# Intelligent Environments

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## 1. Introduction

The paper reflects the discussion that was held in Brighton for the GROE initiative on intelligent environments. Input for this event was the 'white paper on Intelligent Environments' and the 'Road map for Education Technology' resulting from the first workshop held in Tempe, Arizona in April 2009.

The section 2 below presents visions. It takes the notion of Active Learning Objects (ALOs) mentioned in the white paper a step further. In addition, section 2 presents new visions on issues such as: seamless transition between real and virtual world, self-explanatory simulations, expressive freedom, developing significantly advanced learner models, and inducing motivation on behalf of the learner. The section 3 focuses on technology, highlighting the advancements and challenges that need to be tackled to realise the visions.

## 2. Visions

### 2.1 Active Learning Components

We envision environments that are domain independent and go beyond one specific task. In that sense, in 20 years such environments will also cover soft skills and will be open ended, exploratory in nature allowing the learners to question and enhance their understanding on what they are motivated to learn.

These environments will comprise of agents that act as 'facilitators' according to the needs and preferences of the learner. They may request particular topics and knowledge components and expect Active Learning Components (ALCs) to interact with each other. These agents will orchestrate this, allowing certain (evaluated and approved) ALCs to place themselves in context and expect from them to self-assemble and adapt to the learner's characteristics (cognitive, conative, previous skills, culture) and their needs (disabilities, learning difficulties), in other words a complete learner model.

We envision that the environments, the agents in them, and the ALCs will be able to self-learn and improve based on evaluation criteria from their usage and the learning outcomes.

### 2. 2 Learners move seamlessly movement between real and virtual environments

We envision that future intelligent learning environments will allow learners to move seamlessly between real and virtual environments. With little effort on behalf of the learner it should be possible to take current reality as a starting point for a virtual engagement. The software would recognize the current situation, be able to recreate it in the virtual context, provide access to knowledge and competence potentially relevant to that situation, and filter the interaction to those resources by the learner's characteristics and (learning) goals, providing the learner an instrument that is automatically assembled given the specific situation and learner needs.

The virtual worlds can be used to present environments beyond the classroom walls (e.g., a trip to the Egyptian pyramids); for things too small to see (e.g., molecular level transformations); too large to include in the real environment (e.g., a model of Mars and its moons); to long in time (e.g., the erosion by a river); or too quick to see (e.g., the beating of a hummingbird's wings). For example, in learning science in the classroom a student conducting an experiment in chemistry might work with real lab glassware, chemicals and equipment, but then move into a virtual environment to rapidly repeat the same experiment with different chemicals or to automatically collect data on the experiment. The environments might also augment the real world equipment by, for example, embedded sensors in the lab glassware that knows how much of a liquid a student has added, detects that it has been placed on a Bunsen burner, monitors the rising temperature and can display on a screen the resulting graph. The simulation part of the environment could represent the chemical interactions taking place at the molecular level. The virtual part of the environment would also represent characters such as other team members in a group-based learning task. The intelligent environment would be aware of a student's prior knowledge, skills and abilities and would provide appropriate coaching as the student works through the learning task.

A particular feature of such environments would be that learners could call upon virtual characters as authentic role models (based on real people which they value) as virtual teachers and companions. These characters would not only be knowledgeable, but also carefully reflect the characteristics of these real people.

The simulations and augmented reality would not only be used to represent learning situations for the learner, but would allow the learner to represent or model their own thoughts and responses, and those would be interpreted by the system.

### 2.3 Truly interactive and self-explanatory simulations + representations

We envision interactive simulations, and representations, that are able to explain themselves to learners. Such interactive instruments could start by observing numerical data via sensors, and take that as initial starters. They would have a seamless interplay between different kinds of knowledge, such as qualitative (=conceptual) and quantitative knowledge, and use whatever is available and needed for the situation at hand. The explanations would easily switch between modality and use of media as required to induce knowledge and understanding on behalf of the learner. The instruments would also adapt themselves to the knowledge, skills, abilities, interests and goals of the learner, and use flexible argumentation and communication styles, as appropriate in a particular context.

### 2.4 Highly motivating environments

We envision that 20 years from now, digital learning environments will be highly motivating. These learning systems would take into account the intentions and goals of the students. They will be motivating in different ways depending on age, economic, and cultural considerations. They will be motivating by teaching skills in practical/real-life contexts. They will be motivating by including authentic role models as virtual learning companions and teachers.

### 2.5 Expressive freedom and power

We envision that in 20 years learners will have the necessary tools to create powerful and expressive visual and diagrammatic representations. They will express their thoughts freely using pen and paper, or digital technologies, but also other devices beyond the current practice. All seamlessly integrated and interconnected in the learning environment, particularly in terms of meaning. For example, in science and mathematics education it should be possible for students to use freehand drawing, sketches and diagrams in their attempt to solve a problem. Similarly, it will be possible to use flexible representations to express knowledge and understanding of a domain thus enabling not only the assessment of students' knowledge but also the facile creation of new ALCs by teachers, peers and other stakeholders.

### 2. 6 Truly individualised learning (optimised for the individual)

In 2030 we envision an intelligent learning environment that is capable of being completely adaptive and adaptable to a sufficiently complete representation of the learner (user model) in order to deliver the most optimized learning experience.

The most optimized path to knowledge and skill acquisition will be determined by the Active Learning Component Environment (ALCE) which will then assemble a combination of Active Learning Components (ALC) that will provide the most optimized path to the desired learner outcome. For example, if a middle-school student is personally interested in tennis, then concepts taught in physics would be presented in the context of the sport of tennis. If the student is interested in outer space, then lessons and concepts would be presented in this 'interest context'.

The ALCE would take into account a full learner model that includes history, interests, age, previously successful learning methods, etc. that would all generally be considered as a part of standard learner model. However, the complete model will also include heroes, role models, personal interests, and personal preferences that will be used to create an individualized and highly motivating learning environment that is tailored directly to the needs of student. This includes students with physical and/or cognitive disabilities.

## 3. Technology

### 3.1 Architectural and design of Active Learning Components

Active Learning Components (ALCs) are learning instruments that will automatically adapt themselves to fit the requirements of a learner. We recommend that funding agencies support research on the design, self-assembling and orchestration of such ALCs, both as components and concerning the environment in which they exist and operate. Main research questions include:

- Competence and granularity regarding how much knowledge it brings to convey to a learner in a particular context, depending on the knowledge it in principle has access to, the learning goals of the learner, and maybe the requirements brought forward by other stakeholders such as parents (care-takers) and governmental institutes. Addressing this may even include negotiation among the stakeholders involved.

- How they encode their knowledge about sensitivity to student characteristics, cultural contexts or special needs, and e.g. use layers or skins to adapt themselves in terms of appearance.
- How their meta-data is created to describe their functions and purposes. Related is the issue of establishing benchmarks, standards and expected outcomes, according to which ALCs can be compared and organised.
- How they get orchestrated and communicate with each other, particularly concerning the sequencing of a set of ALCs for a certain learner.
- How they self-improve and learn to become more effective/efficient components, e.g. depending how well they performed with learners in the past.

### 3.2 Self-explanatory and interactive simulations + representations

We recommend that funding agencies support research on interactive simulations and representations that are able to explain themselves to learners such that the competence captured in the simulation is effectively conveyed to the learner. Main research questions include:

- Continuous interaction between the simulation and the sensors, obtaining and potentially including new data, albeit without inappropriate interruption of an ongoing simulation and dialogue.
- Seamless interplay between different kinds of knowledge, and representations thereof, such as qualitative (e.g. conceptual, causal, structural) and numerical (e.g. differential equations). Typically, overcoming the outstanding problem that each representation is important and has unique added value in a learning situation as such (e.g. ‘causal’ for creating explanations, and ‘differential equation’ to calculate specific values), but to date are none-interoperable and therefore cannot be automatically integrated and simultaneously used in a interactive setting.
- How to address the communicative interaction, and use multimedia and switch modalities as appropriate to explain a phenomenon (what media is best suited for explaining what?) while also taking user characteristics into account (such as knowledge, skills, abilities, culture, general preferences and interests)?
- Including appropriate Assumptions and Perspectives concerning the applicability of the knowledge used for the situation at hand.
- Flexibility in using multiple argumentation and communication styles.

### 3.3 Compartmentalised knowledge and skill resources

We recommend that funding agencies support research on how to compartmentalise knowledge and skills, and establishing indexes for retrieval thereof, such that fragments can be re-used and automatically assembled into a particular learning context to form a whole that is appropriate and sufficient to a address a learner goal. Main research questions include:

- Re-use of existing resources, both those using an explicit representation (e.g. Cyc) and those using an implicit or less explicit representation (e.g. Wikipedia).
- Ways to measure and establish a notion of (sufficient) cover. How much and what kind of knowledge is needed for solving a certain problem? Is there a lower or upper boundary? Is there an optimal amount?
- Knowledge capture for not covered or only sparsely covered areas (e.g. ecology and environmental sciences), and re-representation and re-capture of

'available' knowledge such that (1) knowledge parts become reusable as 'self-contained' fragments, and (2) the knowledge is formulated such that it can address different use-levels (e.g. novice versus expert).

- Indexing and compartmentalising knowledge including dimensions such as type of Domain, Granularity, Perspectives, Assumptions, etc., and probably also concerning task and problem types
- How to establish interconnections and computer processable relationships between different kinds of knowledge (e.g., conceptual, subtype, qualitative, equations, consists-of), but also between different representations thereof (e.g. rules, frames, XML, OWL). Research on the Semantic web provides a good starting point for this endeavour, but represents only a tip of the iceberg that needs to be tackled.

### 3.4 Benchmarks, Standards, and Outcomes

We recommend that funding agencies support research on establishing benchmarks, standards, and further means to index and classify educational materials, certificates, institutes, etc. Particularly, when the default boundaries of schools, and other traditional educational institutes, vanish due to abundant computer-based interactive learning components, it becomes important to create a meta-framework in the context of which these new materials can be referenced. This implies funding research on techniques and mechanisms to manage simultaneous and conflicting educational goals, such as achieving learning of the domain, keeping student interest, developing of self-esteem and social skills development. Part of this research involves the use of sophisticated mechanisms to judge effectiveness of active learning components, which combine human/committee experts with machine learning optimization and search mechanisms. It also involves the assessment of not only one final outcome, but of the process of learning and achievement of other educational outcomes. In order to optimize outcomes, these systems would have to handle multiple measures of a student's interaction with the environment that are not limited to responses to questions, but also how they manipulated virtual or real objects, for how long, and even facial expressions.

We recommend that funding organizations conduct research into how various 'standards of learning' can be represented and standardized.

### 3.5 Advanced learning modelling

We recommend funding organizations to invest in research that will facilitate a widely used and highly flexible approach to learner modelling that will evolve to a global standard. We envision that for a learning component to be effective in assembling itself to deliver the optimal learning experience for a learner, the model of the user will be complex, including not only a representation of what the learner knows, can do and has abilities in, but other factors too. For instance, it will also track when and how these were learned and what pedagogy worked best for this learner. Moreover, the advanced user modelling will include information on the cultural preferences of the learner, their personal interests, their learning goals, and their personal characteristics, in order to be able to select the optimal mix of learning environments, pedagogy, visualizations, and contexts to maximize engagement, motivation and learning outcomes for that individual. When the learner is part of a group, the advanced learner model will be used in a similar way to create a learning environment that is the best compromise among the individuals that are part of the group as a whole.

### 3.6 Machine learning / Data mining

We recommend that research is conducted on machine learning and data mining, and develop algorithms that are particularly adapted to the educational domain and the unique characteristics of educational data. As systems will be integrated in all sorts of situations, vast amounts of data will become available and be collected. Research therefore is required in understanding how to effectively store, make available and analyse the data for different purposes and stakeholders including the self-improvement and evaluation of learning components.

### 3.7 Sensors / vision / object recognition / Augmented manipulatives

We recommend that funding agencies support research to develop innovative interfaces that allow learners to move seamlessly between real and virtual environments. We also recommend that the funding agencies support research to investigate when it is best to use such virtual learning environments for learning.

An active learning component will accommodate full sensory input into any optimized learning environment. This environment could be augmented reality in which sensors, object recognition, and augmented manipulatives are used to create the most optimized learning environment. For example, students doing an ecology project at a wetland near their school would be able to use virtual lab equipment to take and analyze water and soil samples all projected into their augmented reality and all used in the context of their ecological analysis. In general a whole series of basic problems in computer vision need to be addressed in order to arrive being able to do such scenarios.

### 3.8 Multi-media/modal explanations & Flexible argumentation and communication

We recommend that research be conducted to contribute to the understanding of the necessary multimedia and multimodal interfaces, and to the knowledge of how to design environments for flexible argumentation and communication styles. Technological advancements are required in the field of vision, object and drawing recognition, and in diagrammatic reasoning to have semantically aware and operationalised representations.

### 3.9 Advancements in knowledge representation

A standardized approach to the representation of knowledge needs to be developed in order to build the quality and quantity of Active Learning Components (ALCs) required. Such a representation will accommodate low-level knowledge and skills as well as complex and meta-cognitive tasks and skills. This representation of knowledge becomes the framework that multiple systems can use to build their ALCs. While it may be hard for educators within and between countries to agree on standard descriptions for complex knowledge and skills, the system should map between them to assist in recognizing similarities.

### 3.10 Pedagogy

We recommend research be initiated to advance the understanding of effective pedagogical approaches and in their detailed operationalisation according to different styles, needs and characteristics of different learners.