iTalk2Learn*

Table 1 also determines the structure of the rest of this section. In particular, the review of relevant examples that leads to conjectures is reported in Section 2.3. The literature review that leads to the drivers follows in Section 2.4. Both conjectures and drivers that together have led to the design of the ELE as of M9 (presented in Appendix A) are summarised in Section 2.5.

2.3 Review of relevant examples

Through previous experience of the partners (particularly from partner IOE) and an explicit search for recent work (mainly from partners IOE and TL), we identified a variety of exploratory environments from mathematics. Of course a complete collection of these examples is beyond the scope of this deliverable and therefore we selected the examples that provide distinct points with respect to the student interaction and the system inherent feedback elements, particularly relevant to iTalk2Learn and WP3. As mentioned in the Introduction further discussions related to the cognitive domain and student learning are addressed in D1.1 and D1.2. The aim of the review was to:

- bring the consortium up to speed with state of the art ELEs so that we develop a shared understanding particularly in relation to interaction types and feedback
- utilize the common affordances identified within the review in a bootstrapping process for the design and to get initial students' and designers' reactions
- derive the design conjecture (reported in Section 2.5) that act as initial requirements for the design of the iTalk2Learn ELE and enable discussions between all the interested parties in the project.

We group the ELEs into two main categories, games and microworlds, and we include a catch-all category for other interactive applications with a direct-manipulation interface, that do not have the characteristics of games or microworlds but are exploratory in nature. We expand on each of these and provide relevant examples in the following sections.

2.3.1 Games

Research in mathematics education has long identified that some of difficulties with mathematics learning stem from motivation (see a more detailed recent discussion in Clark-Wilson, Oldknow, & Sutherland, 2011). A response to this realisation comes from designers of mathematical games. "The promise of games is that we can harness the spirit of play to enable players to build new cognitive structures and ideas of substance" (Klopfer, Osterweil, & Salen, 2009, p. 5) also identify how designers of educational games usually start from a common set of assumptions. These are: students who play regularly exhibit persistence, risk-taking, attention to detail and problem solving skills, and they actively construct understanding at their own pace. The designers also understand that well-designed games enable students to follow alternate paths at times appropriate to each student's interests and abilities, while also fostering collaboration and "just-in-time" learning. These assumptions reflect some of our own, and can be seen borne out in the design of the types of ELEs that exist on the right of the continuum in Figure 1.

While there are some very appealing games that can support learning of mathematics, most of them are designed to provide intrinsic or extrinsic reward for effectively doing drill and practice arithmetic in well-designed contexts full of graphics and avatars. Although some of these are also often backed up by research, the majority of software is unfortunately not designed in a principled way neither are they informed by evidence on their efficacy. In addition, research indicates that some features within educational games may lead to off-task behaviours (Rowe, McQuiggan, Robison, & Lester, 2009) or be too seductive and essentially influence students' learning (Harp & Mayer, 1998; Moreno & Mayer, 2005). We will not concern ourselves with such games.

Some examples are starting to appear that make authentic use of mathematics within the digital environment and can help demonstrate that mathematics and the various procedural skills one needs to develop are means to an end and not only the end itself. Such approaches of course require considerably more investment both in their design and application and on behalf of the user to master.

Groff et al. (2010) identified 18 different game genres, many of which offer educational potential in some way. The popularity of educationally-based games has lead to 'edutainment' becoming big business, but often the focus is on entertainment rather than education and where education-based development budgets are used, the games tend to be more simplistic (Groff, Howells , & Cranmer, 2010).

In what follows we present two very different types of games, Refraction, one of the most successful and relevant games in the domain of fractions and Quads that does not have the look and feel of a game explicitly in the design of the environment, but is used in a gaming context. These are analysed in relation to student interaction and system inherent feedback.

(a) *Refraction* is an educational game developed by a team from the University of Washington (http://centerforgamescience.org/portfolio/refraction/). The goal is to use the pieces on the right (see Figure 3) to split lasers into fractional pieces and redirect them to satisfy target spaceships (Andersen et al., 2011).

Figure 3 *Screenshot of Refraction (University of Washington). Bending laser beams to target spaceships.*

The main student interaction involves dragging and dropping the pieces onto the screen to bend laser beams. Students are offered increasingly challenging levels, with different pieces available in each challenge.

Students receive integrated feedback in way of the laser 'working' and they are able to move or remove pieces based on that feedback. When the student has achieved the desired outcome, there is a celebration of shooting stars on the screen. Feedback about using the game is in the form of popup messages instructing the student that certain activity is not allowed, e.g. "lasers cannot go through rocks".

(b) Some educational games may not necessarily have the look and feel of a game such as *Refraction*. (Groff et al., 2010) define games that "have a primary focus of achieving a learning outcome rather than being played purely for pleasure" as "serious" games. While we feel that this label is misleading (because the game is enjoyed by the students), the description is accurate. One such ELE that has a game element to it is *Quads* (Hansen, 2008).

Quads (see Figure 4) was designed to help 9-11 year old students develop geometric understanding. The game element involved students setting clues for opponents to help lead them to a specific figure or definition (e.g. parallelograms). Interestingly, the game element was not intentionally designed into the ELE. However, when being challenged to set clues, the students wanted to "trick" their "opponents" and went about setting clues they knew would be redundant or misleading. This self-introduced game element had a considerable impact on learning because the students developed understanding about necessary and sufficient conditions, something normally delegated to much older students' curricula.

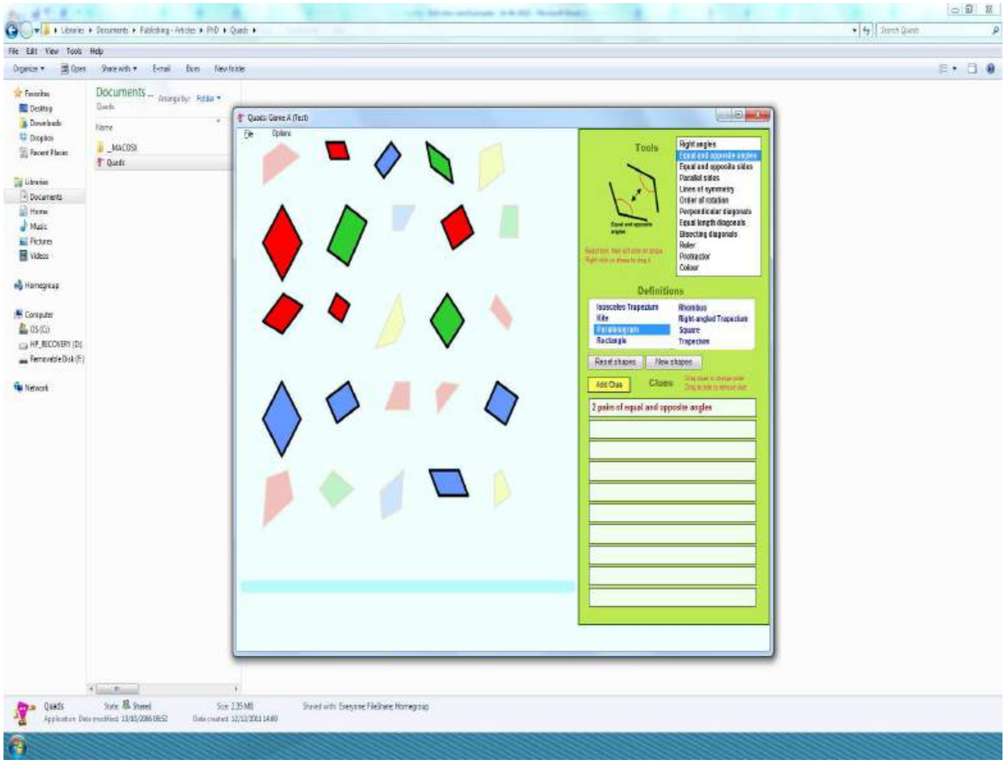


Figure 4 *Quads (Hansen, 2008). Highlighting the parallelogram instantiations.*

The interactivity involves drag & drop, whereby figures could be moved around the left of the screen and clues could be dragged to the list (bottom right). Students can select various buttons for an action. For example, selecting a definition (middle right) highlights the figures in that definition, clicking on "reset shapes" moves the shapes back to their original position, clicking on "new shapes" provides a new set of figures, and selecting one of the tools (top right) provides tools for the students to identify attributes (such as equal and opposite angles and colour, the latter becoming unavailable when definitions are required over individual figures) and subsequently set a clue in relation to them. The advantage of the tools is that the children are able to efficiently and accurately gain information about a given figure without having to carry out the cumbersome operation themselves, e.g. when a student wishes to know the interior angles of a quadrilateral, they use a tool to instantly receive this information. This enables students to focus on defining figures, often with unfamiliar attributes, without being delayed in the process by undertaking sub-tasks that detract from the focus on defining.

Quads uses integrated feedback that results from students' interactions. Examples of feedback include figures being highlighted or 'greyed out', and being informed of the properties or attributes of figures through tool use. There is no game-play feedback as it is expected that the students learn through trial and error and the teacher takes a facilitating role.

2.3.2 Microworlds

Microworlds sit at the 'Open' end of the ELE continuum and can be seen as ‘model building systems’ that belong to a particular genre of discovery learning. In discovery learning situations students are provided with a suite of model-building tools and are encouraged to ‘test their own intuitions about a domain’ (Lynch, Ashley, Aleven, & Pinkwart, 2006). Unlike (most) games, microworlds are designed to enable students to pursue their own learning intentions within the environment (Reiber, 2005) by providing access in a (usually simplified) representation of the domain. With respect to the domain in particular, Balacheff and Sutherland (1994) highlight that microworlds have ‘epistemological domain of validity’ to refer to the knowledge domain as it has been transformed by the affordances and interface of the microworld.

Perhaps the most well-known microworlds are the ones based on LOGO or variants of it, such as the recent Scratch from MIT (http://scratch.mit.edu/). Microworlds have mostly been used in geometry and other topics in mathematics education (Noss & Hoyles, 1996) or inquiry learning (Joolingen & Zacharia, 2009). In microworlds students are able not only to explore the structure of accessible objects in the environment, but also to construct their own objects and explore the representations that make these objects accessible (Thompson, 1987). This introduces a qualitative change in the level of exploration as compared to other tools with all the potential benefits and dangers that this entails. Most educational games (like the ones we present here) can also be considered as simplified microworlds (but most microworlds would not be considered games by learners).

Most microworlds provide non-adaptive scaffolds designed to help students explore the underlying principles of a domain. However, as with other criticism of constructivist approaches (c.f. Mayer, 2004) it is clear that explicit support is important both to draw attention to the microworld’s feedback and to structure and provide meaningful goals (Mavrikis, Gutierrez-Santos, Geraniou, & Noss, 2012).

(a) eXpresser

eXpresser is a microworld designed to help students develop algebraic ways of thinking (Mavrikis, Noss, Hoyles, & Geraniou, 2013; Noss et al., 2012). In eXpresser students undertake activities that require them to construct algebraic rules that underpin figural patterns composed of square tiles (see Figure 5). Similar activities are often found in the UK National Curriculum and have the potential to help students understand that their algebraic rules can derive from the structure they observe in the pattern and thus provide a rationale for using algebra to express generalisations.

Figure 5 shows the main interface of eXpresser. When starting up an activity in eXpresser students see a main construction area (right) and an activity ‘document’ (left). Students can build their models in the main construction area using square tiles that can be turned into building blocks and patterns.

On the left hand-side, is the Activity Document that (depending on the chosen Activity) includes dynamic task descriptions, reflective questions and a list of goals explicitly listed. Students can check a goal when they consider it completed. If the goal is not achieved the students will receive help towards the goal. Students can also click on the smiley to get more help on the particular goal.

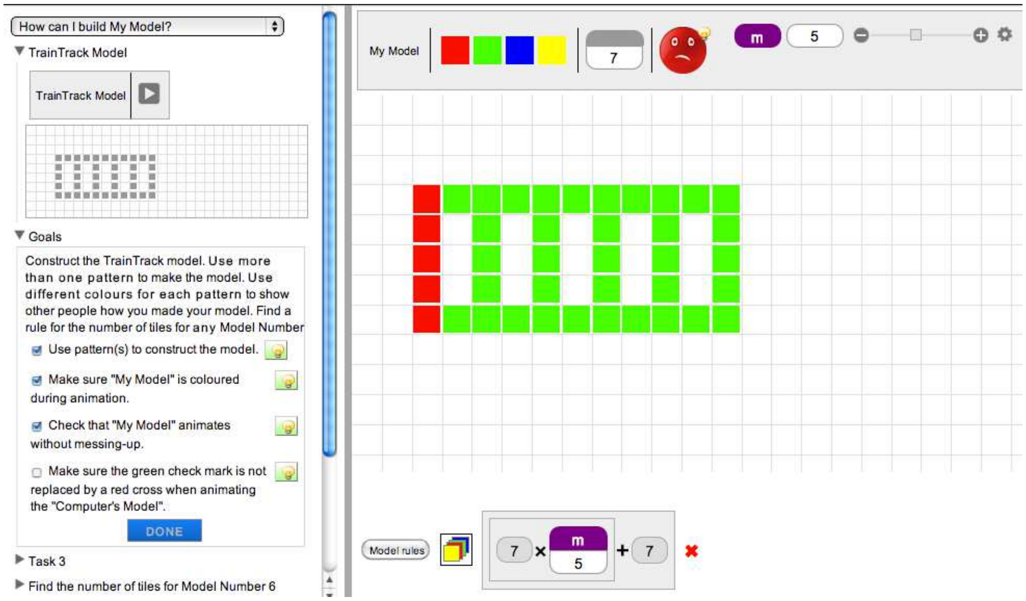


***Figure 5** The main interface of eXpresser.*
Students construct patterns and their underlying expressions. In this occasion the expression is wrong and the emoticon at the top bar is sad. The bulb indicates that there is feedback available for the student. On the left there is a list of goals and tasks.

Appreciating the need for supporting students and teacher when working in an ELE, eXpresser comes equipped with intelligent components that analyse students' interactions and generate real-time explicit feedback for students (and to teachers). In order to determine the most appropriate form of feedback, a set of rules are used to combine information about the student's current construction and recent history of actions (Gutierrez-Santos, Mavrikis, & Magoulas, 2010). The feedback that eXpresser provides was designed to meet the following general requirement that were derived after a series of expert knowledge elicitation sessions, design and Wizard-of-Oz experiments (Mavrikis et al., 2012).

In particular, eXpresser has specific help-request features (a suggestion button) that is disabled unless the system observes' something that warrants feedback. This way, if student's actions would render the feedback irrelevant the student would not be interrupted. On the other hand, if the student seems unable to progress, then a suggestion is available to scaffold their interaction. There are also some occasions that justify an interruption e.g. to encourage students to reflect on an action that requires explicit attention (see Figure 6) . This way students' interaction is interrupted only when they ask for help or to take advantage of a learning opportunity (Mavrikis et al., 2012).

In addition, eXpresser messages appear co-located to the objects they refer to. This is because verbal and textual feedback requires the use of anaphoric or deictic language (e.g. pronouns like 'this' and 'that') which is problematic in rich environments with many objects in the screen.

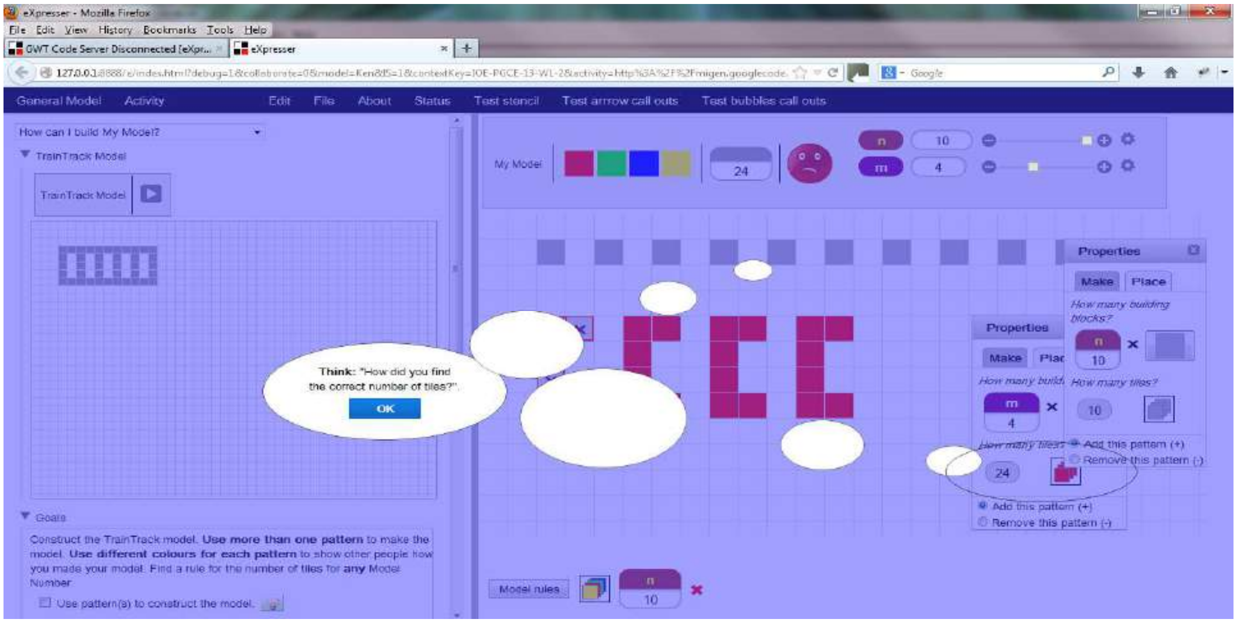


***Figure 6** Example of feedback in eXpresser.*
The student has taken an action that requires specific adaptive feedback. This is one of the rare occasions where the system interrupts the student and provides a reflective prompt.

Figure 6 Example of feedback in eXpresser. The student has taken an action that requires specific adaptive feedback. This is one of the rare occasions where the system interrupts the student and provides a reflective prompt.

Lastly, although eXpresser can be used as a free-play exploratory microworld, a designer (e.g. teacher) can set specific activities eXpresser that include a set of tasks and a list of explicit goals that students have to reach in order to proceed to the subsequent tasks. This allows the system to align the support provided with students' preferred solution strategy and adapted to the goals they are trying to accomplish. This will concern us more in D1.2 and from a technical perspective to D2.2.

(b) *Logotron Visual Fractions* (LVF)

LVF is the most relevant tool to the iTalk2Learn project due to the emphasis on fractions. LVF comes with a set of visual mathematics objects and tools that can be manipulated to provide opportunities to understand fraction concepts. It is essentially an authoring tool for designing activities that explore and play with visual representations of fractions, for investigating fractional properties and relations (Lehotska & Kalas, 2005). LVF offers the designer various fraction representations (such as area, number line, symbols) as well as decimal, ratio and percentage equivalents. It is possible to connect these representations. This enables a dynamic environment where it is possible to change an independent object and dependent objects will change in value. See for example the activity in Figure 7 that was designed in the context of iTalk2learn to help bootstrap the design process and collect voice data.

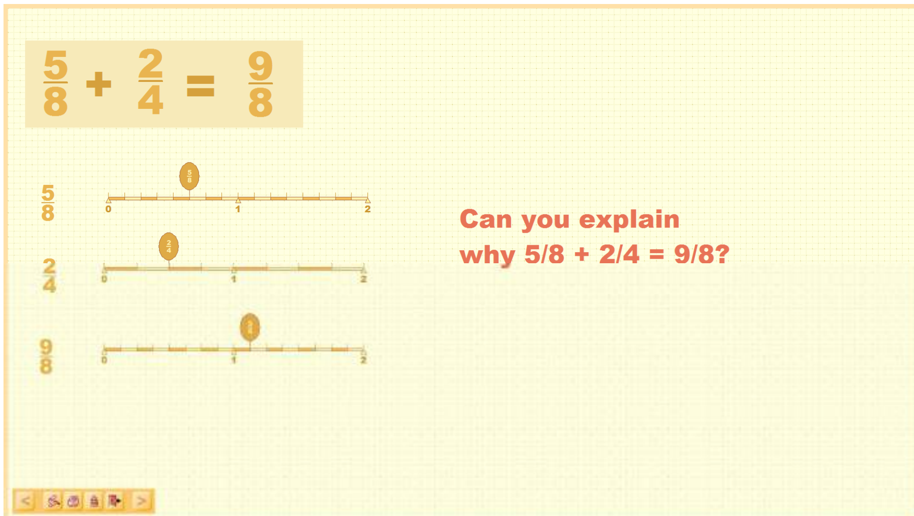


Figure 7 *An activity with Logotron Visual Fractions.*
It is possible for students to change the numerator and denominator of the two addends. The addends are independent. The sum is dependent on the addends. Each number line is dependent upon each fraction symbol.

The LVF environment provides three modes of work. In the Explore mode all tools and fraction representations with all their settings are available. Although some researchers have looked into students using the explore mode (e.g. to create activities for other students Jones & Pratt, 2006), it was mostly designed with the intention that teachers can develop activities for pupils or to demonstrate visual relationships on an interactive whiteboard. The Run mode allows students to solve prepared activities. Here they can use only those objects, which the activity author has chosen (although one can also just switch between these two modes to for example ask students to first solve a prepared task in the Run mode and then unlock the task and investigate it further in the Explore mode). Sequence mode allows teachers to link sequences of existing activities. A pupil, group or class can then work through related activities in a specific order.

Interaction and complexity varies within the three modes of work, but students will typically drag & drop, select tools to create different representations of fractions, change the size and colour of representations, lock objects, set dynamic dependencies, and change fraction values. Feedback is driven both by linking the available representations and tools but also by using additional elements that can provide slightly more explicit feedback. For example, integrated feedback will occur when two or more representations are connected. Students making a change in the first receive immediate feedback by seeing that change in the other representation(s). Feedback that is triggered by student product is shown in Figure 8.

Figure 8 *Feedback example using LVF.*
Here, a teacher has designed a task for students to rank numbers and representations in ascending order. Once the answer is correct the student receives a green star.

2.3.3 Other applications with a direct-manipulation interface

There are literally thousands of ad-hoc interactive applications (ranging from Java applets to Flash animations and from tablet to mobile apps) that are designed to help students learn particular concepts in mathematics and fall towards the right side of the Structured-Exploratory continuum of Figure 1. Most are developed either through a specific programming language or an authoring tool. It is out of the scope of this deliverable to review them all and classify them explicitly as they are referred to in various terms such as interactive activities, interactive simulations or virtual manipulatives. Notable examples include PhET[1] from the University of Colorado (that started initially by providing interactive simulations of physical phenomena but now includes several interactive applications to help students appreciate abstract mathematical concepts) and the National Library of Virtual Manipulatives (NLVM)[2] (a library of interactive, web-based virtual manipulatives for mathematics). Usually, such applications, despite their exploratory and interactive features, they tend to be more structured than open-ended and follow the intentions of the designer towards a specific learning objective rather than allow a complete open-ended, student-led interaction.

Relevant to this deliverable and the iTalk2Learn project are the following two applications (a) Gizmos, a set of small interactive applications that were also used for initial data collection to inform the design of the iTalk2Learn ELE, and (b) the Whizz Whiteboard, which is part of the set of Whizz tools developed from one of the consortium partners ad acted as initial inspiration for the initial ideas behind the integration of structured Whizz exercises with more exploratory ones.

[1] http://phet.colorado.edu/
[2] http://nlvm.usu.edu/

(a) Gizmos (ExploreLearning, 2008)

There are a number of so-called Gizmos available from ExploreLearning.com. Their designers refer to all of them as simulations but especially the ones for mathematics are closer to what we would refer to as virtual manipulatives or interactive representations. A related example, used also as part of the bootstrapping process for the design of the iTalk2Learn ELE is *Adding fractions*, a snapshot of which can be seen in Figure 9 below. In this Gizmo the fraction tiles can be placed on one of two number lines, with one showing the sum as an improper fraction and the other as a mixed number. The accompanying teachers guide provides recommendations for teacher-led and student-guided activities. Using Gizmo, students can work individually or in small groups to make equivalent fractions to add fractions with like or unlike denominators.

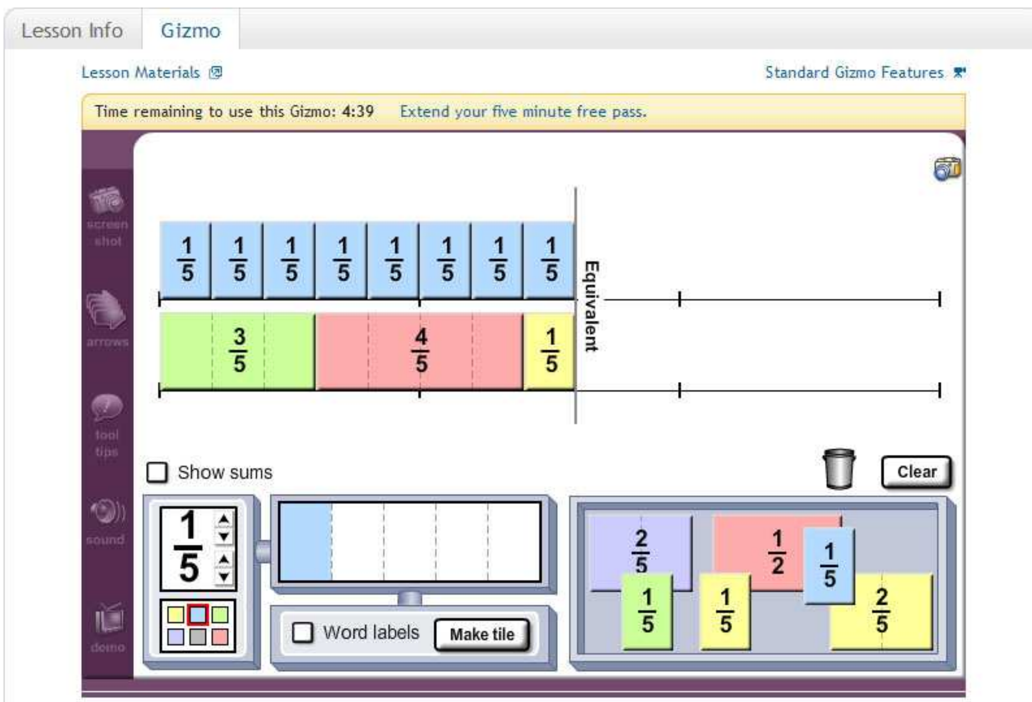


***Figure 9** Adding Fractions Gizmo.*
It shows the solution to 3/5 + 4/5 + 1/5 as an improper fraction and a mixed number (ExploreLearning, 2008).

Student interaction involves being able to generate any fraction tiles with numerators and denominators between 1 and 12, from 1/1 to 12/12. Once made, these can be dragged onto either number line. The 'show sums' boxed can be selected for the sum to be recorded as a fraction or mixed number. Students can also take a screenshot using the camera to the top right of the screen. The number lines can be cleared or individual tiles can be dragged to the rubbish bin to be removed.

When the two number lines represent equivalent fractions a line appears to show this (see Figure 9). Explicit feedback that provides the sum can be provided by selecting the "show sums" button. Integrated feedback occurs through the visual cues that the fraction tiles provide on the number lines.

b) *Maths-Whizz Teachers' Resource (TR) Interactive Board*

Maths-Whizz® Teachers' Resource (TR) is a library of Whizz Education's Maths-Whizz content for teachers. Like LVF, TR can be utilised with a class on a projector or interactive whiteboard, with small groups or with individuals in computer suites environments.

One of the learning tools available in TR is the *Interactive Board*, used for exploratory learning purposes. The *Interactive Board* allows teachers and students to choose from objects such as 2D shapes, 3D shapes, coins, drawing tools, fractions, graphs, number, text, tools, wallpapers and characters. The fractions function enables the user to drag and drop a fraction to the board, and click to 'show pictorial representation' in order to demonstrate different representations of the same fraction. The fractions that can be chosen are constrained by the pre-defined fractions provided in the *Interactive Board.* Other functions, such as the graph function, allow users to enter their own values.

The 'tools' function is dynamic and one of the most varied of the interactive board tools. For example, students are able to explore volume by using an interactive tap to fill containers or they can use other 'tools', such as a clock, scales and a thermometer. As mentioned above, these tools acted as initial inspiration for the design of the iTalk2Learn ELE. They are, however, quite limited in that they were mostly designed for teacher-led use of interactive boards. For example, fractions cannot be easily manipulated and their visual representations are not linked to exploratory operations.

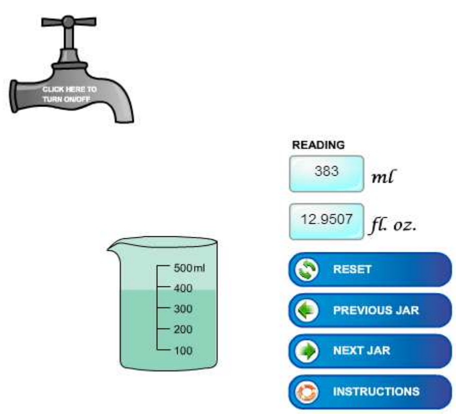


Figure 10 Maths-Whizz Interactive Board *showing the tools for filling containers with liquid.*

2.4 Design drivers - Literature review

Design drivers act as principles that guide the design of the system and are derived from supporting related literature (see Table 1). In our case design drivers have emerged from literature covering a range as diverse as social constructivism, cognitive load theory, instructional design and mathematics education and the consortium's (particularly IOE's) previous work in designing and evaluating ELEs in the classroom. Similar to the design conjecture and for the scope of this deliverable, we keep the discussion purposefully at the level of interaction but of course this is not completely separate from domain decisions. In what follows we first provide the driver and a brief justification for including each driver based on relevant literature review. Specific details on how this relates to the domain and the tasks that will be developed for iTalk2Learn will be presented in D1.2.

<u>Design Driver 1</u>: The design of the ELE will embed a 'reconstructive' approach to learning, involving a range of mental objects/processes

Realistic Mathematics Education (RME) sets out a curriculum based on principles (van den Heuvel-Panhuizen, 2000) of which two have particular relevance to ELE design. The *reality principle* relates to Freudenthal's (1968) premise that mathematics must be learnt "so as to be useful." This learning occurs throughout the process of "progressive mathematization" (Gravemeijer, 1994). In addition to this, the rich contexts that afford mathematization are a prerequisite of the tasks in the RME curriculum. The *guidance principle* is concerned with giving students a 'guided' opportunity to 're-invent' mathematics through tasks that meet the intended learning trajectories. By ELEs providing activities that allow for reinvention, students are able to "construct mathematical insights and tools by themselves" (van den Heuvel-Panhuizen, 2000).

This concurs with the "reconstructive" approach that suggests using "genuine mathematical processes" in which the content can be "developed or reconstructed" through use of object/processes that include: reflection (Ackermann, 1991; Hoyles, 1985; Y. B. Kafai & I. Harel, 1991; Y. B. Kafai & I. Harel, 1991); intuition (specifically in fractions (specifically in fractions Hunting & Sharpley, 1988; Mack, 1990, 1995; Mamede, Nunes, & Bryant, 2005; Newstead & Murray, 1998; Nunes, 2006) and visualisation (Goldenberg, Cuoco, & Mark, 1998). These represent the need for students to undertake thoughtful, reflective, reconstructive work.

<u>Design Driver 2</u>: The design of the ELE will utilise a variety of representations and interpretations of fractions and support students in making connections between them

Seminal work in fractions by Kieran (1976, 1988, 1993) identified five interpretations of fractions: part-whole, ratio, operator, measure, quotient. Researchers typically refer to these interpretations using four broad pictorial representations: area, number line and set of objects Lamon, (Behr, Lesh, Post, & Silver, 1983; Brousseau, Brousseau, & Warfield, 2004; Charalambos Y. Charalambous & Pitta-Pantazi, 2007; 1993, 1999, 2001; Pantziara & Philippou, 2012). However, there is also some use of liquid measures (Common Core State Standards for Mathematics Initiative, 2010) and Silver (1983) identified these as a representation that is used intuitively by some. While striving to develop a theoretical framework for examining student understanding of fraction concepts, Cooper et al. (2012) make it clear that representations and manipulatives are crucial for students to understand fractions. In addition to pictorial representations, they add language, symbols and action as types of representation. Despite this, research continues to show that learners across the world receive a limited number of interpretations and representations in their curriculum diets (Alajmi, 2011; Charalambos Y. Charalambous, Delaney, Hsu, & Mesa, 2010; Clarke & Roche, 2009).

Based on the above, in terms of ELE design, it is possible and desirable to include all these representations of fractions in order to provide opportunities for students to enhance or develop further their conceptual understanding of fractions. However, research has also shown that a significant amount of support is required to help students make the necessary connections between them – see (Ainsworth, 2006) and (Rau, Aleven, & Rummel, 2013) for a more recent detailed review of the topic. The level of support and feedback required will mostly concern us in WP1 tasks T1.2 and T1.3 but it is worth stating here that from an interaction point-of-view this provides additional justification to our design conjecture and efforts to include a range of feedback types that will support students.

Multiple representations will enable students to experience particular ‘instances’ of a concept so that over time: a) they develop abstractions (Tennyson, 1996); b) avoid prototypical representations; c) provide a resource which shapes the way in which ideas are expressed (Noss & Hoyles, 1996); d) they are enabled to generate examples rather than check them.

Design Driver 3: The design of the ELE will motivate students

The notion of student motivation leading to increased learning in active, self-directed, inductive and exploratory computer activities began in the 1980's (Becker, 2000). It is now widely accepted that computers can afford motivating circumstances for students to learn. Although there are many intrinsic and extrinsic factors that cannot be controlled in an ELE it is possible for instructional designers to create environments that enhance the possibility of student motivation (Barger & Byrd, 2011). Three factors are presented here as way of illustration.

Control

Many (e.g. (Kerres, 2007; McLoughlin & Oliver, 1995; Reigeluth, 1999) claim that there is a place for learner control in learning environments. Control involves accommodating learners' needs and granting "some degree of flexibility in pacing, sequencing or content allowing students to make decisions about what sections to study" (Väljataga & Laanpere, 2010) (pg. 280). Hede (2002) also identifies an appropriate amount of learner control in the software in his “integrated model of multimedia effects on learning” as one essential element.

Inquiry, self-explanation and communication

Related to motivation are findings that suggest an increased level of motivation on behalf of the students not only when they engage with traditional games (see Section 2.3.1), but also when they engage in ‘inquiry-oriented mathematics instruction’ (Edward A. Silver, 1997), i.e. instruction where responsibility for problem formulation and solution is shared between teachers and students. For example, in relation to Quads mentioned in the previous section students were highly motivated to set challenges for each other to work through. It is also well documented that motivational and learning effects also arise from social interaction e.g. situations where students are encouraged to explain their actions to a peer (Rajala, Hilppö, & Lipponen, 2012), an adult (Mercer & Hodgkinson, 2008; Mercer & Littleton, 2007; Rose, 2009)(Alexander, 2003, Mercer and Hodgkinson, 2008; Mercer and Littleton, 2007; Rose, 2009).

Taking into account the positive effects of self-explanation (c.f Section 3.2) there is substantial evidence to support a design of activities where there is some scope of students' agency with respect to the task they choose and reflection on their work to an audience of (either or both) the computer and other students. D1.2 will elaborate on this based on preliminary evaluations with students.

Task efficiency drive

(Hansen, 2008) observed how students were highly motivated to undertake tasks in the most efficient way when they used Quads (see Section 2.3.1). As students worked through carefully-structured tasks, they were able to shift from a procedural approach to a more strategic stance. The ELE was designed in such a way that students were able to complete the tasks both procedurally and strategically. In turn, the students demonstrated a more conceptual approach to their understanding of the domain. Designing an ELE to enable students to use it both procedurally and strategically as required enables learners at any stage of cognitive development to access it.

Design Driver 4: The design of the ELE will use a familiar metaphor to guide students to act in a desired way

Instructional media designers have carried over a number of older instructional genres, referred to as "instructional metaphors." E.g. Macintosh and Windows operating system designers using a 'desktop' metaphor with 'trash', 'recycle', 'folders', and 'files' etc. Indeed, it is impossible for instructional designers not to conceive of their product in older, familiar ways (Sundberg, 1998). Erickson (1990, cited in (Sundberg, 1998)) explains, "metaphors function as natural models, allowing us to take our knowledge of familiar, concrete objects and experiences and use it to give structure to more abstract concepts" (p.66). It is worth remembering that the software context is a "construction that makes selective, holistic sense of the environment of interaction" (Boyle, 2002) (pg. 5). Using a familiar metaphor is essential because it guides the user to act within that environment in a particular way.

Design Driver 5: The design of the ELE will provide access tools to support their activities that, whilst they are essential to completing the task, would normally detract from the completion of the task if undertaken manually

In cognitive load theory (Sweller, van Merrienboer, & Paas, 1998), working memory deals with new information and it is extremely limited in capacity (Miller, 1956) and duration (Peterson & Peterson, 1959). (Sweller, 1988) explains that novices (students who use working memory) "fall back on weak problem-solving strategies … which leads to a high cognitive load" because they do not have the schemata to support their work" (pg. 7).

In order to avoid a high cognitive load, the students will be able to use manipulatives built into the ELE. For example, designing a knife that will cut a figure into a given number of equal-sized sections would negate the need for them to put aside their line of thought regarding the size and shape while they tested their hypothesis that the fraction was equivalent to another. According to cognitive load theory this would free up the working memory to focus on achieving the objective of the task (Kalyuga et al., 1999) and support the students' move from the position of being a 'novice' towards an 'expert'.

2.5 Design conjectures and drivers, based on the review of the state-of-the-art

Section 2.2 referred to the framework that we are using for our principled approach to ELE design. This section summarises the design conjectures (that arise from critical analysis and experience of existing related educational software and provide the means of raising requirements) and the drivers that arise from the literature. Table 2 provides an overview of the reviewed software and the two design conjectures related to interaction and feedback.

Software	(1) Student interaction types	(2) Feedback types and timing
Refraction	Drag and drop	Pop-up messages As a result of student action Celebration when completed
Quads	Drag and drop Highlighting Select objects Select and use tools Reset environment Generate objects	As a result of student action Greying out / highlighting objects
eXpresser	Build models using building blocks Check goals list	Real-time feedback based on analysis of student activity Help towards goal Emoticon As a result of student action
Logotron Visual Fractions (LVF)	Connect representations Change representations Drag and drop Select and use tools	As a result of student action Emoticon
Maths-Whizz TR Interactive Board	Drag and drop Choose to see representation	As a result of an action
Gizmos	Generate objects Drag and drop Screenshot Reset	As a result of student action

Table 2 *Overview of the ELEs review (Section 2.3) with respect to student interaction and system feedback*

Based on the categories of ELEs reviewed in Section 2.3 (and other relevant examples under each category) we summarise the conjectures that are guiding the design of the iTalk2Learn ELE:

Design Conjecture 1: There is ground for designing the ELE to provide the following range of interaction for students:

a) dragging and dropping representations

b) changing the size and colour of representations

c) choosing and using tools to manipulate representations

d) seeing or setting dynamic dependencies between representations

e) quickly setting and changing a fraction's value

Design Conjecture 2: There is ground for designing the ELE to provide the following range of feedback to students that is:

a. integrated (i.e. by the design of the environment e.g. linking representations)
b. explicit (i.e. resulting from an action)
c. non-interruptive (e.g. on request or on appropriate occasions)
d. co-located with objects in the environment (e.g. focus or pointing to crucial aspects) and
e. enables students freedom to choose the aspect they receive feedback upon

It is worth stating that there are obviously some design conjectures that relate to the actual fraction representations and their potential for student thinking and learning but, as mentioned in the Introduction, this falls under the remit of WP1. It will be discussed particularly in D1.2 as a reflection from the studies with the relevant examples mentioned in Section 2.3 and the subsequent versions of the iTalk2Learn ELE prototype as these become available.

For completeness we also summarise the design drivers arising from the literature review (Section 2.4)

- embedding a ‘reconstructive’ approach to learning, involving a range of mental objects/processes (Design Driver 1)
- utilising a variety of representations and interpretations of fractions (Design Driver 2)
- motivating students (Design Driver 3)
- using a familiar metaphor to guide students to act in a desired way (Design Driver 4)
- providing access to *tools* to support students' activities that, whilst they are essential to completing the task, would normally detract from the completion of the task if undertaken manually (Design Driver 5)

As mentioned in Section 2.2 the design assumptions are implicit at this stage and will be elaborated in D1.2 as they arise from the designers’ pedagogical approach.

3 State-of-the-art and requirements in voice interaction for learning

As described in Section 1, a VUI is the second constituent of intuitive interaction as we assume it in iTalk2Learn. This section, therefore, reviews the state-of-the-art in this particular field and particularly the two different aspects of a VUI in iTalk2Learn: automatic speech recognition (ASR) and speech synthesis (SS).

With respect to ASR, D3.1 discussed the state of the art mostly and how, from a technical perspective, ASR converts spoken language input into text. From an HCI-perspective and in our context in particular, speech recognition provides support for spoken language input which enables students to communicate verbally with the tutoring system and thus interact without using human interface devices such as a mouse or keyboard. D3.1 also mentioned the difficulties of ASR for children and the efforts the project will undertake to improve performance. However, it is worth bearing in mind that HCI-research suggests that imperfections in ASR accuracy should not limit its usage. Instead, the literature suggests that the overall VUI design and the match of the application to its context should be able to compensate for possible flaws (Canny, 2006). The approach taken in similar projects (such as the LISTEN project in the US presented in the following section) also suggests that, in general, 100% accuracy can neither be expected nor relied upon. In light of this, it is preferential to err on the side of caution, thereby ensuring the least negative impact on learning (Mostow, personal communication).

Similarly, SS takes an important step towards the realization of natural, more intuitive interaction with learning tools. A typical solution for achieving such an objective is the creation or integration of speech-generation software that will allow the transformation of written text into spoken words and phrases - i.e. text-to-speech technology (TTS). It is worth reminding the reader that although iTalk2Learn will undertake research in speech recognition, we consider that state-of-the art speech generation fits the purposes of iTalk2Learn, and therefore - in order to minimize the cost - we will use off-the-shelf technology and integrate it in the system.

Section 3.1 reviews relevant learning systems with a VUI from a more general perspective while Sections 3.2 and 3.3 review specifically ASR and SS respectively and their relationship to learning. Section 3.4 summarises the findings and the consortium's options with respect to ASR and SS as of M9 in the project.

3.1 Relevant systems with VUI for learning

Business use is perhaps the most well-known context for the use of ASR (e.g. call centres). In such contexts, the cost-reduction benefits are considered to outweigh the disadvantages of recognition errors resulting from inaccuracies of the voice recognition. With respect to learning, however, the field is still in its infancy. We provide below an overview of existing learning systems that involve either speech recognition, speech production or both.

a) AutoTutor

AutoTutor is an intelligent tutoring system that simulates a human tutor by holding a conversation with the learners in natural language (Graesser, Chipman, Haynes, & Olney, 2005). AutoTutor appears as an animated agent that acts as a dialogue partner with the learners. The animated agent of AutoTutor presents a series of challenging questions that require approximately a paragraph of information for the learner to answer and guides the learner to reach an ideal answer through interactive dialogs that utilise synthesized speech, intonation and facial expressions. AutoTutor is sensitive to learner emotions by tracking conversational clues such as facial expressions, body postures, speech parameters and dialog history.

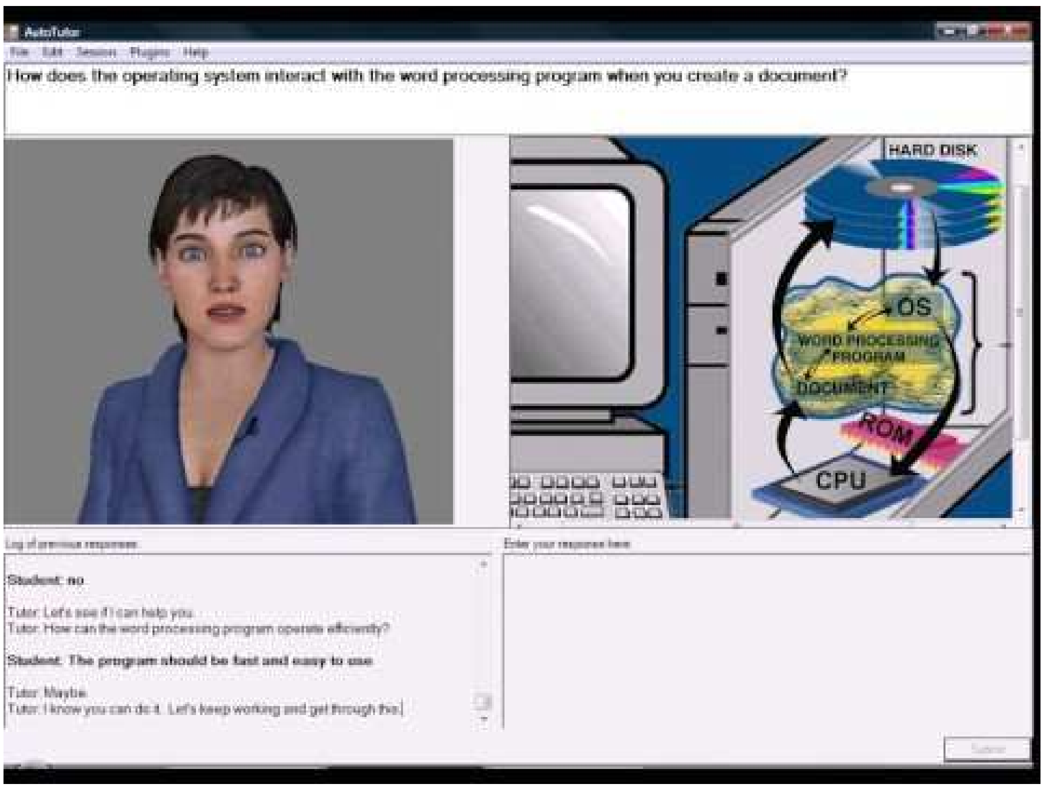


Figure 11 *A snapshot of Autotutor with animated agent and written text displayed*

b) ITSPOKE

ITSPOKE is a speech-enabled version of the Why2-Atlas (VanLehn et al., 2002). Student speech is digitized from microphone input and sent to the Sphinx2 automatic speech recognizer and subsequently to

Why2-Atlas for parsing and dialogue management (see Litman & Silliman, 2004 for technical details) The tutor's text output is produced from the Cepstral SS system. ITSPOKE has been tested with pre-recorded voice and synthesized voice. Results showed no trends or significant differences in student learning gains across the two conditions, suggesting that tutor voice quality does not impact learning in ITSPOKE (Litman & Silliman, 2004). However, this result can only be interpreted in the context of ITSPOKE (or similar systems), where the dialogue transcription is available to the student. This likely diluted the impact of tutor voice quality, because since students could read the transcription simultaneously, their learning was not entirely dependent on understanding the tutor's speech.

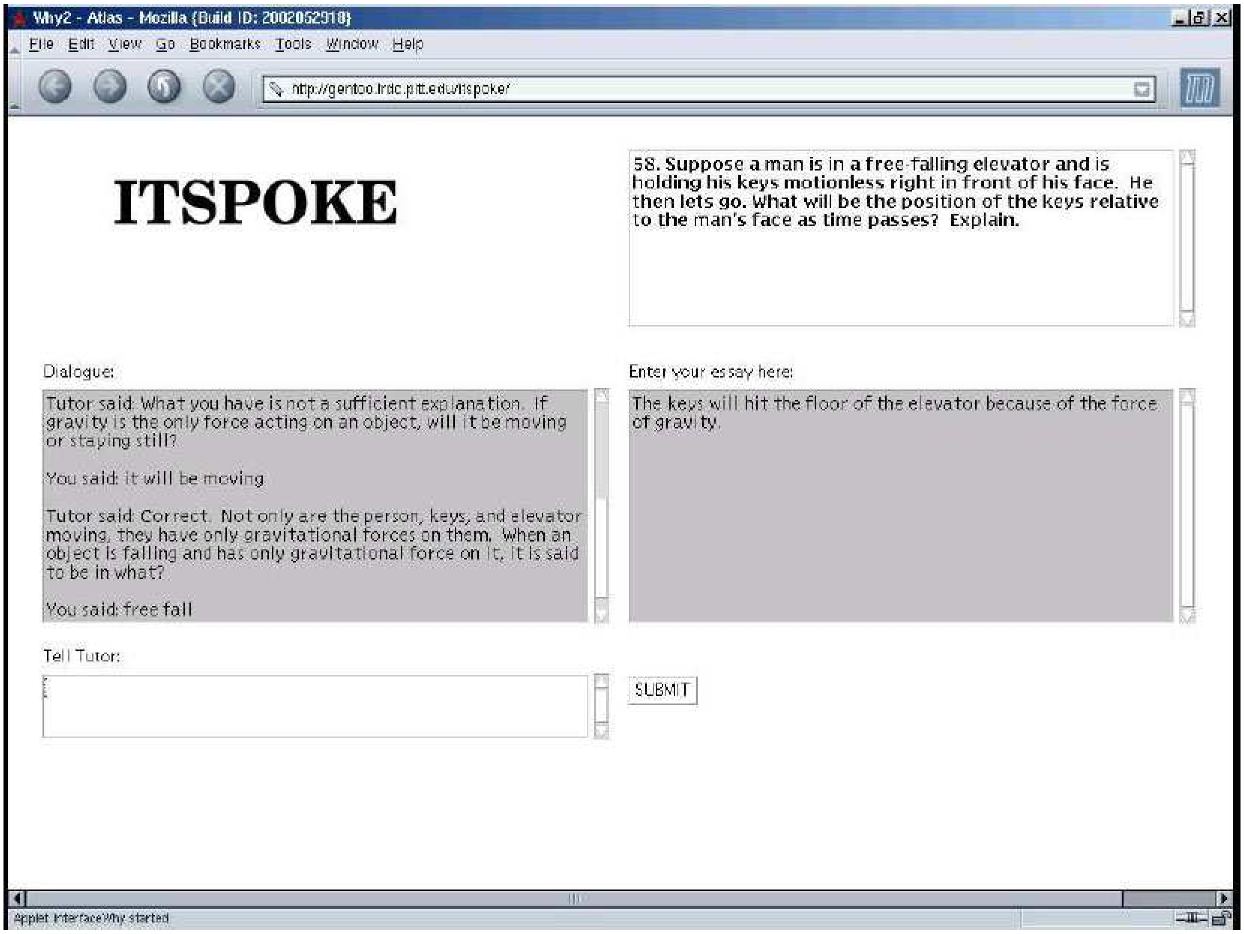


Figure 12 *A snapshot of ITSPOKE with written text displayed*

c) LISTEN

In the area of elementary reading skills, project LISTEN (Literacy Innovation that Speech Technology ENables) is an inter-disciplinary research project at Carnegie Mellon University that developed a novel tool to improve literacy – an automated Reading Tutor that displays stories on a computer screen and listens to children read aloud. To provide a pleasant, authentic experience in assisted reading, the Reading Tutor:

- Takes turns with the child picking stories from Weekly Reader and other sources – including user-authored stories

- Adapts Carnegie Mellon's Sphinx speech recognizer to analyze the child's oral reading
- Intervenes when it notices the reader makes a mistake, get stuck, click for help, or encounter difficulty
- Gives spoken and graphical feedback based on expert reading teachers, but adapted to the capabilities and limitations of the technology

Results from experiments with LISTEN suggest that the addition of a natural UI is not only plausible in practice but also that it has a positive impact on learning gains (Mostow & Aist, 2001).

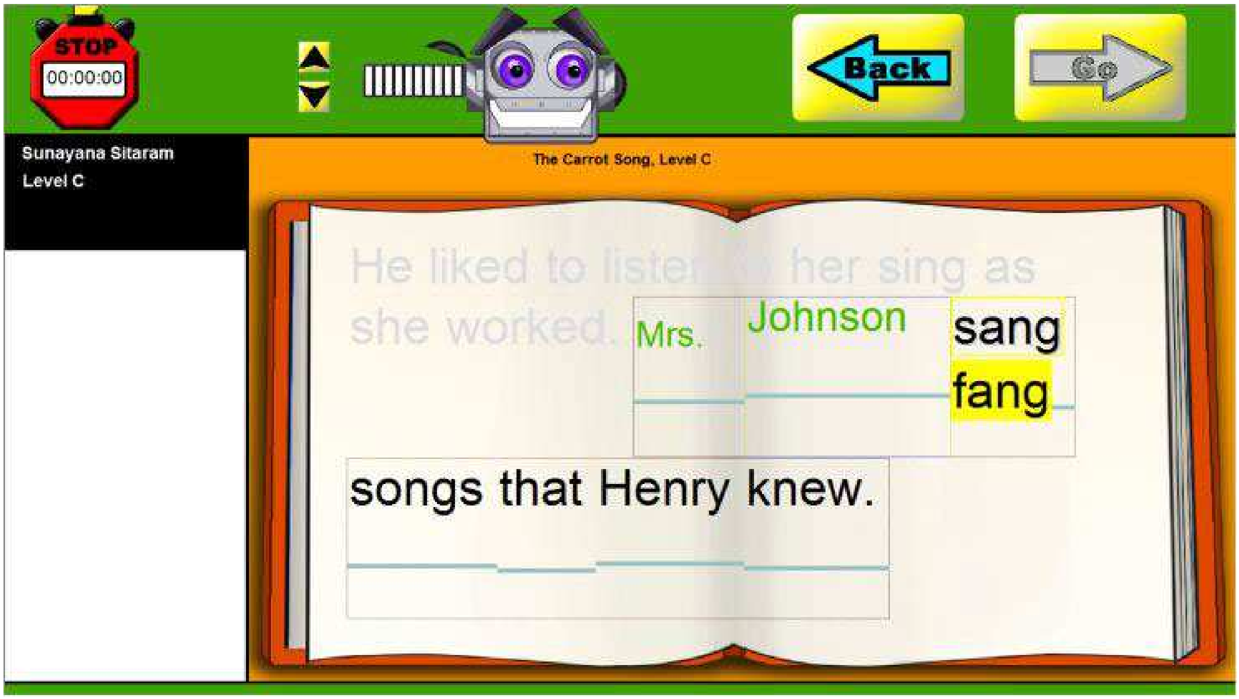


Figure 13 *A snapshot of Reading Tutor from LISTEN project*

d) SCoT

Spoken Conversational Tutor (SCoT) is a tutorial dialogue system that engages students in natural language discussions through a speech interface. The natural language components which make the spoken dialogue possible include a bi-directional unification grammar and off-the-shelf tool for ASR and text-to-speech synthesis. Incoming student utterances are handled by SCoT in the following way. First, the utterance is recognized using Nuance2 speech recognition, which uses a grammar compiled from a Gemini natural language understanding grammar (Dowding et al., 1993). Subsequently, a dialogue manager interprets the utterance in context. The system responds to the student via a FestVox3 synthesized voice (Pon-barry, Brady, Bratt Owen, & Schultz, 2004).

3.2 Automatic speech recognition (ASR) for learning

We remind the reader that D3.1 provided a summary of commercial and academic systems that make use of ASR for children. With respect to learning in particular, the hypothesis that ASR can facilitate learning is based mostly on educational research that has shown benefits of verbalization for learning (e.g., Mercer & Sams, 2007; Rajala et al., 2012; Teasley, 1995; Zakin, 2007). The possible verbalization effect could be enhanced with ASR since cognitive load theory (Sweller et al., 1998) and cognitive theory of multimedia learning (Mayer & Moreno, 2003) predict that a more natural and efficient form of communication (c.f. (Rosenfeld, Olsen, & Rudnicky, 2000; Schuller et al., 2006) will also have positive learning gains.

The few existing research studies have found mixed results with respect to whether the input modality (speaking vs. typing) has a positive, negative or no effect on learning. (D'Mello, Dowell, & Graesser, 2011), for example, investigated whether student typing or speaking leads to higher computer literacy with the use of AutoTutor. In a study implementing a within subject design D'Mello and colleagues (2011) found that the input modality had no effect on learning. However, due to the limited sample size and age range as well as the use of a different learning domain (computer literacy vs. fractions) these results still leave open how young learners with still to-be-developed reading and typing skills might benefit from communicating verbally with the system.

The importance of students' verbal communication becomes apparent, if we further consider the research about self-explanations. Self-explanation is an efficient learning strategy where students are prompted to verbalize their thoughts and explanations about the target principle. These positive effects of self-explanations are not limited to an "analog" learning environment, but hold true when students are asked to type in their self-explanations in a computer-supported learning environment (e.g., Aleven, Koedinger, & Cross, 1999; Aleven, Koedinger, & Popescu, 2003). In concrete, providing students with the possibility to type in their explanations in their own words ("natural language") instead of selecting an explanation from a predefined menu results in even deeper conceptual understanding (Hausmann & VanLehn, 2010). Therefore positive effects for communicating verbally with the system and reflecting on interaction can be expected, particularly when taking into account anecdotal observations and related research that suggest that spontaneous self-explanation is more frequent in spoken rather than typed tutorial interactions (Hausmann & Chi, 2002).

Additionally, recording the speech of the learner gives us the chance to record the tone and pitch of speech in conjunction with other auditory signs like sighs, gasps etc., which form the base for analyzing e.g. learners' emotion and engagement. If we know the latter, we might provide learners with even more individualized help, for instance, in form of motivational prompts.

3.3 Speech Synthesis (SS) and educational software

Many learning tools have made use of feedback based on spoken text, with the aim of motivating students, helping them in case of visual impairments or when they were unable to read and, in general, as an alternative means of providing information to them. Despite this is not the main research focus of iTalk2Learn, it is worth providing an overview of some notable tools (apart from the tools mentioned above that provide both ASR and SS) that partners have experience with and which have inspired and stimulated the consortium during the designing phases of the project (a running task at the time of writing).

In the context of the EU-funded project "80Days - Around an inspiring virtual learning world in eighty days", consortium partner TL has developed a serious game for learning Geography, inspired by a science-fiction concept where an alien was represented as a 3D virtual character. In order to ensure that the alien appears to speak, two approaches have been followed and compared. At first, a human performer has recorded a series of phrases to be integrated in the Game Engine (GE) and then played based on game events. In a second phase, a TTS system has been integrated into the Game Engine (GE). In particular the CEREPROC system was selected, with following characteristics: based on Cereproc SDK, DLLs and Voices integrated in GE, generated Wav files played by the GE, interfaced with Character Engine managing the alien. While the overall gaming experience was better with pre-recorded voice, anecdotal evidence from the project was that learning quality is not affected and students also demonstrate an appreciation of the synthetic voice, thanks to the animations, visual aspects and the general atmosphere of the game.

Consortium partner Whizz considers the voiceover functionality essential for students that are not able to read the instructions unaided - particularly for the youngest students, students with learning disabilities, English Language Learners (ELL), or students with visual impairments. The English voiceovers in Whizz are created in one of two ways – they are either recorded in an audio recording studio or the text is converted into synthetic speech audio files. The voiceovers for exercises usually cover all the instructions in the teaching section and the main part of the question text. The instructions are also repeated for every question in all of the tests and most of the exercises. Ideally, the voiceover function would replicate the visual instructions throughout all of the Maths-Whizz lessons for all age-groups. However, this is not the case, since voiceover functionality is currently limited to the younger age groups and key instructions. For some language translations (e.g. Russian), voices have been separated into an adult voice for the instructions and a child's voice for any other voiceover functions. This has been recommended by educationalists in order to emphasise the teaching process.

Although it is often viewed as an essential requirement for a comprehensive learning tool, the provision of voiceover function presents a number of issues. On a practical level, pre-recorded voiceover is very time-consuming to produce. The process for this includes translation of transcriptions, recordings, editing, naming sounds with correct codes, uploading, and testing. Alternatively, synthetically produced voiceovers are not easy to decipher (due to limitations such as monotonous intonation). On a functional level, voiceover is not essential for students that are able to read instructions unaided. Particularly where unfamiliar accents or unclear recordings are used, anecdotal evidence from Whizz suggests that voiceover can actually detract from the learning objective. The problem is intensified when the voiceover does not directly replicate the visual text, leading to confusion from the student perspective.

Further to the anecdotal evidence mentioned above and efforts of the iTalk2Learn partners related research suggests that audio feedback is beneficial both to task performance and learning (Fiorella, Vogel Walcutt, & Schatz, 2012). In our literature review on Intelligent Tutoring Systems (ITS) with pedagogical agents (PA) we have identified positive effects if the PA speaks to the learner using a human rather than computer generated voice (Atkinson, Mayer, & Merill, 2004). Repeated findings include a spoken conversation (PA talking to learner) compared to the PA communicating via on-screen text results in better learning (Atkinson et al., 2004; Moreno & Mayer, 2004). For example in a series of (five) experiments (Moreno, Mayer, Spires, & Lester, 2001) investigated the two following questions. First, does a speaking PA or a "writing" PA foster retention and transfer in particular? Second, does the visual presence or absence of a PA foster retention and transfer in particular? To answer these questions Moreno and colleagues used the "Design-a-Plant-Environment" where students learned to develop a plant to flourish under given circumstance of an alien planet with the help of "Herman the bug" (PA). In two experiments (Experiment No. 4 n= 64 college students and Experiment No. 5 n= 79 college students) it was confirmed that students learning with a speaking PA outperformed those who learned with a "writing" PA (= on-screen-text). Interestingly, Moreno, Mayer, Spires and Lester (2001) as well as Craig, Gholson and Driscol (2002) found that the visual presence or absence of the (speaking) PA had neither positive nor negative results. The positive effects of a speaking PA became especially apparent if the PA addresses his verbal messages in a personalized way (using 1st and 2nd person, instead of the neutral 3rd person) (Moreno & Mayer, 2000). However, it is not clear yet, how the quality of the computer-generated voice affects these results.

3.4 VUI in the context of iTalk2Learn

As mentioned already, WP3 is looking the VUI of iTalk2learning from an HCI perspective but also taking into account the opportunities that relate to the ASR and SS that will be developed in the project. Since our main preoccupation is the educational use of iTalk2Learn, the project is looking into VUI both as a means of improving the student's experience and, more importantly, as a feature that can contribute directly to improving students' learning.
Table 3, therefore first summarises the review of the relevant examples reviewed in the previous section by pointing out the means by which students and computer tutors interact.

Software	Domain	(1) ASR	(2) SS
Autotutor	Various topics (Newtonian physics, computer literacy)	- Latest versions of Autotutor allowed spoken input that was sent the commercial Dragon ASR. Transcript not shown. - Wizard-of-Oz experiments have been conducted with the computer literacy versions of Autotutor	- Animated agent with intonation and facial expression - Written transcript also provided to student
ITSPOKE	Physics	- Students' answers to tutor questions are sent to the Sphinx2 ASR and subsequently to Why2-Atlas for syntactic and semantic analysis - Transcript available to student	n/a

LISTEN	Elementary reading skills	- Children read aloud stories which are sent to the Sphinx2 ASR	- Gives spoken and graphical feedback
SCoT	Shipboard damage control	- Students reflect after completing a problem-solving session with a real-time, multimedia training environment for damage control - Student speech is sent to the Nuance2 ASR and then to Gemini for natural language parsing.	- Festival and FestVox3 is used for text-to-speech synthesis. - Written transcript also provided to student
80 days	Serious game for geography	n/a	Both pre-recorded and synthetic voice that fitted the general atmosphere of the game (aliens)
Whizz	Elementary mathematics	n/a	Mostly pre-recorded voice particularly for instructions.

Table 3 Overview of relevant to iTalk2Learn ASR and SS systems for learning

As far as the relationship of the VUI to learning is concerned, the literature review in the previous sections provided the consortium a common ground not only about the possible impact and importance of both ASR and SS in student's interaction and learning, but also about the open research questions in the field. We have therefore dedicated explicit effort and communication between all partners to specify feasible and appropriate contexts for integrating ASR and SS in both the structured and exploratory activities that iTalk2Learn platform will provide.

Whilst this effort will continue iteratively, we provide below the consortium's options as of M9. These will be revisited based on early pilots and studies with prototypes of the system.

3.4.1 Structured activities

- The system will be able to provide task descriptions and feedback in written and partly in spoken format. The questions and feedback will use mathematical vocabulary appropriate to the attainment of the students.
- Students will be able to provide answers to structured tasks that are processed by the system and inputted to Whizz or Fraction Tutor for evaluation.

3.4.2 Exploratory learning activities

- Similar to structured activities, the system will be able to provide task descriptions, feedback and other elements of the environment (e.g. labels etc.) in written and partly in spoken format using appropriate mathematical vocabulary.
- The students will be encouraged to reflect upon their work and the work of others by using the opportunity to record their work within the ELE.

3.4.3 Both structured and exploratory activities

As mentioned in more detail in Section 3.3, self-explanation is an important strategy for learning (e.g. (Hausmann & Chi, 2002; Hausmann & VanLehn, 2010) that can be used both in structured and exploratory activities. Students can be encouraged to "think aloud" (to the microphone) and to explain why things work or not while they interact with the system. Similarly, students could reflect verbally on the difficulty of a question and request easier or harder exercises.

The ASR system can recognize these explanations or requests. Even keyword-based recognition can provide enough information for the ASR system to provide support both within (e.g. hints) and across activities (e.g. recommendations for next activity). For example, the system could identify the terms students are using and encourage them to use more appropriate or more precise vocabulary when they are talking. Particularly within the ELE it could support suggestions based on how the students are using the fraction representations available to them. For the structured activities it could provide information for the sequencing of tasks.

4 Conclusion

This deliverable reviewed the state-of-the-art for ELEs and VUIs in order for the partners to develop a common understanding about the possibilities afforded by the corresponding technologies. By reviewing the state-of-the-art and key literature in the field we have reached specific design decisions and high-level requirements for the iTalk2Learn platform that inform the relevant work packages (particularly WP2 and WP4). In summary we provide the following requirements that serve as a starting point and guiding principles for the consortium:

1. The UIs and usability of the platform overall will be designed according to the latest standards and attempt to provide an intuitive website for children.
2. The ELE and the activities should be designed in accordance to the design drivers and design conjectures outlined in Section 2.5. An iterative design process will continue in the context of D3.6.
3. The utilisation of the ASR should not be constrained upon the error rates of the technology. Depending on the context where ASR is integrated an effort should be made for any possible errors (false negatives or positives) to not interfere with learning.
4. The SS should be easily understood, consistent with any text provided simultaneously in the screen and utilise appropriate mathematical vocabulary.

Note that for both ASR and SS the consortium is limiting its efforts to English and German but, at least from a technical and methodological perspective, we are not closing the doors to other languages.

5 References

Ackermann, E. (1991). From decontextualized to situated knowledge: Revisiting Piaget's water-level experiment. In I. H. S. Papert (Ed.), *Constructionism* (pp. 269-295). Norwood, NJ: Ablex Publishing Corporation.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*(3), 183-198.

Alajmi, A. H. (2011). How do elementary textbooks address fractions? A review of mathematics textbooks in the USA, Japan, and Kuwait. *Educational Studies in Mathematics, 79*, 239–261.

Aleven, V., Koedinger, K. R., & Cross, K. (1999). *Tutoring Answer Explanation Fosters Learning with Understanding. Artificial Intelligence in Education, Open Learning Environments: New Computational Technologies to Support Learning, Exploration and Collaboration.* Amsterdam: IOS Press.

Aleven, V., Koedinger, K. R., & Popescu, O. (2003). *A Tutorial Dialog System to Support Self-Explanation: Evaluation and Open Questions. In: Hoppe, U., Verdejo, F. & Kay, J. (Eds.).* Amsterdam: IOS Press.

Alexander, R. (2003). *Talk for learning: The first year.* North Yorkshire County Council. Retrieved from http://www.robinalexander.org.uk/docs/nyorks_eval_rep_03.pdf

Andersen, E., Liu, Y.-E., Snider, R., Szeto, T., Cooper, S., & Popović, Z. (2011, June 28 - July 1, 2011). *On the Harmfulness of Secondary Game Objectives.* presented at the meeting of the Foundations of Digital Games, Bordeaux, France.

Atkinson, R. K., Mayer, R. E., & Merill, M. M. (2004). Fostering social agency in multimedia learning: Examining the impact of an animated agent's voice. *Contemporary Educational Psychology*(30), 117-139.

Balacheff, N., & Sutherland, R. (1994). Epistemological domain of validity of microworlds: the case of LOGO and Cabri-G\'eom\`{e}tre*North-Holland Publishing Co.* Symposium conducted at the meeting of the Proceedings of the IFIP TC3/WG3.3 Working Conference on Lessons from Learning Retrieved from http://www.citeulike.org/group/6164/article/3512098 doi:citeulike-article-id:3512098

Barger, A., & Byrd, K. (2011). Motivation and computer-based instructional design. *Journal of Cross-Disciplinary Perspectives in Education, 4*(1), 1-9.

Becker, H. J. (2000). Pedagogical motivations for student computer use that lead to student engagement. *Educational Technololgy, September-October.*

Behr, M., Lesh, R., Post, T., & Silver, E. (1983). Rational Number Concepts. In R. Lesh & M. Landau (Eds.), *Acquisition of Mathematics Concepts and Processes* (pp. 91-125). New York: Academic Press.

Ben-Naim, D., Marcus, N., & Bain, M. (2008). *Visualization and Analysis of Student Interactions in an Adaptive Exploratory Learning Environment.* presented at the meeting of the CEUR-WS,

Blackler, A. L., & Hurtienne, J. (2007). Towards a unified view of intuitive interaction : definitions, models and tools across the world. *MMI-Interaktiv, 13*, 36-54.

Boyle, T. (2002). Towards a theoretical base for educational multimedia design. *Journal of Interactive Media in Education., 2.*

Brousseau, G., Brousseau, & Warfield, V. (2004). Rationals and decimals as required in the school curriculum. Part 1: Rationals as measurements. *Journal of Mathematical Behavior, 23*, 1-20.

Canny, J. (2006). The future of Human-Computer interaction. *Queue, 4*(6), 24-32.

Charalambous, C. Y., Delaney, S., Hsu, H.-Y., & Mesa, V. (2010). A Comparative Analysis of the Addition and Subtraction of Fractions in Textbooks from Three Countries. *Mathematical Thinking and Learning, 12*(2), 117-151.

Charalambous, C. Y., & Pitta-Pantazi, D. (2007). Drawing on a theoretical model to study students' understandings of fractions. *Educational Studies in Mathematics, 64*(3), 293-316.

Chuang, M. L. (2009). *Using intuitive interaction technology to promote learning of mathematics in young children*. presented at the meeting of the World Conference on Educational Multimedia, Hypermedia and Telecommunications, Chesapeake, VA.

Clark-Wilson, A., Oldknow, A., & Sutherland, R. (2011). *Digital technologies and mathematics education 11-19*: Joint Mathematical Council/Royal Society. doi:citeulike-article-id:12462665

Clarke, D., M., & Roche, A. (2009). Students' Fraction Comparison Strategies as a Window into Robust Understanding and Possible Pointers for Instruction. *Educational Studies in Mathematics, 72*(1), 127-138.

Common Core State Standards for Mathematics Initiative. (2010). *Common Core State Standards for Mathematics* Retrieved from http://www.corestandards.org/assets/CCSSI_Math Standards.pdf

Cooper, S. M., Wilkerson, T. L., Montgomery, M., Mechell, S., Arterbury, K., & Moore, S. (2012). Developing a Theoretical Framework for Examining Student Understanding of Fractional Concepts: An Historical Accounting. *Forum on Public Policy, 2012*(1).

Craig, S., Gholson, B., & Driscoll, D. (2002). Animated pedagogical agents multimedia educational environments: Effects of agent properties, picture features, and redundancy. *Journal of Educational Psychology, 94*(2), 428-434.

D‘Mello, S. K., Dowell, N., & Graesser, A. (2011). Does it Really Matter Whether Student‘s Contributions Are Spoken Versus Typed in an Intelligent Tutoring System With Natural Language? *Journal of Experimental Psychology; Applied 2011, 17*(1), 1-17.

de Villiers, M. (1998). *To teach definitions in geometry or teach to define?* presented at the meeting of the 22nd Conference of the International Group for the Psychology of Mathematics Education, University of Stellenbosh, RSA.

Deubel, P. (2003). An investigations of behaviourist and cognitive approaches to instructional multimedia design. *Journal of Educational Multimedia and Hypermedia, 12*(1), 63-90.

Dowding, J., Gawron, M., Appelt, D., Cherny, L., Moore, R., & Moran, D. (1993). Gemini: A natural language system for spoken language understanding. In *In Proceedings of ACL 31* (pp. 54-61). Columbus, OH

Ericsson, K. A., & Kintsch, W. (1995). Long-term memory. *Psychological Review, 102*, 211-245.

ExploreLearning. (2008). *Adding Fractions (Fractions Tiles).* Retrieved from http://www.explorelearning.com/

Fiorella, L., Vogel Walcutt, J., & Schatz, S. (2012). Applying the modality principle to real-time feedback and the acquisition of higher-order cognitive skills. *Educational Technology Research and Developmen, 60*(2), 223-238.

Freudenthal, H. (1968). Why to teach mathematics so as to be useful. *Educational Studies in Mathematics, 1*, 3-8.

Goldenberg, E. P., Cuoco, A. A., & Mark, J. (1998). A role for geometry in general education. In R. Lehrer & D. Chazan (Eds.), *Designing Learning Environments for Developing Understanding of Geometry and Space* (pp. 3-44). Mahwah, NJ: Lawrence Erlbaum Associates.

Graesser, A. C., Chipman, P., Haynes, B., & Olney, A. M. (2005). AutoTutor: An intelligent tutoring system with mixed-initiative dialogue. *IEEE Transactions on Education, 48*, 612-618.

Gravemeijer, K. (1994). Educational development and educational research in mathematics education. *Journal for Research in Mathematics Education, 25*(5), 443-471.

Groff, J., Howells , C., & Cranmer, S. (2010). *The impact of console games in the classroom: Evidence from schools in Scotland.* Scotland: Learning and Teaching Scotland / Futurelab. Retrieved from http://archive.futurelab.org.uk/resources/documents/project_reports/Console_Games_report.pdf

Gutierrez-Santos, S., Mavrikis, M., & Magoulas, G. (2010). Layered Development and Evaluation for Intelligent Support in Exploratory Environments: The Case of Microworlds. In *Intelligent Tutoring Systems* (Vol. 6094, pp. 105-114): Springer Berlin. Retrieved from http://dx.doi.org/10.1007/978-3-642-13388-6_15. doi:citeulike-article-id:7530805

doi: 10.1007/978-3-642-13388-6_15

Haipeng, M., Krzywinski, A., Fujita, T., & Sugimoto, M. (2012). RoboTable: An Infrastructure for Intuitive Interaction with Mobile Robots in a Mixed-Reality Environment. *Advances in Human-Computer Interaction, 2012*, 1-10. doi:10.1155/2012/301608

Hansen, A. (2008). *Children's geometric defining and a principled approach to task design*. Warwick University.

Harp, S., & Mayer, R. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. *Journal of Educational Psychology, 90*(3), 414-434. doi:citeulike-article-id:12462777

Hausmann, R. G. M., & Chi, M. T. H. (2002). Can a computer interface support self-explaining? *Cognitive Technology, 7*(1), 4-14.

Hausmann, R. G. M., & VanLehn, K. (2010). The Effect of Self-Explaining on Robust Learning. *International Journal of Artificial Intelligence in Education, 10*(4).

Hede, A. (2002). An integrated model of multimedia effects on learning. *Journal of Educational Multimedia and Hypermedia, 11*, 177-191.

Hoyles, C. (1985). What is the point of group discussion in mathematics? *Educational Studies in Mathematics, 16*, 205-214.

Huk, T. (2002). The role of navigation and motivation in e-learning: The CRIMP-approach within a Swedish-German research cooperation Symposium conducted at the meeting of the EDEN Annual Conference

Hunting, R. P., & Sharpley, C. F. (1988). Fraction Knowledge in Preschool Children. *Journal for Research in Mathematics Education, 19*(2), 175-180.

Illera, R. J. L. (2004). Multimedia Learning in the Digital World. In A. D. Brown, N. (Ed.), *World Yearbook of Education 2004: Digital technology, communities and education* (pp. 91-108). London: Kogan Page.

Jones, I., & Pratt, D. (2006). Connecting the equals sign. *International Journal of Computers for Mathematical Learning, 11*(3), 301-325. doi:citeulike-article-id:1093774

doi: 10.1007/s10758-006-9107-6

Joolingen, W., & Zacharia, Z. (2009). Developments in Inquiry Learning. In N. Balacheff, S. Ludvigsen, T. de Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-Enhanced Learning* (pp. 21-37). Retrieved from http://dx.doi.org/10.1007/978-1-4020-9827-7_2. doi:citeulike-article-id:6564142

doi: 10.1007/978-1-4020-9827-7_2

K√°chemann, D. (1981). Algebra. In K. M. Hart (Chair), *Antony Rowe Publishing Services*. Symposium conducted at the meeting of the Children's Understanding of Mathematics doi:citeulike-article-id:2797841

Kafai, Y. B., & Harel, I. (1991). Learning through consulting: When mathematical ideas, knowledge of programming and design, and playful discourse are intertwined. In I. Harel & S. Papert (Eds.), *Constructionism*. Norwood, NJ: Ablex Publishing Corporation.

Kafai, Y. B., & Harel, I. (1991). Learning through design and teaching: Exploring social and collaborative aspects of constructionism. In I. Harel & S. Papert (Eds.), *Constructionism*. Norwood, NJ: Ablex Publishing Corporation.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology*, *13*, 351-371.

Kerres, M. (2007). Microlearning as a challenge to instructional design. In T. Hug & M. Lindner (Eds.), *Didactics of Microlearning*. Münster: Waxmann.

Kieren, T. E. (1976). On the mathematical, cognitive, and instructional foundations of rational numbers. In R. Lesh (Ed.), *Number and measurement* (pp. 101-144). Columbus: Ohio State University.

Kieren, T. E. (1988). Personal knowledge of rational numbers: Its intuitive and formal development. In J. Hiebert & M. J. Behr (Eds.), *Number concepts and operations in the middle grades* (pp. 162-181). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kieren, T. E. (1993). Rational and Fractional Numbers: From Quotient fields to Recursive understanding. In T. P. Carpenter, E. Fennema, & T. A. Romberg (Eds.), *Rational Numbers: An Integration of Research* (pp. 49-84). Hillsdale, NJ: Erlbaum.

Klopfer, E., Osterweil, S., & Salen, K. (2009). *Moving learning games forward: Obstacles, opportunities and openness*

Lamon, S. L. (1993). Ratio and proportion: Children's cognitive and metacognitive process. In P. Carpenter, E. Fennema, & T. A. Romberg (Eds.), *Rational Numbers: An Integration of Research* (pp. 131-156). New Jersey: Lawrence Erlbaum Associates.

Lamon, S. L. (1999). *Teaching Fractions and Ratios for Understanding*. New Jersey: Lawrence Erlbaum Associates.

Lamon, S. L. (2001). Presenting and representing: From fractions to rational numbers. In A. Cuoco & F. Curcio (Eds.), *The Roles of Representations in School Mathematics - 2001 Yearbook* (pp. 146-168). Reston: NCTM.

Lehotska, D., & Kalas, I. (2005). *LVF – Interface for Dynamic Fractions*. presented at the meeting of the 7th International Conference on Technology in Mathematics Teaching, Bristol: University of Bristol.

Litman, D. J., & Silliman, S. (2004). ITSPOKE: An Intelligent Tutoring Spoken Dialogue System. *Proceeding HLT-NAACL- Demonstrations '04*, 5-8.

Lynch, C., Ashley, K., Aleven, V., & Pinkwart, N. (2006). Defining "Ill-Defined Domains"; A literature survey Symposium conducted at the meeting of the Intelligent Tutoring Systems (ITS 2006): Workshop on Intelligent Tutoring Systems for Ill-Defined Domains doi:citeulike-article-id:2553912

Mack, N. K. (1990). Learning Fractions with Understanding: Building on Informal Knowledge. *Journal for Research in Mathematics Education*, *21*(1), 16-32.

Mack, N. K. (1995). Confounding Whole-Number and Fraction Concepts When Building on Informal Knowledge. *Journal for Research in Mathematics Education*, *26*(5), 422-441.

Mamede, E., Nunes, T., & Bryant, P. (2005). *The equivalence and ordering of fractions in part-whole and quotient situations*. presented at the meeting of the 29th Conference of the International Group for the Psychology of Mathematics Education, Melbourne.

Mavrikis, M., Gutierrez-Santos, S., Geraniou, E., & Noss, R. (2012). Design requirements, student perception indicators and validation metrics for intelligent exploratory learning environments. *Personal and Ubiquitous Computing*. doi:citeulike-article-id:10648591

doi: 10.1007/s00779-012-0524-3

Mavrikis, M., Noss, R., Hoyles, C., & Geraniou, E. (2013). Sowing the seeds of algebraic generalization: designing epistemic affordances for an intelligent microworld. *Special Issue on Knowledge Transformation, Design and Technology. Journal of Computer Assisted Learning*, *29*(1), 68-85. doi:citeulike-article-id:10548315

doi: 10.1111/j.1365-2729.2011.00469.x

Mayer, R. E. (2004). Should There Be a Three-Strikes Rule Against Pure Discovery Learning? - The Case for Guided Methods of Instruction. *American Psychologist, 59*(1), 14-19. doi:citeulike-article-id:6347339

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43–52.

McLoughlin, C., & Oliver, R. (1995). *Analysing interactions in technology supported learning environments*. presented at the meeting of the 13th Annual National Computers in Education Conference, Perth, Western Australia.

Mercer, N. (2000). *Words and minds: How we use language to think together*. London: Routledge.

Mercer, N., & Hodgkinson, S. (Eds.). (2008). *Exploring talk in school*. London: Sage.

Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking: A socio-cultural approach*. London: Routledge.

Mercer, N., & Sams, C. (2007). Tecahing children how to use language to solve maths problems. *Language and Education, 20*(6), 507-528.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Moreno, R., & Mayer, R. E. (2000). Engaging Students in Active Learning: The Case for Personalized Multimedia Messages. *Journal of Educational Psychology, 92*(4), 724-733.

Moreno, R., & Mayer, R. E. (2004). Personalized Messages that Promote Science Learning in Virtual Environments. *Journal of Educational Psychology, 96*(1), 165-173.

Moreno, R., & Mayer, R. E. (2005). Role of Guidance, Reflection, and Interactivity in an Agent-Based Multimedia Game. *Journal of Educational Psychology, 97*(1), 117-128. doi:citeulike-article-id:12462751

Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The Case for Social Agency in Computer-Based Teaching: Do Students Learn More Deeply When They Interact With animated Pedagogical Agents? *Cognition and Instruction, 19*(2), 177-213.

Mostow, J., & Aist, G. (2001). Evaluating tutors that listen: An overview of Project LISTEN. In K. F. P. Feltovich (Ed.), (Smart Machines in Education ed., pp. 169-234). Menlo Park, CA: MIT/AAAI Press.

Newstead, K., & Murray, H. (1998). *Young students' constructions of fractions.* presented at the meeting of the Twenty-second International Conference for the Psychology of Mathematics Education, Stellenbosch, South Africa.

Noss, R., & Hoyles, C. (1996). *Windows on mathematical thinking: Learning cultures and computers*. Dordrect: Kluwer Academic Publishers.

Noss, R., Poulovassilis, A., Geraniou, E., Gutierrez-Santos, S., Hoyles, C., Kahn, K., . . . Mavrikis, M. (2012). The design of a system to support exploratory learning of algebraic generalisation. *Computers & Education, 59*(1), 63-81. doi:citeulike-article-id:9845356

doi: 10.1016/j.compedu.2011.09.021

Nunes, T. (2006). Fractions: difficult but crucial in mathematics learning. In T. a. L. R. Programme (Ed.).

Pantziara, M., & Philippou, G. (2012). Levels of students' "conception" of fractions. *Educational Studies in Mathematics, 79*, 61–83.

Peterson, L., & Peterson, M. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*, 193–198.

Pon-barry, H., Brady, C., Bratt Owen, E., & Schultz, K. (2004). Evaluation the effectiveness of SCoT: A spoken conversational tutor. *Proceedings of ITS 2004 Workshop on Dialogue-based Intelligent*.

Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., & Carey, T. (1994). *Human-Computer Interaction*. Harlow: Addison-Wesley.

Rajala, A., Hilppö, J., & Lipponen, L. (2012). The Emergence of Inclusive Exploratory Talk in Primary

Students' Peer Interaction. *International Journal of Educational Research, 53*, 55-67.
Raskin, J. (1994). Intuitive equals familiar Communications of the ACM. *37*(9), 17. Retrieved from http://www.asktog.com/papers/raskinintuit.html
Rau, M. A., Aleven, V., & Rummel, N. (2013). Interleaved practice in multi-dimensional learning tasks: which dimension should we interleave? *Learning and Instruction, 23*, 98-114.
Reiber, L. P. (2005). Multimedia Learning in Games, Simulations, and Microworlds. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning.* Cambridge: Cambridge University Press. Retrieved from http://lrieber.coe.uga.edu/mayer2005/
Reigeluth, C. M. (Ed.). (1999). *Instructional-design theories and models: An new paradigm of instructional theory* (Vol. II). Mahwah, NJ: Lawrence Erlbaum Associates.
Rose, J. (2009). *The independent review of the primary curriculum: Final report*. London: DCSF.
Rosenfeld, R., Olsen, D., & Rudnicky, A. (2000). *Human-Machine Speech Interface: A White paper.* Retrieved from http://www.cs.cmu.edu/~roni/papers/USI-TR-00-114.doc.gz
Rowe, J., McQuiggan, S., Robison, J., & Lester, J. (2009). Off-task behavior in narrative-centered learning environments Symposium conducted at the meeting of the In Proceedings of the Workshop on Intelligent Educational Games at the 14th Annual Conference on Artificial Intelligence in Education, Brighton. doi:citeulike-article-id:12462780
Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.
Schuller, B., Ablaßmeier, M., Müller, R., Rei nger, S., Poitschke, T., & Rigoll, G. (2006). *Speech communication and multimodal interfaces* (Kraiss, K,F ed.). Berlin: Springer-Verlaig.
Self, J., & Yr, L. (1988). Bypassing the Intractable Problem of Student Modelling Symposium conducted at the meeting of the Proceedings of the Intelligent Tutoring Systems conference, ITS'88 Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.55.2809 doi:citeulike-article-id:6551630
Silver, E. A. (1983). Probing Young Adults' Thinking about Rational Numbers *Focus on Learning Problems in Mathematics, 5*(3&4), 105-117.
Silver, E. A. (1997). Fostering creativity through instruction rich in mathematical problem solving and problem posing. *ZDM, 29*(3), 75-80. doi:citeulike-article-id:12463148

doi: 10.1007/s11858-997-0003-x
Sundberg, J. (1998). Expressivity in singing. A review of some recent investigations. *Logopedics, Phoniatrics, Vocology, 23*, 121-127.
Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.
Sweller, J., van Merrienboer, J. G., & Paas, G. W. (1998). Cognitive Architecture and Instructional Design. *Educational Psychology Review, 10*(3), 251 - 296.
Tabbers, H. K. (2002). *The modality of text in multimedia instructions: Refining the design guidelines.* Open University of the Netherlands, Heerlen.
Teasley, S. (1995). The role of talk in children's peer collaboration. *Developmental Psychology, 3*, 207–220.
Tennyson, R. D. (1996). Concept learning. In T. Plomp & D. P. Ely (Eds.), *International encyclopedia of educational technology* (2nd ed. ed.). Oxford, England: Elsevier Science Ltd.
Thompson, P. (1987). Mathematical microworlds and intelligent computer-assisted instruction*Addison-Wesley Longman Publishing Co., Inc.* Symposium conducted at the meeting of the Artificial intelligence and instruction: Applications and methods doi:citeulike-article-id:3832810
Väljataga, T., & Laanpere, M. (2010). Learner control and personal learning environment: a challenge for instructional design. *Interactive Learning Environments, 18*(3), 277-291.
van den Heuvel-Panhuizen, M. (2000). *Mathematics education in the Netherlands: A guided tour, in*

Freudenthal Institute. presented at the meeting of the ICME9, Utrecht: Utrecht University.

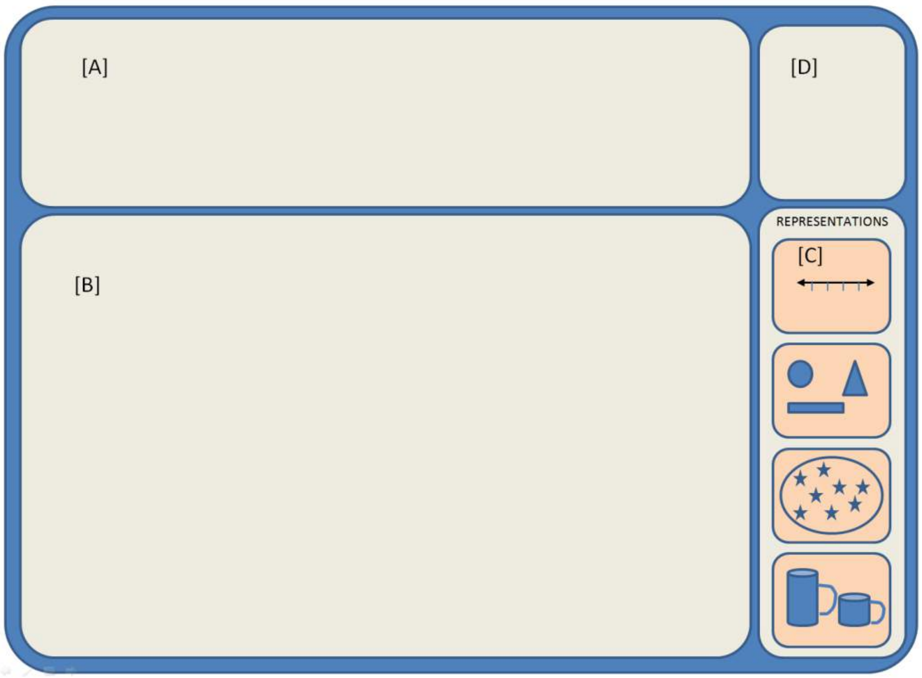
VanLehn, K., Jordan, P. W., Rose, C., Bhembe, D., Bottner, M., A, G., . . . Wilson, R. (2002). The architecture of Why2-Atlas: A coach for qualitative physics essay writing. . In *In Proceedings of Intelligent Tutoring Systems*

Zakin, A. (2007). Metacognition and the use of inner speech in children's thinking: A tool teachers can use. *Journal of Education and Human Development, 1*(2), 1 - 14.

Appendix A – The design of the Fractions Lab (v 1.1)

This appendix provides a 'snapshot' of the design of the ELE as of M8 as shared between partners IOE and TL. It is worth stating that a static document fails to demonstrate the dynamic nature of both the ELE and its design process. In practice IOE and TL share powerpoint presentations, drawings and have teleconferences that clarify the features presented here. As the ELE is being developed IOE and TL will continue iterating over its design which will evolve to meet the requirements particularly of WP1 and the feedback that IOE and RUB collect.

1. LAYOUT



1.1 Exploratory Learning Activity and Symbol Display Area [A]

This area shows the ELA as text. The area also shows the fractions being used in section [B] by simultaneously representing the operation that is occurring. E.g. if a student places a circle with a half shaded in, then ½ is shown on the symbol display area. If a child then adds a quarter, then the + sign and ¼ are both shown too.

This works in reverse too, so if a fraction is changed by typing, any representation in section [B] reflects that change.

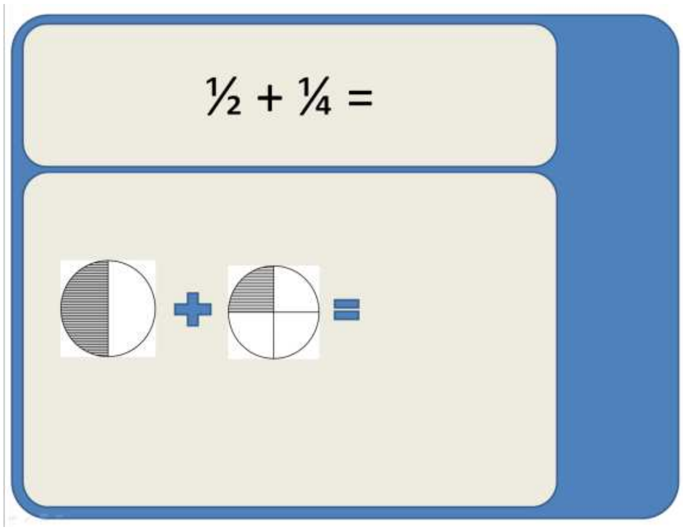


Fig 1:When the pie in [B] shows 1/2, the numeral 1/2 appears in [A]. ***Note:*** *the numerator and denominator* *<u>WILL</u>* *be directly on top of each other with a horizontal line and not as shown on the screenshots or this appendix.*

1.2 The Experimentation Table [B]

The student can select various representations (from [C]) and manipulate them using tools that they can right mouse click to select (see section 2 for further explanation).

Whatever happens in [B] is shown in [A] simultaneously. So, a child can place a half a pie, and 1/2 is shown in [A]. They can place a quarter of a pie and 1/4 is shown in [A]. They can place a '+' symbol in [B] and the symbol appears in [A]. They can place a '=' symbol in [B] and the symbol appears in [A].

It must be possible to swap the representations, so change 1/2 + 1/4 to 1/4 + 1/2 and the equation will change in [A] too.

Finding the answer is discussed in section 3 detail below for each representation.

1.3 Representations [C]

The student can select which representations they would like to use. There is a set of four types of representations available that the student can select from. The student will then have a variety of representations available to use within each type (see below).

The student can have more than one representation showing at a time, and whatever they do with one of the representations changes in the other.

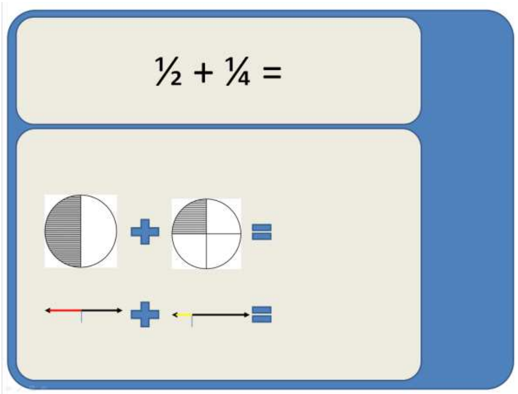


Fig 2: Showing pie representations and number line representations. See section 3.1 and 4 for detailed information about how these two representations behave.

All the representations can be dragged around the Experimentation Table by holding with a left mouse click.

<u>1.3.1 The number lines</u>

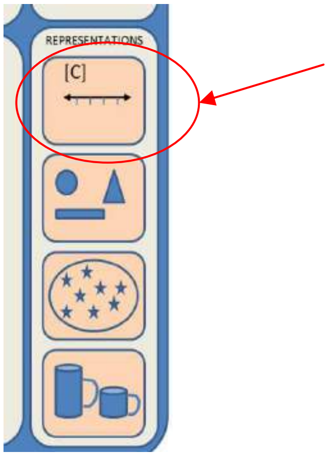


Fig. 3: Access to number line representations

This requires a range of representations that the student can select from within this section:

- A number line
- A road
- A length of string

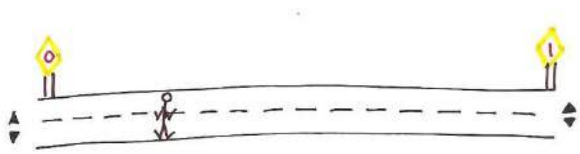
A number line

The student can see the number line changing colour a particular length (pre-determined by a selected fraction) and then they can add or subtract another fraction which is a different colour along the line.

The demarcations along the number line can be changed and more than one set (i.e. Different denominators) can be shown on the number line at the same time.

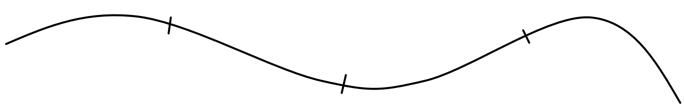
A road

A person can walk forwards and backwards along the road, according to whether it is addition or subtraction.



A length of string

The string will not be straight, but the computer can identify different accurate demarcations. E.g.



(Please refer to section 3 for further detail).

1.3.2 Area

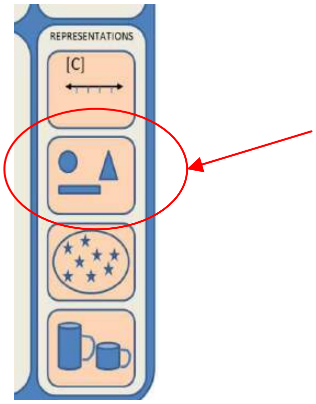


Fig. 4: Access to area representations

This requires a range of representations that the student can select from within this section. These could be:

- Circles
- Rectangles (oblongs)
- Equilateral triangle

All can be cut up into a number of sections that the student chooses on the denominator tool (see section 2.3).

A given number of sections can be coloured in, according to the numerator tool (see section 2.2).

(Please refer to section 4 for further detail)

<u>1.3.3 Sets</u>

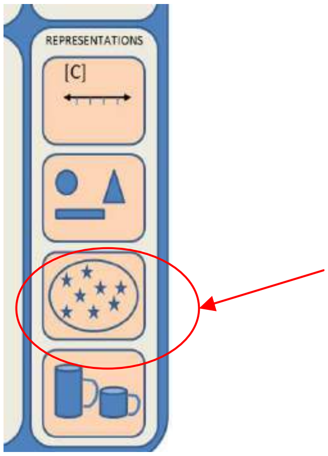


Fig. 5: Access to sets representations

This requires a range of representations that the student can select from within this section. These could be:

Counters (Like checkers) – these could be one colour on one side and a different colour on the reverse side, and the child can flip them.

- Stars
- Flowers
- Or any other object(s) you think are fine.

The objects form a set. It is possible to make a subset by changing the colour of the objects.

The number of objects that the student chooses on the denominator tool (see section 2.3) are displayed.

A given number can be coloured in, according to the numerator tool (see section 2.2).

(Please refer to section 5 for further detail)

1.3.4 Liquid Measures

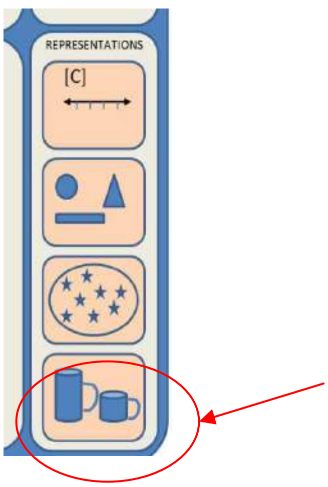


Fig. 6: Access to liquid measures representations

These are measuring cups or glasses or containers or similar.
Two types:

1) Just glasses or containers that hold various fractions
2) Measuring cups, where there is a scale on the side (this would work the same way as the number line)

Liquid can be poured from one container into another, or from both into a third. They can also remove an amount for subtraction.

(Please refer to section 6 for further detail)

1.4 The Lab Book

The students can access the lab book to:

1) Record what they have done

2) See what others have done

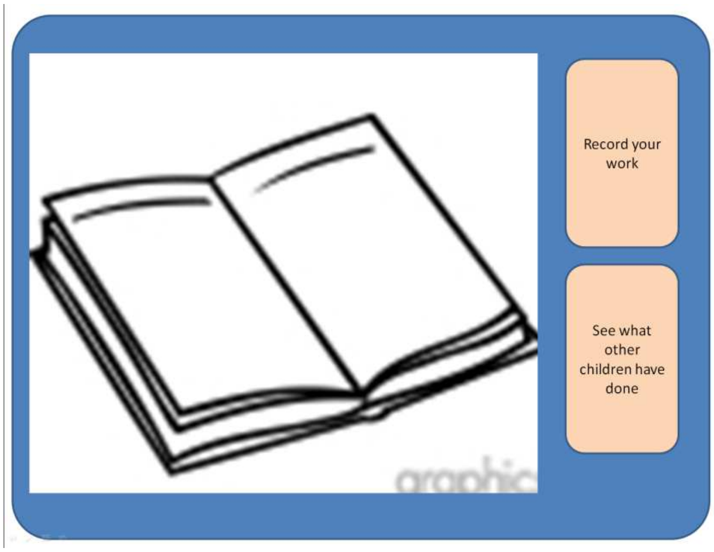


Fig. 7: Students can record and play back through a 'lab book'

1.4.1 Record their own work

The student can record what they have done in the Lab Book by recording their voice and showing on the screen what they mean (this might be using a pointer that they retrieve, for example). So this will need to include recording start/stop buttons and save buttons.

1.4.2 See what others have done

The student can go through the Lab Book to retrieve what others have previously recorded. So this will need to include a menu that the students can select from. It might be that this only allows access to the answers that relate to the same question the student is working / has worked on.

The retrieval may be student-led or system-led, based on recommendations.

2. TOOLS

When the student right mouse clicks on the Experimentation Table [B], they see a menu of tools that they can use to operate upon the representations (or experiment with). This is a common toolbox that they will see regardless of what representation(s) they are using. The tools appear whenever they right mouse click. Some tools will not be available for some representations.

These are:

- Add / subtract / equals
- Numerator
- Denominator
- Size
- Colour
- Clone
- Cut

[Others might be:

- Multiply/divide
- Simplify
- Mixed number]

2.1 Add / subtract / equals

The child is able to show that they are adding or subtracting two fractions. They can select the add/subtract/equals tool and choose what operation they wish to use. The symbol is left on the screen and they can place it either between two representations (for + or -) or at the end (for =).

The software will work from left to right, so if the child has made ½ on the left and then ¼ on the right, then select subtract, the machine will take ¼ from ½.

The software will prompt the child to provide their own answer when they select '='. There will then be an opportunity for the computer to check the answer and provide feedback.

All operations will be shown using animation (see detailed explanation of representation behaviour in sections 3-6).

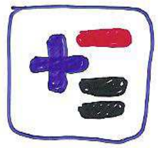


Fig. 8: Sample add / subtract / equals icon

2.2 Numerator

This allows the student to choose the numerator, so if a fraction is ¾, the three is the numerator. They could select from a drop-down menu or type in or say the number they want the numerator to be.

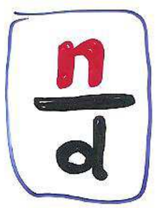


Fig. 9: Sample icon: Could the icon for this perhaps be a 'n' over a 'd', with the 'n' really bold and clear and the 'd' nearly faded?

2.3 Denominator

This allows the student to choose the denominator, so if a fraction is ¾, the four is the denominator. They could select from a drop-down menu or type in or say the number they want the numerator to be.

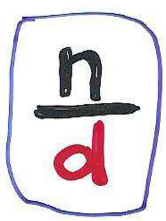


Fig. 10: Sample icon: Could the icon for this be the inverse of the numerator - with 'n' over 'd', with the 'd' really bold and clear and the 'n' nearly faded?

2.4 Size

When a student uses this, they can readjust the size of the model. The actual fraction does not change, just the size of the representation.

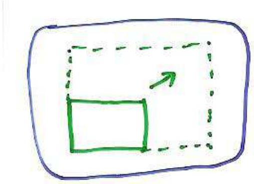


Fig. 11: Sample icon

2.5 Colour

When a student uses this, they can change the colour of the shaded areas. It gives them a limited palette to choose from.

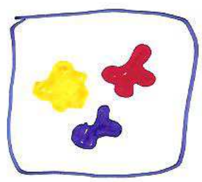


Fig. 12: Sample icon (paint blobs)

2.6 Clone

A student can use this to make another identical representation. It may be faster than starting from scratch.

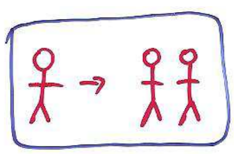


Fig. 13: Sample icon

2.7 Cut

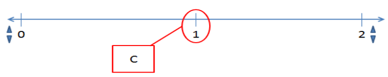
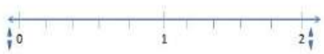
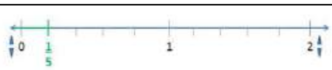
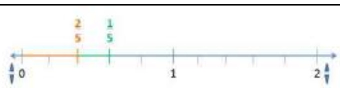
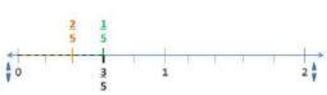
A student can use this to cut the string and a selection of other representations too (see behaviour sections 3-6).

Fig. 14: Sample icon

3. BEHAVIOUR OF REPRESENTATIONS I: NUMBER LINE

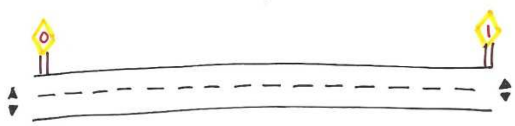
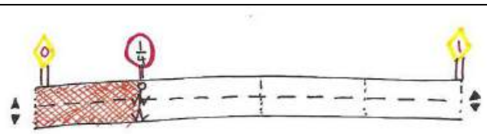
The commentary here uses the number line as an example. Most behaviours will apply for the road and the string too, and variations are discussed in sections 3.2 and 3.3.

3.1 Behaviour of the number line

	A&B: These arrows enable the user to control the start and end numbers on the number line. The default should be 0 and 1.
	C: As the ‘A’ & ‘B’ arrows move, the whole numbers automatically appear on the number line.
	The tool for denominator creates demarcations along the number line (in this e.g. fifths)
	The tool for numerator identifies the fraction and the part of the number line changes colour (in this e.g. it is 2/5). **It is important that the number line changes colour by the new colour slowly filling in along the line from 0 to the fraction.**
	Here, a second number line has been made (either by the clone tool or starting from scratch).
	The coloured fraction from either number line can be cut (using the cut tool) and the cut section can added to a new number line. When it is, the symbol moves to the top.
	The student can then use the numerator (and denominator tool when applicable) to show on this third number line the answer. So, for this, the answer is 3/5. Note: For fractions where the denominators are different (e.g. 2/6 + 1/5) the student will need to place more demarcations (e.g. 30ths) before they can identify the solution.

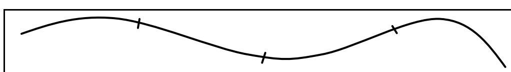
3.2 *Behaviour of the road*

This behaves in a similar way to the number line. Only differences are identified here:

	The length of the road can be increased/decreased using the arrows like the number line (on the screen the road size does not change, just the whole numbers) The whole numbers could be mile-stones or signposts.
	When the denominator tool is selected, the demarcations are shown on the road - they are not shown as signposts (as it would get too crowded) The tool for numerator identifies the fraction and the part of the road changes colour (in this e.g. it is 1/4). **It is important that the road changes colour by the new colour slowly filling in along the road from 0 to the fraction as the person walks along. When the person stops, the signpost shows the distance walked.**
	As for the number line, two distances travelled can be brought together on a third road to add or subtract.

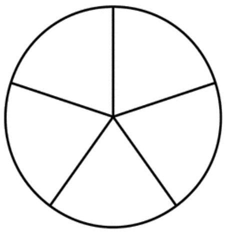
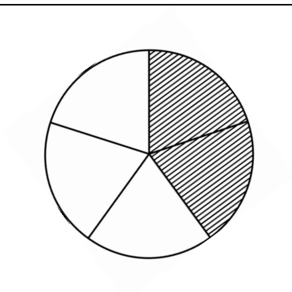
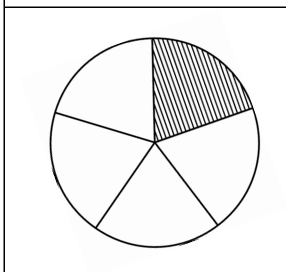
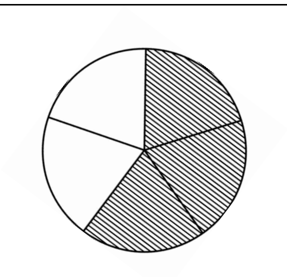
3.3 *Behaviour of the string*

The string behaves in exactly the same way as a number line, but it is curved and looks like string!

	The tool for denominator creates demarcations along the string (in this e.g. quarters)

4. BEHAVIOUR OF REPRESENTATIONS II: AREA

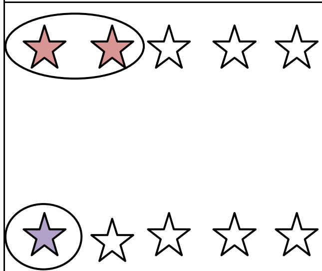
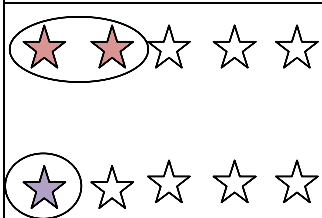
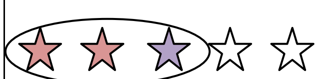
The commentary here uses circles as an example. All behaviours will apply to the oblong (rectangle) and isosceles triangle too.

	The tool for denominator creates demarcations within the shape (in this e.g. fifths).
	The tool for numerator identifies the fraction and the part of the shape changes colour (in this e.g. it is 2/5). **It is important that the fraction slowly fills the shape by the new colour slowly filling in along the uppermost vertical line clockwise.**
	Here, a second circle has been made (either by the clone tool or starting from scratch).
	The coloured fraction from either shape can be cut (using the cut tool) and the cut section can added to a new shape. When it is, the symbol moves to the top.

	The student can then use the numerator (and denominator tool when applicable) to show on this third shape the answer. So, here, the answer is 3/5. Note: For fractions where the denominators are different (e.g. 2/6 + 1/5) the student will need to place more demarcations (e.g. 30ths) before they can identify the solution.

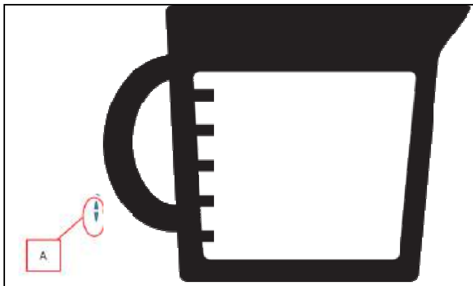
5. BEHAVIOUR OF REPRESENTATIONS III: SETS

The commentary here uses stars as an example. All behaviours will apply to other objects too.

	The tool for denominator identifies the number of objects (in this case five)
	The tool for numerator identifies the fraction and the part of the set that changes colour (in this e.g. it is 2/5). **It is important that the objects change colour slowly, one at a time.**
	Here, a second set has been made (either by the clone tool or starting from scratch).
	The coloured fraction from either set can be cut (using the cut tool) and the cut section appears with a set grouping circle around it. They can added to a new number line. When it is identified, the symbol shows at the top.
	The student can then use the numerator (and denominator tool when applicable) to show on this third set the answer. So, for this, the answer is 3/5.

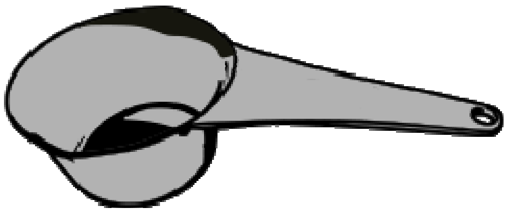
6. BEHAVIOUR OF REPRESENTATIONS IV: LIQUID MEASURES

The commentary here uses measuring cups as an example. All behaviours will apply to other objects too.

	A: This arrow enables the user to control how much is held in the measuring cup. The default should be 1. It should be somewhere on the cup near the top (but the clipart prohibits it here). As with the number line, whole numbers automatically appear on the cup as appropriate
	As with the number line, the tool for denominator creates demarcations along the number line
	The tool for numerator identifies the fraction and the part of the jug changes colour (in this e.g. it is 2/6). **It is important that the jug fills up slowly. Keep the demarcations visible (poor graphics here)**
	Here, a second number line has been made (either by the clone tool or starting from scratch).

	The coloured fraction from either jug can be cut (using the cut tool) and the liquid is 'poured' into a new jug. The original colours remain the same in the new jug. When it is complete, the symbol moves to the top.
	The student can then use the numerator (and denominator tool when applicable) to show on this third measuring jug the answer. So, for this, the answer is 3/5. Note: For fractions where the denominators are different (e.g. 2/6 + 1/5) the student will need to place more demarcations (e.g. 30ths) before they can identify the solution.

The second variation is baking cups.

	These baking cups are discrete objects and do not operate a continuous mechanism as above.
	The tools for numerator and denominator identify the fraction and the cup appears with its name on (here, 1/2 cup).
	When two cups are to be added, the student needs to identify the cup they wish to pour the contents into. If the cup is too large, space is shown at the top and the student receives feedback that there is x/y space in the cup. If the cup is too small, the student receives feedback that x/y of the sugar/flour will not fit.