i-TUTOR

Intelligent Tutoring Systems: an Overview

Lifelong Learning

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...Abstract...

1. Intelligent Tutoring System: a short History and New Challenges

The evolution of ITS is the product of the researches that move from the border territory between the education field and the artificial intelligence and its progress marks the relation between the educational research and the research on educational technologies, since ITS is not only the most advanced peak of that relation, but also the most significant modelling.

In the last sixty years didactics and knowledge technologies have worked on similar topics, but not always with an effective dialogue and with a co-disciplinary process. We think the last researches show new and interesting synergies.

The chapter underlines the last thirty years: from the classical models (as ANDES) to last proposals.

Recently (2011-2013), the interest of the community moves from the disciplinary domains to didactic strategies that can be transversal and support the educational action. A sample is the attention to ill-defined domain. We don't deal with different domains, but with different tasks and mostly with a different knowledge model in which the objective world and the subjective action (cognitive and practical) interweave and interact determining auto-poietic processes.

We propose a further observation that emerges from the proposed topics in the last meetings of ITS and AIED and that will become more and more central. The ITS has to foster the awareness of the student in action, but also the regulation of the teacher in the didactic action.

The perspective is to add to a single-use ITS – located in specific disciplinary domains and based on one to one relation – environments with software agents, based on the centrality of the group class, that supports both the student in the learning process and mainly in the reflection, and the teacher in the monitoring process, assessment and representation of the built knowledge, an environment which offers to the teacher a tool box with plenty of strategies among which to choose.

2. Cognitive Models and their Application in Intelligent Tutoring Systems

The chapter reports an overview of the main ITSs in the literature from an AI biased perspective. The main goal is to point out the analogies in such systems when they are regarded as instances of some cognitive model. The chapter will introduce the main cognitive architectures in the literature. Then a general cognitive architecture will be described as as the underlying model for all the presented ITSs. Such a model is more abstract than existing ones, and focuses on a symbolic view of their features: it will be described as a set of AI based components. The presented ITSs will be regarded as instances of the general cognitive model.

3. Data Mining in Education

Mining data in educational settings has the potential to offer significant support to: students, teachers, tutors, authors, developers, researchers, and the education and training institutions in which they work and study. Recent developments in the emerging discipline of educational data mining are very promising. In this chapter, a short literature review summarises and classifies potentials and constraints in the use of data mining in education, focusing on the main topics that should be considered for future research.

4. User Profiling in Intelligent Tutoring Systems

One of the most important characteristic of e-learning systems is that of being personalized, in order to fit the needs of a variety of students with different backgrounds and skills. Over the last twenty years there has been several research to design and test the most effective way to build user's profiles in order to customize online learning environments and to achieve a better motivation of the students. Researchers analysed the level of knowledge and skill possessed by the students in a specific domain, but also their behaviour and characteristic while participating in online courses. Some research try to identify the learning style of the students, while others focus on "personal predispositions" related to memory, understanding and content associations. During the last ten years new aspects emerged, like psychological aspects and affective states, focused on the types of emotion involved in the learning process.

In this chapter, a literature review is presented, in order to summarises directions and research paths in the use of user-profiling, trying to define the main topics that should be considered in future research.

5. The Role of Instructional Design and Learning Design in Intelligent Tutoring Systems - A Review

From the early years of the systematic use of Instructional design, educational scientists wanted to use the results of artificial intelligence to support authors, developers, researchers, in their pedagogical work to create "automatic" course designing machines or make the built in process more and more responsive and adaptive to the tuition circumstances, therefore design a more intelligent training material. The last thirty years' developments in this discipline are still in an emerging phase. The problem of not knowing how we learn, and the limitation to theoretically describe any learning content, leads us to particular solutions for particular problems. In this chapter, a short literature review summarises potentials and constraints in the instructional design field of education, focusing on the main topics that should be considered in future research.

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Intelligent Tutoring Systems (ITS): a European point of view

Introduction

The project I-TUTOR seeks to develop an intelligent tutoring system to be applied in online education to monitor, track, record behaviours, and to perform formative assessment and feedback loop to students to foster a professional and reflective approach. This will allow online teachers/trainers/tutors to better individualize learning paths and to enhance quality of Education and Training.

The I-TUTOR (Intelligent Tutoring for Lifelong Learning) project started in January 2012 with the aim of developing a multi-agent based intelligent system to support online teachers, trainers and tutors.

1. Why I-TUTOR?

Tutoring in distance education plays a crucial role in ensuring support and facilitate learning of students. Tasks carried out by tutors ensuring individualized paths and effective learning are often very time consuming; at least online educators have to:

- monitor, track and assess what the student does within the learning environment (i.e. pages and documents consulted/downloaded);
- analyze students' writings;

- manage knowledge sources by, for instance, building representations of knowledge through conceptual maps or taxonomies;
- watch the network of formal and non-formal relationships as it develops within the class, fosters its strengthening and supports the inclusion of all individuals;
- give formative evaluation and feedback.

The above mentioned activities lead to the effective planning of learning paths, and aim at student-centered, individualized learning. Considering the numbers of students involved in (full or blended) distance learning, the possibility to fully perform the activities needed to follow the students and therefore planning accordingly is put at risk by the load of work necessary for each student.

ICT can further support online teachers, trainers and tutors, by means of a multi-agent based, intelligent tutoring system pursuing the goal of monitoring, tracking, assessing students, giving formative feedbacks and useful data to better individualize learning paths.

During the last twenty years ITS showed their effectiveness in supporting learning and knowledge construction. Their structure changed, starting from the first ITS, strongly based on disciplinary domains, to different research path, as ill-defined domains. This new trend emerged in the last five years and showed a major attention on pedagogical and didactical aspects, with a stronger integration with LMS.

Despite the documented advantages derived from the research in ITS use, their didactical adoption is not widespread especially in Europe. How can we explain this lack of dissemination? Which possible development in order to reach a better integration between ICT and education?

Which is the direction to follow, especially in the European context, in order to allow the enormous advances in new technologies, in particular in the field of software agents, to become an enjoyable contribution in education and to develop a dialogue between educational research and research on new technologies? Such a dialogue could close the gap between a cognitive approach (often present in technological research), based on a deterministic vision of the relationship between teaching and learning, and a different approach, focused on open activities, authentic reflection and awareness in learning (typical of educational research).

The first phase of the project presents a literature review on the ITS sector, summarized in the five chapters of this e-book.

2. E-book structure

The first chapter provides an historical excursus and a description of the ITS, from a pedagogical and didactical point of view. Starting from the first domains-centered ITS, to arrive to the ill-structured domains ITS, and finally to reach the actual solutions. In these new solutions, a shift can be seen from ITS that supports one to one learning and interaction to system for collaborative and social learning, from ITS for learning in tightly defined domains and educational contexts to open-ended learning in ill-defined domains across varied physical and social cultural settings and throughout the lifetime, from ITS to support knowledge acquisition to systems for knowledge construction, skills acquisition and reflexive, motivational and affective support, leaving a psychological approach to reach a more pedagogical approach.

Actually, research is increasingly focusing on accessible, ubiquitous, wireless, mobile, tangible and distributed interfaces. The final aim is to develop systems that could be used widespread and on a large scale.

The second chapter analyses Cognitive Modeling and the classic modeling used by informatics designers in the ITS construction.

The third chapter, data mining in education, examines potentials and constraints in the use of data mining in education, summarizing the potential they have to offer meaningful support to: students, teachers, tutors, authors, developers, researchers, and the education and training institutions in which they work and study.

In the fourth chapter a literature review is presented, in order to summarise directions and research paths in the use of user-profiling, trying to define the main topics that should be considered in future research.

Finally, the fifth chapter analyses the basic elements of Instructional Design and the perspectives of the ITS research, dealing with the issue of educational design software. This kind of software allows teachers, even if they are not experts in informatics but only in technology of education, to design their didactic path with the support of software agents.

1. Intelligent Tutoring Systems: a short History and New Challenges

Pier Giuseppe Rossi ◖ Laura Fedeli

Introduction

The evolution of ITS is the product of the researches that move from the border territory between the education field and the artificial intelligence and its progress marks the relation between the educational research and the research on educational technologies, since ITS is not only the most advanced peak of that relation, but also the most significant modelling. In the creation of ITS the didactic knowledge is reified. To introduce ITS is, thus, necessary to analyse the interaction between education and technologies. Also the technological artefacts have always been present in the educational context, our focus will be the last sixty years.

In the last sixty years didactics and knowledge technologies have worked on similar topics, but not always with an effective dialogue and with a co-disciplinary[1] [1] process. Besides the positive or negative value, that will be considered later in the contribution, the interest in engineering the educational process was a need in the pedagogical field, in the stakeholder field and in the technological one, highlighting processes and problems that otherwise wouldn't be clarified.

The modalities with which the two sectors faced each other present different solutions, also related to the models and according to the scientific communities.

In the ITS construction pedagogical models and technological ones compare each other. It's necessary to take into account that each pedagogical model implies a technological model, in the same way each technological

model includes pedagogical aspects. In other words it's not possible to instrumentally connect a pedagogical model to a technological one. So the engineering itself is not unaffected by the educational models, but connected to a specific one. Without this premise it was taken for granted that a technological model, from a positivistic perspective, was something to accept as if it didn't have a pedagogical reflex in the applications. In the educational field the epistemic value of the technological models has not been grasped since educators' attitude was characterized by an instrumental approach to technologies.

The underestimation of the interactions between the two fields has produced processes that are not co-disciplinary in which either technologist were in charge of the ITS execution or the technologies were considered mere tools.

1. The history of the relation in between education and technologies

The Fifties start with Skinner and the design of the teaching machine. In the same years the first experimentations begin in which prevails a behaviourism approach. In the Sixties the behaviourist approach evolves towards the cognitive approach and Simon, who can be considered the father of the classical Artificial Intelligence (AI), started a movement whose work moved from the hypothesis that the human brain and the computer had a common functional description. Hereof a strong synergy between cognitivism in education and technological research was born. The cognitivist model facilitated the engineering process. Such a factor has surely fostered the permanence of the cognitivist models in the sector of the technological research, producing a division between most studied trajectories in the International technological research compared with the ones that addressed wide sectors of the education field from the middle of Eighties.

In different sectors of the educational field, in fact, that decades marks a strong interest for the situated approach [2] [3] and the constructivist approach [4]. It's worth noting that two authors that at the end of the Eighties had worked in the sector of AI became afterwards the paladins of a new learning model: Wenger [5] and Brown who has coined the word ITS [6]. But this shows also the importance of the experimentation in the sector of the engineering of the education for the comprehension of didactic models and strategies.

The firm contrast between cognitivists and constructivists in the sector of technologies continues, a contrast that characterized the educational field in the Nineties. Also in relation to ITS the goals of the technologies in the constructivist educational action were different from the ones with which the cognitivist and the most of technologists worked. In the cognitivist approach the ITS is valuable because it allows a tailored education (fostered by the direct interaction between the student and the computer typical of CAI)[2]. Many papers underline how the use of ITS provides better results and that improvement depends on the individualization[3] [9] [10] [11] [12]. From a constructivist perspective knowledge is a social process and the interest for technologies is primarily based on the chance to offer an environment in which the student can act [4] and to foster the typical CMC (and thus the group class who learn) and the social construction of knowledge.

Cognitivists believe that the domain ontology and the meta-cognition models let the teacher foresee and guide the educational process and the structure of the ITS direct towards the solution expected by the teacher. Constructivists see the technological environment as a space-time concept in which actors, supported by communication and the research potentialities provided by technologies, produce knowledge finding unexpected solutions to problematic open-ended situations.

From the beginning of the millennium the atmosphere changes. This situation is not much due to the possibility to find common elements in the diversity landscape as stated by different authors [13], [14], but is due to a paradigmatic leap.

Both approaches highlight some limitations, that come from an exaggerated focus on psychology of education and on learning. From 2000 the interest moves towards the interaction of the teaching-learning processes.

Constructivism is criticized for the necessity to take back the disciplinary knowledge (not everything can be built) and for the impossibility to avoid unwanted results in knowledge construction [47], [48], [21], [25], [26].

Already in the Eighties Shulman [15] had highlighted the importance of the teacher's thinking. From the beginning of the new millennium the attention has moved to the teachers practices and on the non-deterministic connection between teaching and learning [16], [17], [18], [19], [20], [21].

Moreover, thanks to the contribution of the neurosciences [23] [24] and specifically the mirror neurons discovery, the enactivist approach gains strength [25] [26] [27] [28]. Such an approach inverts the Cartesian approach that showed a division between *res cogitans* and *res extensa* to gain a complex vision that is based on the continuity mind-body-artefact-world and

reappraises the role of technologies in the didactics. At the same time such approach discusses the paradigm by Simon, that is the linear process that from the information passes to an elaboration that bring to decision and, finally, to action. A new emerging vision was born in which decision and knowledge are two recursive processes interacting in the action [29], [30], [31], [32], [33]. The overcoming of a computational vision requires a new thinking of ITS themselves because artificial intelligence is not seen as a model of the human intelligence.

Conati synthesizes in this way the new perspectives recently opened in the sector of ITS:

> Other new forms of intelligent computer-based tutoring that have been actively investigated include, among others: support for collaborative learning (e.g. [129]); emotionally intelligent tutors that take into account both student learning and affect when deciding how to act (e.g. [130], [131]); teachable agents that can help students learn by acting as peers that students can tutor (e.g. [132]); intelligent support for learning from educational games (e.g. [133], [134]); and intelligent tutoring for ill-defined domains (e.g. [135])" [7].

Topics commonly addressed by cognitivists and constructivists are examined such as the collaborative learning, games, interaction and aspects covered by enactivism such as the role of feelings in the decision process and the educational games. Finally, the interest for the ill-defined problems arises and moves the attention firmly to new horizons, as we will see later.

Having substantially overcome the old schematic, the new paradigm opens research territories whose researchers within the two areas, educational and technological, can create interaction spaces and possible synergies, and open a dialogue that, hopefully, can bring to solutions mostly co-disciplinary.

The interest for a better synergy between the two sectors shows different examples: the special issue of *Educational Technology & Society* of the 2005, the publication of BJET in the spring of 2006, titled *Advances of the Semantic Web for e-learning: expanding learning frontiers*; the first number of March 2009 of IEEE *Transactions on Learning Technologies*, dedicated to the personalization in e-learning; the number 200 of *Frontiers in Artificial Intelligence and Applications* dedicated to the applications in education of artificial intelligence. Next to those publications , all focused on the exploration of the synergies among e-learning, artificial intelligence, and *semantic web*, it's necessary to remember the conferences promoted by *Artificial Intelligence in Education* (AIED), *Intelligent Tutoring Systems* (ITS). From 2008, *User Modelling* (UM)

and *Adaptive Hypermedia* (AH) have focused the attention on the topic of personalization in education, AAAI has organized, within its conferences, symposium on the problems of education, *American AACE ED-MEDIA, E-Learn conferences* e *European EC-TEL conference Technology-enhanced learning* cooperate on the current topics related to education and technologies.

2. Historical overview of ITS

2.1 What is an ITS?

Some classical definitions are the ones provided by Conati:

> Intelligent Tutoring Systems (ITS) is the interdisciplinary field that investigates how to devise educational systems that provide instruction tailored to the needs of individual learners, as many good teachers do. Research in this field has successfully delivered techniques and systems that provide adaptive support for student problem solving in a variety of domains. There are, however, other educational activities that can benefit from individualized computer-based support, such as studying examples, exploring interactive simulations and playing educational games. Providing individualized support for these activities poses unique challenges, because it requires an ITS that can model and adapt to student behaviours, skills and mental states often not as structured and well-defined as those involved in traditional problem solving. This paper presents a variety of projects that illustrate some of these challenges, our proposed solutions, and future opportunities [7].

And by Graesser who defines an ITS as:

> Intelligent Tutoring Systems (ITS) are computerized learning environments that incorporate computational models in the cognitive sciences, learning sciences, computational linguistics, artificial intelligence, mathematics, and other fields that develop intelligent systems that are well-specified computationally [34].

ITS can be addressed as the initiative to apply AI to education and instructional design. The acronym "ITS" [35] replaced the widely known phrase "Intelligent Computer-Aided Instruction" (ICAI) which has been used for several years with the same intent.

Artefacts in the field of ITS and ITS authoring tools dates back to the early 1970s. At its early stages ITS received a strong input from the mutual need of AI and of the educational system to find successful applications that could demonstrate the power of ICAI by improving instruction in the provision of "effective tutoring for every student, tailored to her needs and pace of learning" [36, 3].

The key word "architecture" can be identified to introduce ITS and its development along the decades from the Seventies to nowadays covering three major steps (1970-1990; 1990-2008; 2008-today) [36] that can be associated with a different perspective on the components of the ITS architecture and, thus, generating each its own philosophy or paradigm.

ITS evolved from CAI "linear programs" proposed by Skinner and that were based on the principle of operant conditioning, that is guiding the student step by step to reach a specified behaviour through "frames". That procedure could neither offer a targeted feedback nor an individualized support [37]. Linear programs were followed by the so called "branching programs" which were able to sequence frames according to the student response and, thus, could overcome the limitation of the linear programs and open the way, in the late Sixties and early Seventies, to the "generative systems". Those systems, on one hand, were able to create and solve meaningful problems, on the other hand, were limited to "drill-type exercises in domains as well-structured as mathematics" [37, 256].

Hence the need expressed by Carbonnel of

> a system which had a database of knowledge about a subject matter and general information about language and principles of tutorial instruction. The system could then pursue a natural language dialogue with a student, sometimes following the student's initiative, sometimes taking its own initiative, but always generating its statements and responses in a natural way [id.]

SCHOLAR can be considered the first attempt to create an ITS, a pioneering project by Carbonnel with a representation of what Self had addressed as "*what* is being taught, *who* is being taught and *how* to teach him/her" [id.].

This takes to the three-model architecture consisting in the expert knowledge module, the student model module, the tutoring module.

From the three-model architecture (addressed in Chapter 2) ITS passes to the four-model opening the way, in the last years, to a new-generation of

architectures based on different paradigms such as the learning perspective by Self [38] which implies a revised three-model architecture (situation, interaction and affordance).

The traditional architecture presents three main components: student, tutor and domain [164]. The four-model consists in the addition of the "user interface" as a fourth component [39] and represents the standard for ITS construction also in authoring tools which have been produced to help instructional designers and teachers with no programming skills to develop ITS in the educational field.

It's necessary to underline that a great number of researches has highlighted as the use of ITS can improve the results of learning[4]. Of course it would be necessary to clarify what we mean as "better results" and how they can be assessed. But this reflection goes beyond the aim of this publication.

2.2 Some examples

Some examples of mostly used ITS are offered using the selection proposed by the paper: Intelligent Tutors: Past, Present and Future [51].

2.2.1 ANDES (Physics) [9w]

Personalized help on 500 online physics homework problems. Effect sizes: 0.52 (non-science students); 0.223 (engineers). 1.21 (using diagrams); 0.69 (using variables). 9.8 -12.9% increase in grades on hour-long exams, p= 0.0001-0.03. Replaces grading homework; manipulated only the way students do their homework. Implementing subsequent mathematics courses.

ANDES[5] deserves a specific discussion since it is often presented as the ancestor of the new generation ITS. It was born from the researches by Kurt VanLehn, the father of the last decade ITS. Already from the start of the Nineties he had deepened the topic in the didactics of Physics and connected the study on AI to the ones on knowledge [90], [91], [92], [93]. The first creation of a prototype of ANDES dates back the years '97 and '98 [94] to reach in 2000 a mature development [96], [97], [98], [99], [100]. It continues evolving and it is still used in schools of various American countries by a high number of students.

2.2.2 Cognitive tutor (Algebra)

Adaptive scaffolding on algebra problems. More than 500,000 students per year, middle and high schools. Effect sizes: 1.2 and 0.7.on experimenter-designed tests; 0.3 on standardized tests. 25% more students pass state standardized exams; 70% greater likelihood of courses.

2.2.3 Wayang (Mathematics)

Adaptive help and multimedia for 300 math problems. More than 3,000 middle and high school students. Evaluations measures impact of support, problem difficulty and digital character on student performance. 10-16% more students pass state exams. Increased confidence and reduced frustration. System infers student emotion with 86.36% agreement with what students report.

2.2.4 Project Listen (Reading)

Student reads passages aloud; system identifies words in context. More than 3,000 students. Effect sizes range up to 1.3; 0.63 for passage comprehension. Differences in oral reading fluency (words read correctly per minute). Students outgained control group in word comprehension (e.g., effect sizes of 0.56), passage comprehension, phonemic awareness, word identification, passage comprehension, and spelling.

2.2.5 ASSISTments (Mathematics)

61,233 homework questions plus feedback. Randomized controlled tests; log data. 1500 users every day. In sum, 7500 students and 100 teachers, spanning 25 districts in Massachusetts and 12 districts in Maine. Effect size of 0.6. Students improve half a standard deviation.

2.2.6 Crystal Island (Microbiology)

Intelligent 3D game-based environments. 1450 students in grades 5 and 8. Significant learning gains (about 2-2.5 question increase). Student learning and problem solving performance predicted by presence questionnaire. Games motivate inquiry-based science learning with pedagogical agents; students use systems for a single, one-hour session; not yet part of everyday classrooms.

2.2.7 BILAT, Interview, A Military Simulation

Institute of Creative Technology, University of Southern California. Contains: Domain Knowledge; how to improve market, local law enforcement, maintain power grid, etc. Student Model Performance, skills, Communication Knowledge Computer graphics, gaming technology, 40,000 lines of dialogue for virtual characters.

2.2.8 Helicopter PilotUS Army and ARI, StottlerHenke

Motivation: Most flight simulations require the presence of a human trainer; An adaptive tutor is needed to reason about the pilot and solution. Solution: The student model considers the pilot's performance history, past training, patterns of performance, personality traits and learning style The system diagnoses student errors and provides appropriate feedback It encodes instructional goals, instructional planning and agents.

Motivation: Tactical skills cannot be taught as methods or procedures Trainees need extensive practice and to prioritize goals Solution: System provides a variety of tactical situations (ARI vignettes) along with Socratic questioning, hints and feedback System evaluates each student's reasoning by comparing solutions and rationale with that of expert response.

2.2.9 Tactical Action Officer

US Navy, StottlerHenke. Motivation: Tactical training typically requires 1 instructor per 2 trainees. Team members evaluate, coach and debrief other trainees The goal is to reduce the number of instructors needed. Solution: Computer agent plays team member allowing students to practice concepts and principles.

Speech-enabled graphic user interface supports dialogue; Soldiers converse with simulated team member to issue commands Automatic evaluation of trainee; System infers tactical principles used by students.

2.2.10 Blitz Game Studio's Triage Trainer

Controlled trials in UK found Triage Trainer "to be statistically significantly better at developing accuracy in prioritizing casualties and in supporting students to follow the correct protocol to make their decision" (TruSim website).

2.3 What knowledge models to build the ITS?

There are three traditional approaches for representing and reasoning on domain.

Two types of cognitive models used frequently in ITS are **rule-based models** [51], [76], [61], [84] and **constraint-based models** [131]. The third approach for representing and reasoning on domain knowledge consists of integrating an **expert system** in an ITS [43], [44], [45], [46].

2.3.1 Rule-based model

The rule-based (RB) model is set on rules that should be followed by the student step by step during the development of the problem. Each action receive a feedback according to the correct modality/ies to execute the task itself, modalities that must be all foreseen, in the same way possible errors must be foreseen. The model, thus, is used in the solution of problems that can be structured in well defined steps provided that those steps let also solutions easily identifiable and verifiable.

The rule-based models [51], [76], [61], [84] are generally built from cognitive task analysis.

"The process of cognitive task analysis consists of producing effective problem spaces or task models by observing expert and novice users [140] using different solving problems strategies. A task model can be designed for a problem or a problem set. Task models are usually represented as sets of production rules (sometimes structured as a goal decomposition tree [172] or as state spaces in which each rule or transition corresponds to an action or an operation to perform a task. Some of the rules/transitions can be tagged as "buggy" or annotated with hints or other didactic information" [36, 85].

Many ITS are built following this model and would be impossible to list them all: from the classical ANDES to teach Physics in higher education courses to Cognitive Tutors, a Geometry Cognitive Tutor.

The Model-tracing tutor (MT) [56] is connected to the RB model. Some example are Cognitive tutors [105] "which encode the operations for solving a problem as a set of production rules. When a learner performs a task with a cognitive tutor, the latter follows the learner's reasoning by analyzing the rules being applied. This process is called model-tracing. The MT paradigm is beneficial because the reasoning processes of the learner can be represented in great detail (in fact, authors of cognitive tutors claim to model the cognitive processes of the learner), and the models obtained can support a wide

variety of tutoring services, such as: (1) suggesting to the learner the next steps to take, (2) giving demonstrations; (3) evaluating the knowledge that the learner possesses in terms of the skills that are applied; and (4) inferring learner goals.

Model-tracing tutors are recommended for tasks in which the goal is to evaluate the reasoning process rather than simply determining if the learner attained the correct solution. MT-Tutors generally assume that the starting and ending points of a problem are definite" [36, 86].

What problems can be encountered with the MT? "The main limitation of model-tracing with respect to ill-defined domains is that, for some domains, there are no clear strategies for finding solutions, and it can therefore be difficult to define an explicit task model. Moreover, for complex domains, one would need to determine a large number of rules and solution paths, and designing a set of rules or a state space for a task would be very time-consuming" [id.].

Particularly interesting is the Cognitive Tutor Authoring Tool. It's an authoring tool that allows the construction of the ITS tracking the activity of the teacher that makes the path and the possible ways, also the wrong ones that students can follow. According to Aleven such a tool facilitates the construction of an ITS because it requires low technological competencies and reducing the time spent in the design it reduces the costs [40], [114].

2.3.2 Constraint-based model

A second model is the constraint-based modelling (CBM), object of Mitrovic's studies [67].

"Whereas rule-based models capture the knowledge involved in generating solutions step-by-step, constraint-based models express the requirements that all solutions should satisfy" [36, 34].

In other words while the RB model analyses the path monitoring it step by step, the CB model analyses the obtained results, also in itinere, and check that the constraints are being respected.

The constraint-based modelling (CBM) approach [41] [42] is based on the hypothesis of Stellan Ohlsson which were proposed in 1992, specifically on the distinction between procedural knowledge and declarative one, typical of the cognitivist approach.

"It consists of specifying sets of constraints on what is a correct behaviour or solution rather than to provide an explicit task model. When the learner violates a constraint during a task, the CBM Tutor diagnoses that an error has

been made and provides help to the learner regarding the violated constraint" [36, 86].

"The fundamental observation CBM is based on is that all correct solutions (to any problems) share the same feature – they do not violate any domain principles. Therefore, instead of representing both correct and incorrect space, it is enough to represent the correct space by capturing domain principles in order to identify mistakes. Any solution (or action) that violates one or more domain principles is incorrect, and the tutoring system can react by advising the student on the mistake even without being able to replicate it.

CBM represents the solution space in terms of abstractions. All solutions states that require the same reaction from the tutor (such as feedback) are grouped in an equivalence class, which corresponds to one constraint. Therefore, an equivalence class represents all solutions that warrant the same instructional action. The advantage of this approach is in its modularity; rather than looking for a specific way of solving the problem (correct or incorrect), each constraint focus on one small part of the domain, which needs to be satisfied by the student's solution in order to be correct. An important assumption is that the actual sequence of actions the student took is not crucial for being able to diagnose mistakes: it is enough to observe the current state of the solution" [36, 64].

In synthesis the CBM approach works on the products, also the intermediate ones, and defines results and acceptable behaviours. It was born to overcome some difficulties present in the model tracking mostly connected to the difficulties that can be met in the construction of the ITS foreseeing all the possible ways and errors (RB) in too complex systems.

2.3.3 Expert model

"The third approach for representing and reasoning on domain knowledge consists of integrating an expert system in an ITS [43], [44], [45], [46]" [36, 87].

An expert system is a system that emulates the decision ability of an expert. Expert models solve problems simulating the operative modalities of a human expert and his skill in modelling and facing a problem, the modalities with which variables are chosen and connect different elements that the real situation presents. The expert uses a rationale that is more similar to the Aristotelian phronesis rather than to a disciplinary rationale.

How is it used in the ITS? Fournier-Viger et al. [36] show two modalities. "First, an expert system can be used to generate expert solutions. The ITS can

then compare these solutions with learner solutions" [**36**, 87]. They provide the example of GUIDON [**43**]), that is based on knowledge base of MYCIN that contains more than 500 rules built with the knowledge of practitioners. "The second principal means for using an expert system in an ITS is to compare ideal solutions with learner solutions [**43**], [**44**]" [**36**, 87]. Some examples are Auto-tutor [**44**], and DesignFirst-ITS [**46**].

What are the limitations of an expert system approach? Fourire-Viger (et al.) sees the following limitations: "(1) developing or adapting an expert system can be costly and difficult, especially for ill-defined domains; and (2) some expert systems cannot justify their inferences, or provide explanations that are appropriate for learning" [**36**, 88].

3. The debate after the 2000

3.1 The crisis of cognitivism and constructivism

As mentioned above, since the beginning of the new millennium both cognitive and constructivist approach show some limitations.

In the cognitive field we can observe how in many cases ITS:

- do not take account of the emotional aspects;
- are suitable for limited categories of problems (well-defined);
- promote the acquisition of basic skills, but not complex skills;
- are functional to support students who already know how to ask the questions, or to students already prepared.

The effects of the innovation that is breathed since 2000 for ITS concern certainly a greater interest in emotional aspects[6], for natural language dialogue [**118**][**119**], for teaching strategies[7] and cross-cutting skills[8], also a greater interest in technologies, to do engineering in education and especially to explore the field of ill-defined task/domain.

There are so many ITS-related researches taking into account emotional aspects that it is impossible to list them all[9]. The general reference is the study of the emotional intelligence Goleman [**68**]. Researchers are reported that have adopted systems for the analysis of eye-tracking [**76**] and facial movements and should be noted that the central theme of the Conference 2011 AIED was "Next Generation Learning Environments: Supporting Cognitive, Metacognitive, Social and Affective Aspects of Learning".

Towards a flexible approach involved in open-ended problems, Self [52] had already expressed many years earlier. "Self's architecture with a focus on a learning situation as opposed to a domain model opens to the design and use of ITS for ill-structured problems, that is providing a setting in which" multiple processes can be used to reach a solution, and no one solution is considered the "correct" one, even though the general properties of an adequate solution may be known". Since the year 2000, the suggestions of Self have been combined with researches in the educational field that already in previous years had enhanced the authentic problems [54] and also institutional invitations like those of EC about competences [55].

But it goes step by step. Johnson noticed some problems regarding ITS [50] often found in the dynamic student-agent; he considers that they result from a lack of social intelligence of the synthetic agent, therefore defining behaviours such as:

- criticize the same mistakes over again.
- stop the student's activities even after negligible errors;
- make student perceive negative emotions to the own actions;
- do not respect the work of the student;
- fail to offer encouragement, when the student would need.
- failing to provide help when the student is confused and unfulfilled (2003).

A second problem emerges from research of Graesser [53]. They showed that the *feedback* relevance is related to the accuracy of the questions and, about it, two types of problems may arise: on the one hand, there may be generic responses generated by vague questions, given to students who would need a specific orientation, on the other, there may be obvious responses provided to students who, instead, would need greater examination depth (Figure 1).

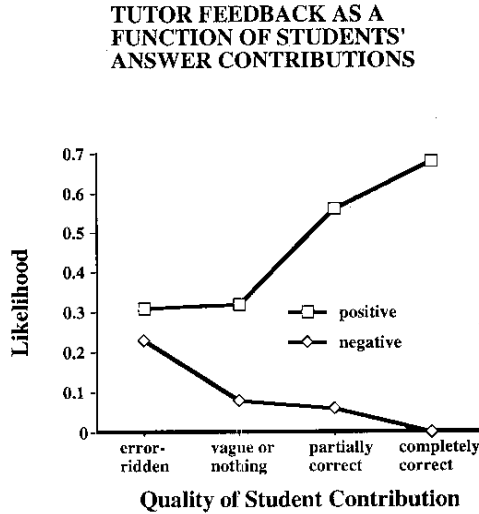**TUTOR FEEDBACK AS A FUNCTION OF STUDENTS' ANSWER CONTRIBUTIONS**

Figure 1 - Relationship between accuracy and clarity of feedback question (Graesser, 1995)

Several solutions have been taken to overcome these problems, such as giving the student the chance to activate or not the tutor in certain phases and to avoid dialogues on topics that are considered acquired, or offering two levels of support identified as the first, the most basic level, in the figure of a tutor or a peer expert, as the second in the figure of a mentor or a teacher. Is then the student to decide which of the tutors turn question depending on his needs and awareness of own preparation.

3.2 The production costs

There is also another problem that maybe has a greater impact than the previous and that connects to sustainability.
    Realizing an ITS requires for each hour of product, some hundreds of hours of production.

It has been estimated, based on the experience in real-world projects, that it takes about 200-300 hours of highly skilled labour to produce one hour of instruction with an ITS [136], [137]. Some approaches to

building ITS, such as example tracing tutors [139] and constraint-based tutors [138], improve upon these development times. Rule-based systems, too, have become easier to build due to improved authoring tools [40] and remain a popular option [141]. Nonetheless, building tutors remains a significant undertaking. In creating tutors with rule-based cognitive models, a significant amount of development time is devoted to creating the model itself. It may come as no surprise that ITS developers carefully engineer models so as to reduce development time. Further, being real-world software systems, ITS must heed such software engineering considerations as modularity, ease of maintenance, and scalability. Thus, the models built for real-world ITS reflect engineering concerns, not just flexibility and cognitive fidelity. Sometimes, these aspects can go hand in hand, but at other times, they conflict and must be traded off against each other, especially when creating large-scale systems [36, 35].

Similar is the analysis that had already made Merrill in the early 90's about the ID[10].

The main point is that the development time estimates should be treated as rough estimates. As our baseline, we use development time estimates reported in the literature, which for ITSs range from 200:1 [137] to 300:1 [136]. The historical development time estimates for the successful Algebra and Geometry Cognitive Tutors (see, e.g., [140]) are in line with these estimates. A rough estimate puts the development time for these two Cognitive Tutors at 200 hours for each hour of instruction. It is important to note that these tutors pre-date CTAT". As mentioned previously they were in fact an important source of inspiration for CTAT [56].

Another attempt to decrease costs was the experimentation carried out by VanLehn to probe the possibility to use the structure of an ITS designed for Physics in another domain (the Statistics). Not a few are the difficulties that arise from the fact that ITS is based on a disciplinary domain [57] [58].

The production costs previously indicated make it prohibitive to construct an ITS in situations where the same cannot be used on a wide scale. Not by chance that the most frequent uses of ITS occur in basic courses common to multiple addresses, offered almost identical in different years, and in military training.

It should also be noted that in addition to the costs exists a time to allow the realization of ITS i.e. the time needed to design and implement the same. Very often in University courses, every year re-designed, the teacher dedicates one week (one month at most) from the beginning of course preparation and

course delivery. Also, work in progress, he continues ongoing adjustments in response to the class context.

To justify these costs of production should be provided that each artefact is used by a large population and for a long time. Not surprisingly the most cared for ITS are in English language and are valid for the basic disciplines for the years-bridge at the end of high schools. ANDES (for basic physics) now used by more than 500,000 students as well as Cognitive tutor (for basic algebra) justify these investments.

4. Well/Ill-defined domain and problem

4.1 Well and ill defined

The previous considerations can support another solution that is present in ITS context since the beginning of the new millennium and that is already partly anticipated.

Most part of the authors agree in pointing out how ITS made during the Nineties are applicable to well-defined domains and that the problems posed have a reliable solution, independent from the individual who solves them.

But there is another category: that of ill-defined or ill-structured domains. In this category there are several acceptable solutions, the solving processes may be different, the domains themselves do not always allow a well-defined ontology, accepted unanimously by the community.

These domains are law, design, history and medical diagnosis, that is especially the field of human sciences, a field where the context can play an important role and where many of the "certainties" are based on conventions and not on natural laws.

A first clarification: do we need to talk about ill-defined domains or ill-defined problems? It is not easy to answer in a precise way. There are ill-defined domains but often even within well-defined domains there are ill-defined areas. Sometimes a mature science is well-defined, while a territory of exploration is ill-defined. Moreover an ill-defined problem is, for example, the design for the construction of a new artefact; in the same way are ill-defined tasks processes where not all the variables are initially defined, but they are defined in relations with the design choices. Even in well-defined domains (for example the mechanical and specific areas of engineering) design requires creative processes whose modelling as well-defined process is an ideal approximation that does not correspond to the real process of the

designers. See in this direction the twenty years research of J. Gero [102], [103], [62]. Indeed the controversy between ill-defined task and ill-defined domain does not seem to be so obvious. If Mitrovic supports the possibility to build four categories of situations crossing ill and well, domain and task [66], other authors, including Fournier, consider that it is necessary to focus the attention on the task [36, 83], while Aleven chooses the "'domain' in order to emphasize that is the end goal of tutoring Typically general domain knowledge or problem solving skills, not problem-specific answers" [101].

4.2 The characteristics of an ill-defined domain and the adopted strategies

P. Fournier-Viger, R. Nkambou, and E.M. Nguifo show the characteristics of ill-defined domains [36]:

> they have many and even conflicting solutions;
> the domain theory is not complete, so it does not allow to determine the solution of a problem solving or to validate a solution in an absolutely way;
> the concepts are open-texture, that is the conceptual structures are constructed in the context and orally transmitted or, often, implicit;
> the problems are complex, so they cannot be divided into sub-problems and they are not easily solved with reductionist methods [36].

Ashley and Pinkus [104] indicate the characteristics of well-defined domains (2204):

1) they lack a definitive answer; 2) the answer is heavily dependent upon the problem's conception; 3) problem solving requires both retrieving relevant concepts and mapping them to the task at hand. [in 101]

Aleven and Lynch [66] define the term "ill-defined" during the workshop about ill-defined domain in ITS in 2006. Their literature survey [101] underlines that the term "has been given a wide variety of definitions in the literature", even in relation to the historical evolution of the concept.

They also determine the characteristics of ill-defined domains: the correctness of the solutions cannot be verified with certainty, there is no formalized theory of the domain, the concepts of the ontology have an open-texture, problems arise sub-problems that interact and cannot be analyzed separately.

The same authors also states that the didactic method through which

problems are dealt with in well-defined domains, that is problems in series and batteries of tests ("Students in well-defined domains are Commonly trained using batteries of practice problems Which Are Followed by tests solved by and checked against a formal theory" [101]), are not successful when the individual meets real problems and for practitioners' training.

Which approach to represent knowledge? "The three aforementioned classical approaches (rule-based, constraint, expert-editor's note.) for representing and reasoning on domain knowledge can be very time consuming and difficult to apply in some ill-defined domains. As an alternative to these approaches, a promising approach for ill-defined domains is to apply datamining or machine-learning techniques to automatically learning partial task models from user solutions. The rationale for this approach is that a partial task model could be a satisfactory alternative to an exhaustive task model in domains in which a task model is difficult to define.

The idea is that even if there are many solution paths for a problem, some parts occur frequently, and, thus, could be used to support tutoring services.

The approach of learning partial task models is appropriate for problem-solving tasks in which: 1) the initial state and the goal state are clear; 2) there is a large number of possibilities; 3) there is no clear strategy for finding the best solution; and 4) solution paths can be expressed as sequences of actions. The advantages of this approach are that it does not require any specific background knowledge by the domain expert, and the system can enrich its knowledge base with each new solution. Also, unlike the expert system approach, this approach is based on human solutions. On the other hand, no help is provided to the learner if part of a solution path was previously unexplored. One way to address this limitation is to combine this approach with other approaches, such as CBM or MT" [36, 88].

Such an approach has been adopted in Canadarm tutor [116], [117], "a robotic arm deployed on the international space station which has seven degrees of freedom. In CanadarmTutor, the main learning activity is to move the arm from an initial configuration to a goal configuration in a 3Dsimulated environment". Canadarm Tutor is presented in literature as an example of an ill-defined domain [36, 90].

What are, instead, the teaching models used in ill-defined domains? Human tutors in *ill-defined* domains use Case Studies, Weak Theory Scaffolding, Expert Review, Peer Review/Collaboration. From these considerations Aleven deduces some strategies for implementing ITS in ill-defined domains.

1. Model-base. "In a model-based ITS, instruction is based upon ideal solution models. These models represent one or more acceptable solutions to a given problem, or a general model of the domain as a whole. The model is used both to check the students' actions and provide help". If "strong tutors force the students to follow the model exactly so that each entry matches it in some way", "weak methods use the model as a guide but do not require strict adherence to its contents" [101]. A similar approach has been used with success in the realization of two ITS: CATO, that supports the discussion in case studies in legal context, and PETE, in which students are engaged in analyzing the ethical problems of engineering.

2. Constraint. Even the model of constraint can be used in ill-defined problems. The project's' constraints can be considered as absolute requirements and prohibitions, or as preferences and warnings. This model incorporates some aspects of the practitioner's acting, who always used to put project's constraints to simplify his work. For this reason the constraint model could be more appropriate from a pedagogical point of view.

3. Discovery Learning. It Incorporates many of the proposals of the constructivist approach and it can have two implementing models: model exploration to support the student in investigating a domain, Model Building by contrast Focuses on the development of domain models, Discovery Support systems operate by providing the user with support-port as they work on a task in an unconstrained domain.

4. Case Analysis. It works by analyzing complex cases that present a particular problem as it exists in reality. It has got the limit of a non-generalization, but it has the advantage of an holistic presentation.

5. Collaboration. As Vygotsky stated, it is important to underline the importance of socialization in the learning process. There are two operating ways. The first aims to activate a virtual student next to the real one, supporting between them a Socratic dialogue. The second requires poor technologies, which could even does not have anything intelligent, but it is becoming increasingly popular in recent years.

> The role of the system is to facilitate user interaction and leverage the users' collective knowledge for learning. This approach follows Burke and Kass' intuition that a relatively ignorant system can nevertheless

support learning gains. Soller et al. [101] provides a nice summary of the state of the art in this area. In recent years systems have been developed along these lines for writing [144], collaborative discovery [145], linguistics [146], and mediation [147]. [65].

4.3 Domain or problem?

It is possible to define ill-defined even domains in which traditional approaches for building ITS are not applicable or do not work well [59], [60], [61].

The attention on the issue of ill-defined in this context derives even from the fact that an ill-defined problem is that in which not all the variables are initially defined, problem that characterizes in general the design and that it has supported recursive designs models as the rapid prototyping [63] [64]. We underline how this situation can derive from two problems: the problem in itself is ill-defined, the problem is ill-defined in relation to the time that we have got for designing. Like Perrenoud says, if teaching is a profession in which we work with uncertainty and decide quickly, the two problems are both present in the work of teachers. In many cases, in the European academy, between the design of the courses and their delivery can pass a month and the courses themselves they are not replicated in the same way year after year. The ill-defined approach might support the majority of the courses offered in online mode and blended mode.

4.4 The history of the workshops on ill-defined ITS

If Aleven talks about ill-defined since 2003, in 2006 the attention on ill-defined invests the whole community in a significant way.

The ITS conference in 2006, in Taiwan and AIED in 2007, in Marina del Rey have demonstrated the high level of interest in ill-defined domains and the quality of ITS work addressing them. Within them an entire section was dedicated to the issue of ill-defined domain/task.

The ITS conference of 2008 introduces the workshop on ill-defined: "Intelligent tutoring systems have achieved reproducible successes and wide acceptance in well-defined domains such as physics, chemistry and mathematics. Many of the most commonly taught educational tasks, however, are not well-defined but ill-defined. As interest in ill-defined domains has

expanded within and beyond the ITS community, researchers have devoted increasing attention to these domains and are developing approaches adapted to the special challenges of teaching and are developing approaches adapted to the special challenges of teaching and learning in these domains. The prior workshops in Taiwan (ITS 2006) and Marina-Del-Rey, California (AIED 2007) have demonstrated the high level of interest in ill-defined domains and the quality of ITS work addressing them" [65].

It is appropriate to follow the development since 2006 of these meetings to better understand the meaning of the work on the ill-defined tasks.

4.4.1 ITS 2006

In the conference ITS 2006 [1w] there is the workshop "Workshop on "Intelligent Tutoring Systems for Ill-Defined Domains" [2w]. In the Appendix 1 we show the call.

In the call they remember the successes obtained from the present ITS (Intelligent Tutoring Systems have made great strides in recent years. Robust ITSs have been developed and deployed in arenas ranging from mathematics and physics to engineering and chemistry.), but they also underline that most part of them has been done in well-defined domains. (Well-defined domains are characterized by a basic formal theory or clear-cut domain model).

After stating the characteristics of well-defined domain (Ill-defined domains lack well-defined models and formal theories that can be operationalized, typically problems do not have clear and unambiguous solutions) and underling that in ill-defined domains are typically taught by human tutors using exploratory, collaborative, or Socratic instruction techniques they describe the challenges facing researchers in the field of ill-defined: "1) Defining a viable computational model for aspects of underspecified or open-ended domains; 2) Development of feasible strategies for search and inference in such domains; 3) Provision of feedback when the problem-solving model is not definitive; 4) Structuring of learning experiences in the absence of a clear problem, strategy, and answer; 5) User models that accommodate the uncertainty of ill-defined domains; and 6) User interface design for ITSs in ill-defined domains where usually the learner needs to be creative in his actions, but the system still has to be able to analyze them").

The issues proposed in the call can be divided into three categories:

1. Didactic Strategies (a. Teaching Strategies: Development of teaching strategies for such domains, for example, Socratic, problem-based, task-based, or exploratory strategies; b. Search and Inference Strategies: Identification of exploration and inference strategies for ill-defined domains such as heuristic searches and case-based comparisons; c. Assessment: Development of Student and Tutor assessment strategies for ill-defined domains. These may include, for example, studies of related-problem transfer and qualitative assessments);

2. Models for the organization of materials (a. Model Development: Production of formal or informal models of ill-defined domains or subsets of such domains; b. Feedback: Identification of feedback and guidance strategies for ill-defined domains. These may include, for example, Socratic (question-based) methods or related-problem transfer; c. Exploratory Systems: Development of intelligent tutoring systems for open-ended domains. These may include, for example, user-driven "exploration models" and constructivist approaches. Representation: Free form text is often the most appropriate representation for problems and answers in ill-defined domains; intelligent tutoring systems need techniques for accommodating that).

3. Teamwork and peers collaboration (Collaboration: The use of peer-collaboration within ill-defined domains, e.g., to ameliorate modelling issues). This issue is significant because it underlines a shift from the one to one approach of the ITS of first generation. [**4w**].

In the same conference, Aleven presents a paper on literature survey, that we have presented before [**101**].

4.4.2 ITS 2008

ITS 2008, held in Montreal. [**3w**] The presentation of the workshop on Ill-defined domains presents an outline structure similar to that of 2006. (Appendix 2).

> "Developing ITSs for ill-defined domains may require a fundamental rethinking of the predominant ITS approaches. Well-defined domains, by definition, allow for a clear distinction between right and wrong answers. This assumption underlies most if not all existing ITS systems. One of the central advantages of classical ITSs over human tutors is the potential for on-line feedback and assessment. Rather than waiting until a task is completed, or even long after, a student receives

guidance as they work enabling them to focus clearly on useful paths and to detect immediately 'the' step that started them down the wrong path.

Ill-defined domains typically lack clear distinctions between "right" and "wrong" answers. Instead, there often are competing reasonable answers. Often, there is no way to classify a step as necessarily incorrect or to claim that this step will lead the user irrevocably astray as compared to any other. This makes the process of assessing students' progress and giving them reasonable advice difficult if not impossible by classical means" [4w].

There is however an interesting underline. In classical ITS students were monitored and they were given a continuous feedback. This was possible thanks to the possibility to precisely control the path because it was always possible to distinguish the good answers from the bad ones. What happens in the ill-defined? How to asses and how to provide feedback?

Not accidentally they suggest two issues for discussion: Assessment. (Development of student and tutor assessment strategies for ill-defined domains. These may include, for example, studies of related-transfer problem and qualitative assessments) and feedback (Identification of feedback and guidance strategies for ill-defined domains. These may include, for example, Socratic (question-based) methods or problem-related transfer).

The seven contributions cover in a specific way the problem of assessment and feedback. Another specific issue is that of the representation knowledge, even using graphical tools, such as maps.

4.4.3. ITS 2010

To understand the maturity that reached the issue from 2009 to 2010, we can remember that IJAIED Special Issues 2009 was intended for ill-defined domains and that the text Advances in Intelligent Tutoring Systems dedicates considerable space to the problem. (Appendix 3)

In 2010, ITS takes place in Pittsburgh [5w] and the workshop in ill-defined sees a presence even more significant. The emphasis is moving on teaching strategies and mixed approaches that involve non-dedicated LMS. "Ill-defined domains usually require novel learning environments Which use non-didactic methods, Such as Socratic instruction, peer-supported exploration, simulation and/or exploratory learning methods, techniques or informal learning in collaborative settings". [6w] We can notice the shift toward an attention on methodologies, instead of the attention on domains. We can

consider with perplexity to define non-didactic methods strategies that have always characterized the research in the field of education.

In relation to the issues suggested, the question of how to support students in problem solving open-ended returns (Defining viable computational models for open-ended exploration coupled intertwined with appropriate meta-cognitive scaffolding) and how to assess and provide feedback when the problem implies an open solution. The attention on interfaces also returns (Designing interfaces That can guide learners to productive interactions without artificially constraining Their work).

At the same time there has been a growing interest in connecting paths monitoring in intelligent learning environments not built on a specific topic.

5. From single-use ITS to intelligent multi-use environments

The last twenty years history of ITS shows the following shift: from well-defined systems, to ill-defined systems, to intelligent environments in the second decade of XXI century. "The specific theme of the ITS 2012 conference is co-adaptation between technologies and human learning" [8w]. We need to clarify that "The intelligence of these systems stems from the artificial intelligence technologies often exploited in order to adapt to the learners (e.g.: semantic technologies, user modelling), but also from the fact that today's technologies, for instance the Web and the service oriented computing methods, facilitate new emergent collective behaviours".

The ITS in well-domain were based on processes for the problem solving in specified disciplines. The students' path was tracked and ITS worked on the simulation of possible paths. They worked on the declarative knowledge and the problem solving was the favourite didactic methodology. The necessary knowledge base was mainly the disciplinary knowledge and the clarification of the possible paths to be followed. The feedbacks were very precise and the suggestions used to bring the students on specified paths. Such ITS, still used today, are very useful for basic subjects in which the typologies of problems is the same for years and is determined more by the rationale of the discipline than by authentic and real situations. The approach is strictly cognitivist and the disciplinary references are, besides the technological ones, those of the psychology of education.

From the beginning of the new millennium the interest moves to the ill-defined domains. The need is caused by many teaching domains cannot be included in the previous category and that it's necessary to consider also the

problems in which it's not possible determine a priori a definite number of certain solutions. The interest is also due to a stronger osmosis between different approaches (cognitivist and constructivist) and by a deeper contact between the educational world (pedagogical/didactic) and the technological world.

The learning strategies are more and more object of analysis and seen in an autonomous way from the domain.

After 2010 such a shift enters a new phase.

The cognitivism-constructivism debate is finally overcome. The last decade of the last century, in the educational field, and not only, was characterized by the war, almost a religious war, between cognitivism and constructivism [16], [148]. The debate of the first decade of the new millennium closed such a contrast, without selecting a winner, but moving the attention to the learning process, to the interaction between teaching and learning [21]. The current post-constructivist scenario [47], [149], [150], [151] also fostered by an interest for the externalism [152] [153], highlighted that teaching cannot be based on the mere psychology of education. In order to teach, besides the psychology of education, is necessary to take into account social and civil values, the cultural sense of the discipline (factors that define what topics to be selected and the relational modalities of the teacher). Moreover from the analysis of teacher practices the initial plan seems to need to be always re-designed in action. Teachers act a "regulation" in action and for this reason they need to have a wide tool box of didactic strategies. The researches about the teacher's thinking [15], [155], [156], [19], have been considered focussing on the didactic action [154], [17], [20], [156].

Besides the ITS focussed on a specific discipline there are the intelligent environments that offer multiple didactic strategies to teachers and support their work.

ITS 2012 shows this rationale. In 2012 there's no one specific workshop on ill-defined domain. The activated workshop are the following:

1. Intelligent Support for Exploratory Environments: Exploring, Collaborating, and Learning Together (Toby Dragon, Sergio Gutierrez Santos, Manolis Mavrikis and Bruce M. Mclaren).
2. Workshop on Self-Regulated Learning in Educational Technologies (SRL@ET): Supporting, Modelling, evaluating, and fostering meta-cognition with computer-based learning environments (Amali Weerasinghe, Roger Azevedo, Ido Roll and Ben Du Boulay).
3. Intelligent Support for Learning in Groups (Jihie Kim and Rohit Kumar).

4. Emotion in Games for learning (Kostas Karpouzis, Georgios N. Yannakakis, Ana Paiva and Eva Hudlicka).
5. Web 2.0 Tools, Methodology, and Services for Enhancing Intelligent Tutoring Systems (Mohammed Abdel Razek and Claude Frasson).

Reading the topics it's clear the attention on the group work and on the connection with intelligent environments and Web 2.0 (1, 3, 5), on self-regulated learning (2), already present in AIED 2011, and on the emotion issue (4).

We grouped the topics addressed in the conference:

1. Analysis of the relation between technologies and human learning (1. Co-adaptation between technologies and human learning; 2. Non conventional interactions between artificial intelligence and human learning; 3. Empirical studies of learning with technologies, understanding human learning on the Web);
2. Strategies and didactics, group work and simulation, informal learning and role of affectivity (1. Adaptive support for learning, models of learners, diagnosis and feedback; recommender systems for learning; 2. Virtual pedagogical agents or learning companions; 3. Discourse during learning interactions; 4. Informal learning environments, learning as a side effect of interactions; 5. Modelling of motivation, metacognition, and affect aspects of learning; 6. Collaborative and group learning, communities of practice and social networks; 7. Simulation-based learning, intelligent (serious) games);
4. Architecture (1. Intelligent tutoring; 2. Ontological modelling, semantic web technologies and standards for learning; 3. Multi-agent and service oriented architectures for learning and tutoring environments; 4. Educational exploitation of data mining and machine learning techniques; 5. Ubiquitous and mobile learning environments);
5. Instructional design e authoring tool (1. Instructional design principles or design patterns for educational environments; 2. Authoring tools and development methodologies for advanced learning technologies);
6. Domain-specific (1. Domain-specific learning domains, e.g. language, mathematics, reading, science, medicine, military, and industry).

But the analysis of the contributions focus on the classical topics of the architectures and of the emotional aspects while the co-disciplinary topic

seems to be not widely present. This could be due to a lack of researchers in the educational sector.

AIED 2011 has been equally interesting in the same direction previously drawn.

We would like highlight the contribution by Joshua Underwood and Rosemary Luckin, *The London Knowledge Lab "What is AIED and why does Education need it?* A report for the UK's TLRP Technology Enhanced Learning – Artificial Intelligence in Education Theme [106].

In the report, whose conclusions are widely shareable and near our position, it is underlined how notwithstanding the progress of technologies and related researches promoted by AIED the impact on the educational context is still little. Recalling Wolf [108]

> there are many notable technological successes (see Table 1) and yet these technologies are not fully exploited for educational purposes [108] particularly within mainstream Education. In the same way they report the position of Cumming and McDougal's [109] of the little relevance of the most advanced technologies in mainstream education.

What can be the AIED contribution to education? Besides the classical contents (AIED helps in the construction of: "1. Model as scientific tool. A model is used as a means for understanding or predicting some aspect of an educational situation. 2. Model as component. A computational model is used as a system component enabling a learning environment to respond adaptively to user or other input. 3. Model as basis for design. A model of an educational process, with its attendant theory, guides the design of technology-enhanced learning) [106], it is underlined as in the last period and, mainly, for a better convergence of the researches in the sectors and the education the interest is moving towards: "Open Models as prompts for learner and/or teacher reflection and action: Computational models, usually of learner activity and knowledge, are made inspectable by and possibly opened for learners and/or teachers to edit. Such open models can prompt users to reflect on their learning and support meta-cognitive activity [110]" [106].

The final recommendations are aimed at a stronger synergy among researches in the sector of ITS and education for learning.

The analysis of the AIED (2000-2010) conferences made by the authors themselves is also interesting. Table 1 synthesizes their work.

Support for 1-to-1 learning	➔	Support for personal, collaborative and social learning
Support for learning in tightly defined domains and educational contexts	➔	Support for open-ended learning in ill-defined domains across varied physical and social cultural settings and throughout the lifetime
Support for knowledge acquisition	➔	Support for knowledge construction, skills acquisition and meta-cognitive, motivational and affective support
Small-scale systems and laboratory evaluations	➔	Large-scale deployments, evaluations in real settings and learning analytics
Focussed analysis of relatively small quantities of experimental data	➔	Discovery and learning from educational data mining of large amounts of data captured from real use
Constrictive technologies and interfaces	➔	Accessible, ubiquitous, wireless, mobile, tangible and distributed interfaces
Designing educational software	➔	Designing technology-enhanced learning experiences

Table 11. Movements in focus of AIED research 2000-2010
From Underwood J., Lucking R. (2011). *What is AIDS and why does Education need it?* [106]

But what could be the reasons of the scarce alley between the research in IT and education and what innovative elements are emerging and fostering in the last years a better relation?

There are structural causes such as the division in disciplines expressed by the Western culture. But we believe there are also conceptual aspects, that if not understood and removed, could come back in different forms. Probably instead of focussing on the task to look for a synergy between different contexts, the base for the collaboration was searched in an ideal common root. Specifically a symmetry was searched between the human modality and the intelligent machine modality and on that model the process has been built. So since a real co-disciplinarity was absent the AI experts looked for pedagogical models that could be similar to the logical models present in AI, without being supported by researches in the educational field and, at the same time, the researchers in the educational field examined the artefacts from an instrumental perspective and they chose the ones that revealed in their perception being structured according to an educational rationale. This situation

brought to the adoption of poor technologies that were not able to promote TEL. In the past co-disciplinary processes were not activated that could have fostered a rationale more connected to the construction of environments and less determined by ideological models, a rationale in which the co-design didn't look firstly for a symmetry, but experimented a revision of educational and technological models according to the didactic functions during the construction of environments.

Today another step is to be made. If the old idea that the computer could be a metaphor of the human was abandoned, today also the computational approach is being under discussion. Brain [112]. In such approach from we have the passing from the datum to the elaboration that determines the choice and, then, the execution by a mechanical executor[11]. If applied to the human the information is analysed by the brain who decides and sends an input to the body that acts. In an approach based on enactivism and on distributed cognition such division doesn't exist and the body participates to the action that is at the same time a world knowledge process and a world building process. Decision and knowledge are interacting and recursive processes. In the educational context the decision made by the teachers in the situation are strongly connected to the context and they were born in the action itself, that is the source of both knowledge and transformation.

6. Conclusions

What does it mean for the ITS? The knowledge process (that is the correct solution to a problem) is not a priori, but evolves in the process of solution itself. While the process of analysis of the context progresses (knowledge gets a structure), choices are made that bring to a better comprehension and recursively to more and more precise choices. You know while you act, you act while you know. Always in a certain situation. Within an authentic task. Besides knowledge is the product of the action because it doesn't happen just in the brain, but in the continuum mind-body-artefact-world. The action becomes also central as space-time in which knowledge and transformation interact.

It's clear that the support offered by an ITS cannot just be a guiding process towards the pre-set solutions, towards a crystallised knowledge, but to make it clear the situation in each phase, to visualize the process itself so that knowledge/transformation in action be a reified object with which you can dialogue. Such visualization facilitates also the process of distancing-immer-

sion of the learning subject in the process itself. The reflection processes on actions are also relevant, so it is the self-regulating learning. The attention given to the monitoring and assessment processes is not casual, so it is on the self-regulating learning, on the reflexive processes in the conferences ITS and AIED of the latest years.

This means also that the expert systems are not a modelling of the human brain, but they provide intelligent artefacts that execute specific functions in a specific way and independently from the modality with which the human brain would have developed them. Intelligence is not monadic. Different intelligences exist, but differently from Stemberg (cognitive styles) and Gardner (multiple intelligences), here we mean different rationales present in different contexts and also used by similar subjects in different situations. Human beings and machines use many and different rationales according to the contexts and the artefacts utilized.

Coming back to the sector of ITS and to the recent history (2011-2013) the interest of the community moved from the disciplinary domains and their rationales (Physics, Algebra, Chemistry) to the interest for the didactic strategies that can be transversal and support the didactic action in its development. We don't deal with different domains, but with different tasks and mostly with a different knowledge model in which the objective world and the subjective action (cognitive and practical) interweave and interact determining auto-poietic processes.

We propose a further observation that emerges from the proposed topics in the last meetings of ITS and AIED and that will become more and more central. The ITS must foster the awareness of the student in action, but also the regulation of the teacher in the didactic action so the teacher should be offered the chance to modify and intervene in the environment in itinere. So the attention to ID and flexibility of the environments acquires more and more relevance.

This perspective is to add to a single-use ITS, located in specific disciplinary domains and based on one to one relations, environments[12] with intelligent objects based on the centrality of the group class that supports both the student in the learning process and mainly in the reflection[13], and the teacher in the monitoring process, assessment and representation of the built knowledge, an environment which offers to the teacher a tool box with plenty of strategies among which to choose. The topics proposed in the call of AIED 2013 (Menphis) [9w] seems to be in this direction (Appendix 5).

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Web sites

[1w]   ITS 2006
[2w]   Workshop on "Intelligent Tutoring Systems for Ill-Defined Domains" – ITS 2006
[3w]   ITS 2008
[4w]   Workshop in Intelligent Tutoring Systems for Ill-Defined Domains: Assessment and Feedback in Ill-Defined Domains – ITS 2008
[5w]   ITS 2010

[6w]   Workshop in Intelligent Tutoring Technologies for Ill-Defined Problems and Ill-Defined Domains – ITS 2010
[7w]   ITS 2012
[8w]   AIED 2013
[9W]   Andes

Note

1   Co-disciplinary is used to mean a research activity in which researchers of different disciplines are involved, in which each researcher contributes to the final solution in an holistic way without the presumption that each researcher can master all the involved sectors. In other words there's no division in separate blocks to be assigned to each researcher (multi-disciplinary approach), but there's also no presumption that everybody can master all the topics (inter-disciplinary approach). The co-disciplinary approach is situated and connected to the solution of a specific problem. Generally in a co-disciplinary team each expert follows two different trajectories that overlap: one is related to the group, to the context and the specific objective, the other is connected to one's discipline. The first process shows narrative modalities and uses an analogical communication, it produces results whose meanings can be shared by the extended group, even if the experimental rigor is not respected. The second process follows the disciplinary consistency and it becomes necessary to confirm the hypothesis and the analogical leaps born in the first process. The two processes are thus strictly connected. A consequence in this approach is the refusal of processes with distinct steps: first the educational constraints are designed and then the technical team realizes the product, but a continuous and recursive comparison is necessary. It's clear that a researcher in the educational field can have all the necessary competencies to realize an artifact and vice versa that a technical researcher can have educational competencies.

2   "ITSs are education systems which aim at high qualified and operational education, by this aim, try to provide an individual atmosphere for a student as if he is in one to one interaction with a professional educator, present necessary resources in time, which are adapted according to individuals and in which the applications that prevent the student from being lost are developed in a data base" [**8**]. The definition by Conati is similar: "Intelligent Tutoring Systems (ITS) is the interdisciplinary field that investigates how to devise educational systems that provide instruction tailored to the needs of individual Learners, as many good teachers do" [**7**].

3   Although one-to-one tutoring by expert human tutors has been shown to be much more effective than typical one-to-many classroom instruction [**22**].

4   "ITSs using rule-based cognitive models have been demonstrated to be successful in improving student learning in a range of learning domains" [**36**, 8].

5   For a wider description please refer to [**89**].

6 "The current research contributes to the broader goal of developing affect-sensitive ITSs by developing multimodal detectors of boredom, engagement/flow, confusion, frustration, and delight; the affective states that accompany learning at deeper levels of comprehension [126], [127], [128]" [12].

7 The reading of the call AIED and ITS from 2006 to today highlights the importance of teaching strategies used in ITS, as will prove in the next chapters.

8 "current direction of ITS research aimed at extending the reach of this technology toward new forms of computer-based instruction beyond traditional problem solving: providing intelligent tutoring for meta-cognitive skills" [7].

9 It seems appropriate to emphasize here the research made by Conati who has devoted much of his work at this issue in the last decade [69], [70], [71] [72] [73], [74] [75]. Another author who has devoted much of his research to the topic is Graesser which promoted a on Emotional computers. Be reported some of his production on the theme of the past two years [76] [77] [78] [79] [80] [81] [82] [83] [84] [85] [86] [87] [88].

10 "The current ratio for designing and developing instruction for the new interactive technologies exceeds 200 hours of design/development for each 1 hour of delivered instruction [143]. Some estimates suggest ratios exceeding 500:1 just for programming" [142].

11 "We define AI as the study of agents that receive percepts from the environment and perform actions" [115].

12 Actually the tension between single-use ITS and environment started at the beginning of 2000, maybe even earlier. "Recent years have witnessed the birth of a new paradigm for learning environments: animated pedagogical agents. These lifelike autonomous characters cohabit learning environments with students to create rich, face-to-face learning interactions. This opens up exciting new possibilities; for example, agents can demonstrate complex tasks, employ locomotion and gesture to focus students' attention on the most salient aspect of the task at hand, and convey emotional responses to the tutorial situation. Animated pedagogical agents offer great promise for broadening the bandwidth of tutorial communication and increasing learning environments' ability to engage and motivate students. This article sets forth the motivations behind animated pedagogical agents, describes the key capabilities they offer, and discusses the technical issues they raise. The discussion is illustrated with descriptions of a number of animated agents that represent the current state of the art.

This paper explores a new paradigm for education and training: face-to-face interaction with intelligent, animated agents in interactive learning environments. The paradigm joins two previously distinct research areas. The first area, animated interface agents [158], [159], [160], [161], [162], [163], [165], [166], [167], provides a new metaphor for human-computer interaction based on face-to-face dialogue. The second area, knowledge-based learning environments [157], [6], [5], seeks instructional software that can adapt to individual learners through the use of artificial intelligence. By combining these two ideas, we arrive at a new breed of software agent: an animated pedagogical agent IS [167], [168], [169], [170], [171]" [112].

13 The word metacognitition, which is within a cognitivist perspective, is more and more often present in the documents. But similar is the result that you obtain including didactic reflexive processes o meta-reflection processes. Fournier et al. [36, 90] state that the use of meta cognitive technologies allows the construction of domain free ITS. We prefer to refer to reflection processes on the topic and on one's learning process.

2. Cognitive Models and their Application in Intelligent Tutoring System

Anna Pipitone ● Vincenzo Cannella ● Roberto Pirrone

Introduction

The literature related to computer based learning environments reports the development of several artifacts, which are inspired by the findings in Education Science, Computer Science (mainly AI), and Education Psychology even if no integrated perspective has been adopted in their design.

Education Science has influenced the development of classical virtual learning environments (VLE) where the potential impact of using recent results in AI has not been exploited. Such systems are mainly repositories of didactical materials where the learning paths are fixed. Some support is provided to monitor either the single student or the whole class during the learning process, and some authoring tools are present in such systems. However the core learning design process is intended to take place outside the learning platform. AI researchers are not education scientists: they produced environments aimed to put in evidence only particular aspects of the learning process as a cognitive process. Such artifacts are only case study implementations of general paradigms intended to build artificial agents. Such systems are referred to as Intelligent Tutoring Systems (ITS).

Finally, education psychologists investigate in deep the one-to-one relation between the man (the learner) and the machine (the artificial tutor) stressing the meta-cognitive dimension of this interaction. Several advanced ITSs have been built to prove their theories, but all of them are suited to a particular domain and/or a particular kind of learner (kids, high school or

undergraduate students, professionals, and so on). ITSs represent the most advanced and promising field of investigation as regards the evolution of VLEs, despite the limitations outlined above. A review of the main ITS architectures is the focus of the present chapter.

Even if there are several differences in their design and implementation, Intelligent Tutoring Systems are always built on cognitive architectures, and assume a similar set of basic representations and information processing. From the perspective of applications, some of these architectures can be seen to share a number of features. When trying to abstract from the implementation details towards a holistic architectural view of such systems, some theoretical aspects can be overtaken to highlight other important features. As an example, the precise psychological theory that is used to model relevant aspects of the student behavior may be not as important as the specification of the system's knowledge at a symbolic level.

This chapter is intended to be an overview of the main ITSs in the literature from a perspective that is strongly biased towards AI. The dual perspective that is the analysis of the same systems from a pedagogical point of view is addressed in another chapter of the book. For this reason in this chapter we'll attempt to describe a general cognitive architecture, which is more abstract than existing ones, while focusing on a symbolic view of the features. As a consequence we'll describe such a model as a set of AI components. Such a model will be the underlying one for all the ITSs dealt with in the chapter.

The rest of the work is arranged as follows. We'll start outlining some of the most prominent cognitive architectures; then the generalized model will be introduced. Next the most common ITSs relying on cognitive modeling will be described in short, along with its abstraction into our architectural perspective.

1. Overview of Cognitive Architectures

Cognitive architectures are combinations of psychological theories and programming environments for building intelligent artificial agents to model human behavior. According to [16] a cognitive model is specified in three levels:

- the knowledge level;
- the symbolic level;
- the architecture level.

The knowledge level models descriptively the view of an external agent [15]; it is a level for analysis in the sense that someone can make assumptions about the knowledge owned by an intelligent entity, observing the actions performed by such an entity. Also the knowledge-level descriptions of intelligent systems are usually based on the "rationality principle". According to this principle, an agent that has access to some relevant knowledge in a particular situation, will use it to take the most correct and convenient decision.

Traditional cognitive architectures dictate that this knowledge must be encoded symbolically to provide the means for universal computation [16]. For this reason, the symbolic level is defined; at this level in fact the "knowledge" of an intelligent system is represented in a structured, executable format. For every intelligent system the knowledge is conceived only as some representation. The knowledge representations at the symbolic level must be managed in order to allow accessing, building new knowledge, modifying existing one, and so on.

The architectural level enables separation of content (the computer program) from its processing substrate; the primary differences between existing models of human behavior are related to knowledge encoding for different applications.

In what follows the main cognitive architectures reported in literature are outlined.

1.1 Soar

Soar [8][7] cognitive architecture was created by John Laird, Allen Newell, and Paul Rosenbloom at Carnegie Mellon University, and now it is maintained by John Laird's research group at the University of Michigan.

Soar provides a functional approach to encoding intelligent behavior [9], and it has been applied to investigations in the field of cognitive psychology and computer science.

Soar has a minimal but sufficient set of mechanisms for producing intelligent behavior. It provides a uniform representation of beliefs and knowledge, methods for integrating different reasoning processes and stable mechanisms for learning and intention selection.

Soar is composed by a production system that is used to provide a set of rules about behavior. This is the long-term memory of the architecture. There are also a working memory and a preference memory; Soar productions in long-term memory have a set of conditions, which are patterns to be matched

to working memory and a set of actions to be performed when a production fires. Productions place preferences for working memory elements into preference memory. Types of preferences include acceptable, reject, require, prohibit, better, worse, reconsider, and indifferent.

A collection of different states, which can be reached by the system at a particular time describes a problem space, while a solution for a problem is represented by a goal state. Soar problem solving strategies can be roughly modeled as the explorations of the problem space for a goal state that is searching for the states that lead the system gradually closer to its goal. Each step in this search is a decision cycle. A decision cicle has two phases:

- the elaboration phase;
- the decision phase.

During the first phase, a variety of different parts of knowledge about the problem are integrated to the Soar working memory. In the second phase, the weights obtained as a result from the previous step are assigned to preferences to decide ultimately the action to be made. If it is not possible to determine a unique set of actions in the decision phase, Soar may use different strategies that are known as "weak methods" to solve the impasse. This is true particularly when knowledge is poor. An example of these strategies is the means-ends analysis that calculates the difference between each available option and the goal state.

Soar proves to be flexible when varying amounts of task knowledge are available. Apart from searching the problem space, Soar is used for reasoning techniques, which do not require detailed internal models of the environment, such as reinforcement learning.

When a solution is found, Soar enters the chunking phase to transform the course of selected actions into a new rule. This phase is based on learning techniques. New rules outputted from chunking phase are then applied whenever Soar experiences again the same situation.

1.2 ACT-R

ACT-R [1] [2] is a hybrid cognitive architecture that looks like a programming language whose constructs are defined from assumptions derived by psychology experiments about human cognition.

This architecture is similar to Soar, and its fields of applications are in the

same researches carried on at Carnegie Mellon University; however ACT-R can be described as a full-fledged psychological theory, while Soar adopts a functional approach. ACT-R produces intelligent behavior using the best available set of interaction mechanisms with the world unlike Soar, which attempts to compose all intelligent behaviors from a minimal set of mechanisms.

The ACT-R symbolic structure is a production system as Soar while the subsymbolic structure is represented by a set of parallel processes modeled by mathematical equations, which control many of the symbolic processes. Subsymbolic mechanisms are also responsible for most learning processes in ACT-R. ACT-R's components can be classified into perceptual-motor modules, memory modules (declarative and procedural ones), buffers and a pattern matcher. Perceptualmotor modules are related to the interface with the real world, and the most well developed modules in ACT-R are the visual and the manual modules. The declarative memory consists of facts such as Rome is the capital of Italy, while the procedural one is used for productions, which represent knowledge about how we do things.

ACT-R architecture accesses these modules (except for the procedural memory) through dedicated buffers; the content of such buffers at a given time represents the state of ACT-R. Finally, the pattern matcher searches for a production matching the current state, and only a production can be executed at a time.

When a production fires, it can modify the buffers; this means that cognition in ACT-R is represented as a succession of production firings. Beside its applications in cognitive psychology, ACT-R has been used in many other fields as human-computer interaction, education, computer-generated forces, and neuropsychology.

1.3 EPIC

EPIC [6] (Executive-Process/Interactive Control) is a cognitive architecture developed by David E. Kieras and David E. Meyer at the University of Michigan. On the one hand, EPIC is a computational model of a human capable of carrying out a wide variety of both simple and complex cognitive tasks; EPIC assumes that the nature of humans is the ability of performing multiple tasks in parallel. These are the situations in which a person is performing more than one action simultaneously, such as talking on the phone while cooking.

The EPIC researchers assume that the interest and the challenge for this aspect is related to the fact that humans have serious limitations when doing many things in parallel; such limitations depend on many aspects of the tasks that are still known poorly. However, understanding these details is very informative about the human information-processing architecture.

The goal in developing the EPIC architecture is to abstract limitations and abilities, and to model them in form of computational modules that represent the known properties of human information processing.

When regarded from a computational perspective, EPIC is a cognitive architecture that models how humans perform specific cognitive tasks. Once a EPIC strategy is selected as a task environment, the simulation can start; this simulated human then produces simulated data. Researchers can then make a comparison: if the real and simulated data are identical, then the researcher has confidence that the model of that task performance is right.

The important thing that separates a computational model built with EPIC from a standard psychological model is the level of detail that the theorist must specify. EPIC models the human-system interactions that are accurate and detailed enough to be useful for practical design purposes. EPIC represents a state-of-the-art summarization of results on human perceptual/motor performance, cognitive modeling techniques, and task analysis methodology. Human performance in a task is modeled by programming the cognitive processor with production rules organized as methods for performing task goals.

The EPIC model interacts with a simulation of the external system and accomplishes the same task as the human would. The model finally creates events whose timing is accurately predictive of human performance.

1.4 GMU BICA

The GMU BICA [5](George Mason University Biologically Inspired Cognitive Architecture) model is based on eight interconnected components. Five components are some kind of memory: working memory, which stores active mental states, semantic memory to store schemas, episodic memory for storing inactive mental states combined into episodes, and the iconic memory also known as input-output buffer.

The last three components are: the cognitive map that is a functionalist mapping of cognitive components onto brain structures, the reward system and the driving engine. The cognitive map is a central component, which

orchestrates the higher-level symbolic ones and to map their cognitive contents. The input-output buffer operates in terms of states of schemas and interacts with working memory. The driving engine and the reward system "run" the above components.

Main paradigms of modeling studies through GMU BICA are related to voluntary perception, cognition and action.

1.5 ICARUS

ICARUS [10] is a recent architecture that has two forms of knowledge: concepts and skills. Concepts describe percepts of environmental situations, while skills specify how to achieve goals by decomposing them into a path of subgoals. Both concepts and skills involve relations among entities, and impose a hierarchical organization on the longterm memory.

The basic ICARUS interpreter performs a recognize-act cycle. On each step of the cycle, ICARUS stores descriptions of visible entities into a buffer, the perceptual buffer. The system compares these percepts to primitive ones and adds matched instances to short-term memory. In turn, such instances trigger matching the other higher-level percepts, and the process is repeated until ICARUS infers all beliefs. In the next step, ICARUS has a top-level goal and finds a path of subskills where each subskill owns some conditions that have been satisfied, while the goal is unsatisfied yet.

When a path terminates in a primitive skill with performable actions, the architecture applies them. This has the effect to create new percepts, changes in beliefs, and reactive execution of additional skill paths to achieve the agent's goals. If ICARUS does not find any applicable path, it attempts to solve the problem using a means-ends analysis variant. ICARUS was employed into agents design for a number of domains that involve a combination of inference, execution, problem solving, and learning. These have included tasks like the Tower of Hanoi, multi-column subtraction, FreeCell solitaire, and logistics planning. Other works aim to use ICARUS for guiding robots that carry out joint activities with humans.

2. Modeling a General Cognitive Architecture

This section introduces a cognitive model for a set of intelligent tutoring systems, which will be detailed later on in the chapter. We want to define a high-level general cognitive architecture underlying all the systems to be described. We focused on a global description of the intelligent behavior of an ITS. In particular, we analyzed each system for highlighting shared functionalities and components.

Our architecture goes beyond single models in that they govern some aspects as knowledge acquisition, and using knowledge for planning. Although some details are ignored, the resulting architecture picks out the essential structure and the major design decisions for each system.

We divided our cognitive modeling process into four sub-tasks:

- knowledge specification;
- memory definition;
- description of the intelligent controller;
- specification of the perception manager.

In this way we observed the classic dictum from the field of artificial intelligence (AI) that tries to promote modularity of design by separating out knowledge (and memory) from general control.

Knowledge specification involves each knowledge about the context of the ITS such as domain knowledge representations, learning materials – documents, text, multimedia, and so on, the user's state and all kind of information about his/her, possible answers, possible questions, constraints and so on. The "world" of the ITS is described also in this task that is what the agent can say about topics and users at a given time. In turn, this information can be used by the controller for changing the ITS's state and for managing the knowledge representation. We named this knowledge as the context of the ITS and it can be regarded roughly as a set of facts.

Each fact is an element of the knowledge; it can be an atomic fact or a not-atomic fact. Atomic facts do not include other sub-facts and can be identified as unique entities in the knowledge. A simple answer to the student is an atomic fact, while the set of possible answers related to a specific conversation is a not-atomic one. A document selected for being studied is an atomic fact because it is an identifiable entity without sub-facts. The set of learning materials in a course is a not-atomic fact.

Memory definition involves rules that specific ITSs apply for managing

the knowledge and for taking decisions about the combination and evaluation of facts in the knowledge structure. In general, such decisions allow performing an action that can update the knowledge and the memory too. In this kind of memory the list of possible actions are also specified. The rule can be production rules, Horn's clauses, and so on; the actions that can be performed depend on some initial conditions i.e. pre-conditions.

Evaluating pre-conditions that is comparing them with the actual state of some parts of the system is a sub-task of the controller description task: plan definition. This task is described next, and we do not detail how a planner can work because this is beyond the scope of this chapter. Here we can model the memory as a finite-state machine where a state represents how some parts of the knowledge structure should be arranged at a given time (i.e. how the knowledge of interest should look like), and the relations between states are governed by actions that must be performed to move from one state to another one with other pre-conditions. When being in a given state, the planner verifies that the pre-condiction is true in the knowledge base.

Defining the intelligent controller includes the description of those components involved in the overall ITS management, ensuring proper communication and sequencing among them. Management involve upgrading knowledge, browsing the memory, action selection and plan execution time by time. The controller is interfaced with all other parts of the ITS.

Finally, the definition of the perception manager involves the specification of those components, which manage the communications with the external users. It involves all strategies related to dialogue as Natural Language Processing techniques (words matching, Latent Semantic Analysis, topic extraction by means of compositional semantics, lexical parsing, statistical analysis), graphical interfaces, sensors, machine perception techniques, and so on.

The modeling process outlined above, gives rise to an architecture consisting in four macro-components: the knowledge base module, which contains all knowledge of the ITS, the memory module, which contains all the rules, the controller module, and the perception manager module. The overall architectures is depicted in figure 1.

The proposed model can be put into correspondence with the components of the cognitive architectures outlined in the previous paragraph. Correspondences are reported in table 3.

The main components of the ITS architectures described in the next paragraph can mapped onto the proposed model. In what follows, we'll show the main characteristics of such ITSs along with their mapping to the general model using the color code reported in figure 1.
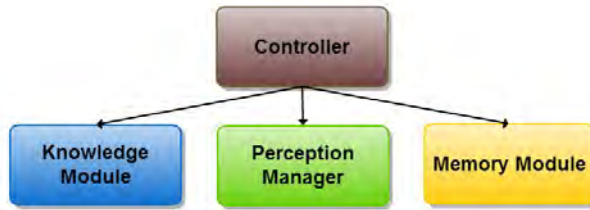
Fig. 1. The general cognitive architecture

	Soar	ACT-R	EPIC	GMU BICA	ICARUS
Knowledge module	problem space	facts	strategies	cognitive map, semantic memory	concepts, skills
Memory module	production system, working memory, preference memory	declarative memory, procedural memory	production rules	working memory, episodic memory, iconic memory	long-term memory, short-term memory
Controller	decision cycles, means-ends analysis, chunking	firing productions, subsymbolic processes	cognitive processor	driving engine, reward system	recognize-act cycle, means-ends analysis
Perception Manager	simulated input	perceptual-motor modules	simulated input	input-output buffer	perceptual buffer

Table 1. Mapping the general architecture onto different cognitive models

3. A Review of the Main Intelligent Tutoring Systems

In this section we'll present a review of the most wide spread ITSs, while regarding their architectures as instances of the general cognitive model presented in the previous section.

The main idea behind this presentation is that ITSs are definitely cognitive architectures because they interact heavily with humans when supporting them in one of the hardest cognitive process that is learning. In the most comprehensive scenario, an artificial tutoring agent has to perceive the actions performed by the user along with the surrounding environment - i.e. visited learning materials, planned actions, self-regulated behaviors, affective state of the user, environmental conditions. All this information has to be represented as a knowledge structure along with the a priori knowledge about the domain to be learned: this is the internal representation of the agent's world.

Finally, the agent has to deliberate about the best strategy to support the learning task at hand, and it has to act on the world, which includes the learner to modify his/her knowledge state. In turn, the learner's mental state is part of the state representation owned by the artificial tutor, and the perception-action cycle restarts. Cognitive modeling is the straightforward way to design such artificial agents.

3.1 MetaTutor

MetaTutor [3] [12] is an adaptive hypermedia learning environment developed by Roger Azevedo. It has been designed to detect, model, trace, and foster students' self-regulated learning (SRL) about human body systems. Treated topics are the circulatory, digestive, and nervous systems.

MetaTutor is mainly a research project, not a technology transfer. It is based on cognitive models of self-regulated learning. It aims at examining how much effective animated pedagogical agents are as external regulatory agents used to detect, trace, model, and foster students' self-regulatory processes during learning about complex topics.

MetaTutor is based on the assumption that students should regulate key cognitive, metacognitive, motivational, social, and affective processes in order to learn about complex and challenging science topics. Its design is based on extensive research by Azevedo and colleagues' showing that providing adaptive human scaffolding enhances students' learning about science topics with hypermedia. The research has identified the self-regulatory processes of students' learning about complex science topics. These processes include planning, metacognitive monitoring, learning strategies, and methods of handling task difficulties and demands. Training students on SRL processes with MetaTutor needs several phases. In the first phase the SRL process are mod-

eled. After this step, the behavior of the student is analyzed to highlight what aspects are used in a good or in a poor manner. At this point, the students see video clips showing persons engaged in similar learning task.

They have to stop videos whenever they see that those processes are used. Finally, students use the environment for learning. The user interface of the learning environment highlights the learning goal, and its related sub-goals for the learning session. The left side of the GUI contains the list of topics and subtopics related to the goals. Both static and dynamic contents are placed in the center of the GUI.
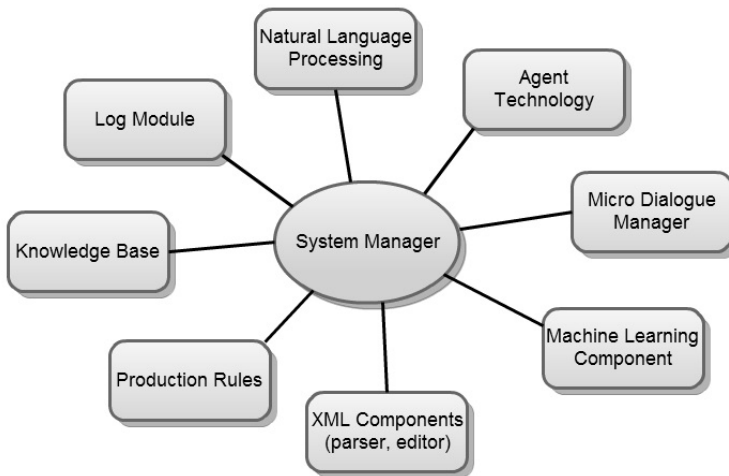
Fig. 2. Metatutor's Architecture

The interaction is managed by the communication dialogue box. It interacts with the student together with the pedagogical agent, devoted to assist the learner through the process of evaluating her/his understanding of the content. The interface lists the SRL processes useful in the learning session. When the student chooses a SRL process, he/she enhances at the same time her metacognitive awareness of the process he/she used during learning. Moreover, the system can track better the student's learning. On the other hand, the system can suggest a particular SRL process.

The architecture of the MetaTutor system is open because modules can be easily changed, defining new components or redesigning existing ones. Processing and data are decoupled in the architecture: such a solution allows

easy transfer of MetaTutor from one domain to another without changes in the processing part. In general, all the domain information is external, and it's contained in separate files that can be edited easily by either domain experts or cognitive scientists.

In what follows the MetaTutor modules are listed (see figure 2):

- the Knowledge Base module that includes the content pages and other knowledge items needed throughout the system, such as the taxonomy of the domain;
- the NLP module and Machine Learning Component that implement functions for evaluating various student inputs (textual input, actions at the interface, time-related behavior) and send these evaluation results to other components that need them;
- the XML parser and editor that is used to implement the authoring functionality for the designer of the system, the domain experts, and the cognitive scientists to make changes to various configurable items in the knowledge base. Moreover the parser is used for the feedback managing;
- the Production Rules module that encodes conditions that are monitored by the ITS. Rules monitoring takes place at specified time steps that are tailored on actual data, through a polling strategy. Rules trigger if their conditions are met. A default policy is used for managing concurrent firing;
- the Log Module that records every single event by the user and the system to perform post-experiment analyses;
- the System Manager that controls the operations of the entire system.
- the Agent Technology module that handles the three agents used in MetaTutor: Mary the monitoring agent, Pam the planner, and Sam the "strategizer";
- the Micro Dialogue Manager that implements the planning that handles the multistep, mixed initiative process of breaking the overall learning goal into more manageable sub-goals. Such a module handles the multi-turn interaction between the system and the student.
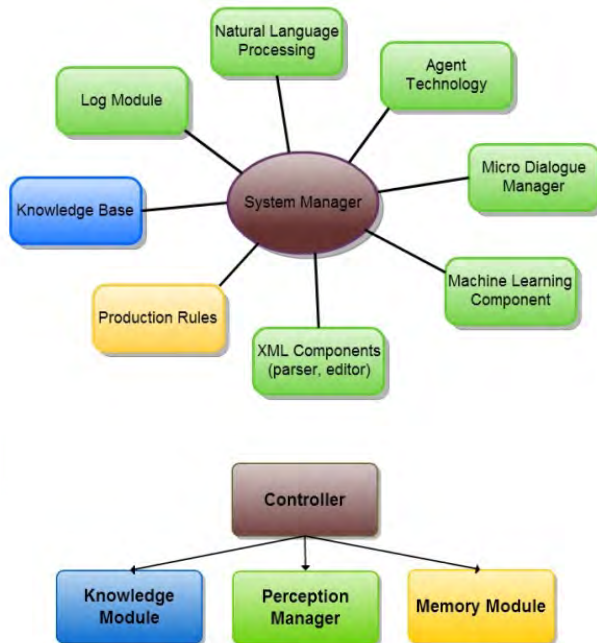
Fig. 3. MetaTutor regarded as an instance of the general cognitive architecture:
the components with the same color correspond to components of the abstract model

Figure 3 reports the Metatutor architecture depicted as an instance of the general model presented in section 3. NLP module, Micro Dialogue Manager, Machine Learning Component, Log Module, and XML parser and editor are mapped onto the Perception Manager because they manage the perception aspects of the system, while Production Rules module is identifiable as the Memory module. Obviously, the System Manager maps to the Controller and the Knowledge Base is identifiable as the Knowledge Module.

3.2 Cognitive Constructor

Cognitive Constructor [18] is an Intelligent Tutoring System Based on a Biologically Inspired Cognitive Architecture (BICA). The term "Constructor" in the name reflects the inherent ability of this system to construct cognitive and learning processes from a metacognitive view. It is based on the

ideas of GMU-BICA and has many of its features, as the mental state framework [17].

The architecture of the system is shown summarily in figure 4, and it is designed to work collaboratively with human users in a lot of paradigms: the user could be a designer, a guide to the agent, a student, etc. All these paradigms require that the human and the system share a common task space; Cognitive Constructor integrates both the user's and the agent's mental states by embedding them into a same symbolic representation of the task space, that provides a symbolic representation of the cognitive paradigm and is made directly accessible to the users interacting with the artifact; this is the virtual environment component in the architecture. Virtual environment is implemented by a buffer.

It can be mapped to some extent onto the Controller of the general cognitive model, because it manages the interactions with users.
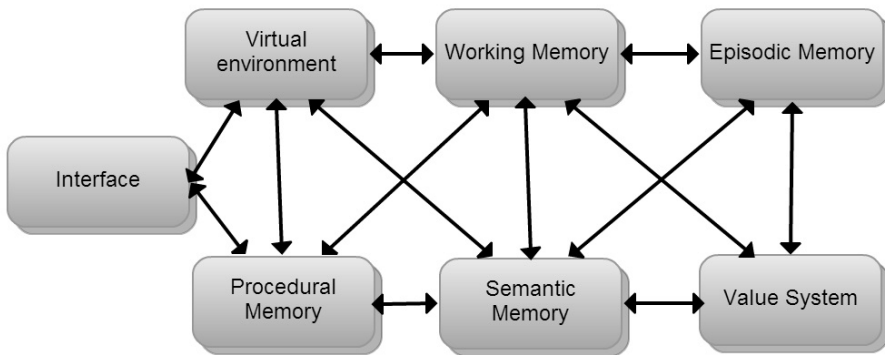
Fig. 4. The Cognitive Constructor architecture

The form, the functional characteristics and the dynamics of subjective experiences in humans appear to be universal and can be described by mental categories (that is a functional token characterizing a certain kind of subjective experience), mental schemas (a functional model of that kind of experience), and a mental state, which is "a set of instances of schemas attributed as the content of awareness to a unique mental perspective of a subject" ([17], 115).

Other components of the architecture with the virtual environment are memory systems: they include procedural, working, semantic, episodic, and value system memories. Procedural Memory consists of a set of sub-symbol-

ic primitives (functions) that connect symbolic representations in virtual environment to the input-output channels, and in general are used to manage such representations. Procedural Memory can mapped to the Memory Module, because such primitives can be intended as production rules to perform changes on the system's state. On the other hand, Working Memory involves the instances of the schemas and is attributed to particular instances of the self i.e. it is organized into mental states as in GMU-BICA, and it's represented as first class objects in virtual environment.

Semantic Memory consists of schemas organized into a semantic net. Schemas may be represented as points in an abstract semantic space based on their semantics. All symbolic representations in the virtual environment, in working and episodic memory are based on such schemas.

Episodic Memory is a set of mental states that were previously active (i.e. they were already present in working memory) and may become active again, although in a different state than in the past.

Finally Value System includes drives and values. A drive is an internal stimulus represented by a number that may represent some resources of the system, global and specific measures of the system activities. A drive can cause the activation of the associated schema. Values correspond to the dimensions of the semantic space mentioned above.

All the memories and the Value System can be mapped onto the Knowledge Base in the general model because they represent the information related to all the aspects of the system's state and interaction. Provided that memories interact with each other according to some internal specification, we can assume that the control functions are spread across all of them so the whole set of memories can be mapped onto the Controller in the general cognitive model (see figure 5).
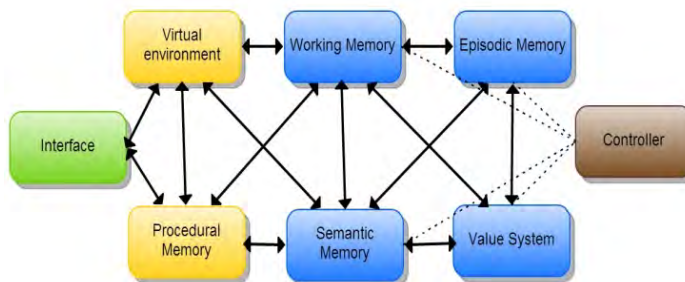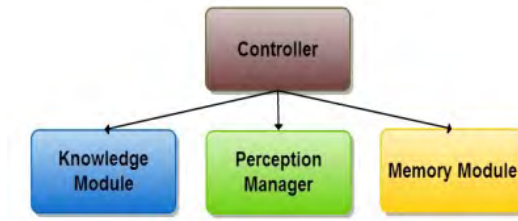
Fig. 5. Cognitive Constructor represented as an instance
of the general cognitive architecture

3.3 Why2-Atlas

Why2-Atlas [19] is an ITS to teach qualitative physics. The system uses natural language interaction to assess the knowledge of the student about simple mechanical phenomena. If the knowledge of the student is wrong or incomplete, the system tries to modify the situation through a dialogue intended to remedy the state of the student. The whole process is repeated many times, until the student's replies are right. Natural language interaction has been used for solving problems at three different levels: the sentence level (implemented by Sentence Level Understanding module – SLU), the discourse level (implemented by Discourse Level Understanding module – DLU), and the pedagogical level (implemented by Tutorial Strategist module).

Communication is managed by the Dialogue Engine. The whole architecture is shown in figure 6.
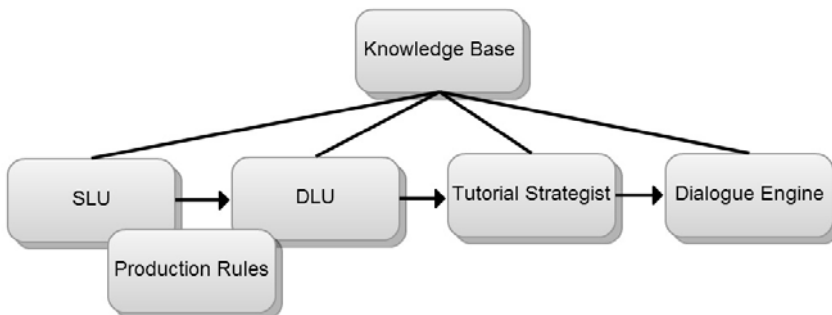

Fig. 6. Why2-Atlas architecture

Each sentence entered by a student is parsed and converted into a set of propositions in first-order logic. These propositions are added to an incremental list. The system tries to prove such assertions starting from its domain knowledge. If the assertions cannot be proven, the system asks more information to the student, or gives an alert signaling that a misconception may be occurred. The result of this control guides the conversation.

At each step, the system chooses the goal of the subsequent part of the conversation to build a correct student's knowledge. Processing a sentence is a very complex task, which involves different analyses at the same time. At the beginning the system corrects the grossest mistakes in the sentence. Next, words are converted into their root forms using a lexicon. This lexicon defines also the syntactic categorization of the words, and possibly a semantic one too. The result of this step is the input of a LCFlex parser.

Parsing relies on a unification-augmented context-free grammar based on both Functional Grammar and Lexical Functional Grammar. If many possible outputs are possible, the system performs a statistical analysis. If the parsing is fragmentary, each fragment is analyzed separately. Then, the system tries to merge them through a genetic search. This task needs a general knowledge of the domain under investigation. If the parser fails, a statistical technique is used that is either a naive Bayes approach or LSA.

The input of the discourse level is made by sentences translated in logical form. The output is a proof of these sentences using abduction. To this aim, the Tacitus-Lie+ system is used. If the sentences cannot be proven, all their facets are returned that make them not provable. The pedagogical level analyzes the list of facets, and plans the next part of the conversation. Planning is achieved by assigning a priority to all the errors made by the student. In the first part of the conversation, the system solves misconceptions. Then, it fixes self-contradictions, errors, and incorrect assumptions.

Finally it fills the gaps in mandatory points. The list of such points is ordered by the user. The goals for remedying a misconception are associated with a specific remediation conversation. In the framework of Why2-Atlas such conversations are called Knowledge Construction Dialogues (KCD). When remedying misconceptions a remediation KCD is used. On the other hand a suitable elicitation KCD is used when the tutor wants to elicit a mandatory point. KCDs are managed by the APE dialogue manager that is invoked with the particular conversation every time it is needed.

In the Why2-Atlas architecture the SLU, the DLU, and the Dialogue Engine can be mapped onto the Perception Manager of the general cognitive architecture, while the Production Rules correspond to the Memory Module,

which includes also the heuristics used for weighting goals. The Tutorial Strategist module governs rules and heuristics for activating parsers, generating FOL predicates, performing assimilation and explanation, and so on. It maps onto the Controller. Each piece of knowledge such as grammar, lexicon, and KCDs is mapped to the Knowledge Module. Figure 7 shows the correspondences outlined above.
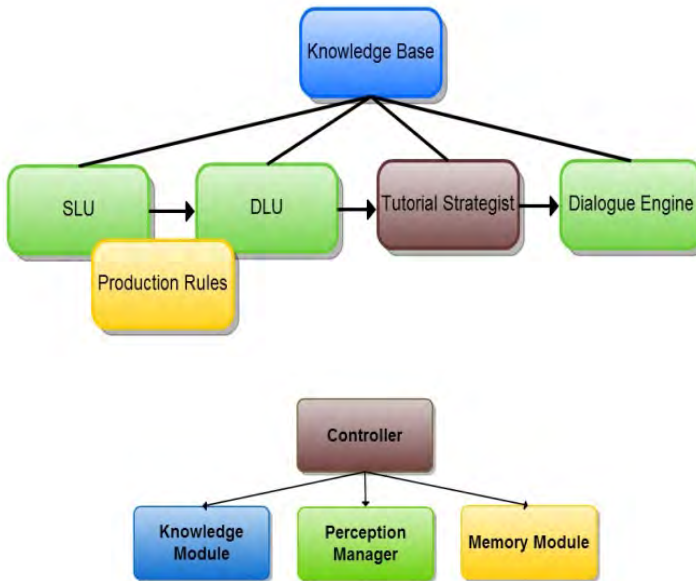

Fig. 7. Why2-Atlas represented as an instance of the general cognitive architecture

3.4 KERMIT

KERMIT [14] is an ITS aimed at modeling Entity-Relational Diagrams according to the ER model specifications [4], which assumes the familiarity of the users with the fundamentals of database theory. Actually, KERMIT is a problem-solving environment where the user acts as a student to build him/her ER schema; KERMIT assists the user during problem solving, and drives himself/herself towards the correct solution by providing tailored feedback considering his/her knowledge.

The KERMIT architecture is shown in figure 8: the main components are

the Interface, the Pedagogical Module, and the Student Modeller. A repository is also present that contains a number of predefined database problems and solutions provided by a human expert. A problem is represented as a tagged text for specifying mapping to the objects in the ideal solution i.e. entities, relationships, and attributes. The student has to highlight (i.e tag) time by time in the text the words corresponding to each entity that he/she adds to his/her ER diagram.

KERMIT's Interface allows the student to present problems and to construct ER schemas for them. The Pedagogical Module drives the whole system in the selection of the messages that best suit the particular student. The Constraint Based Modeller evaluates the student's solution. KERMIT does not have an internal problem solver, because developing a problem solver for ER modeling is extremely difficult. In fact, problems and solutions are described as plain texts: as a consequence, a huge amount of NLP would be needed to compare the student's and the ideal solution.
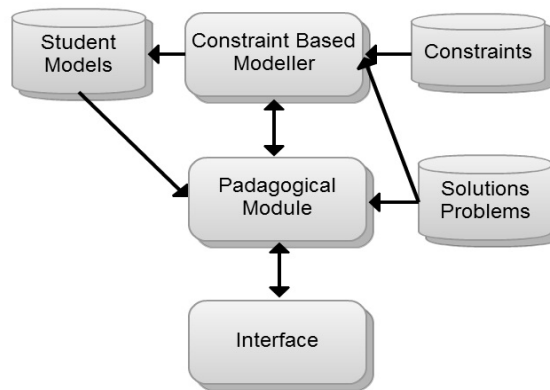

Fig. 8. The KERMIT Architecture

Although there is no problem solver, KERMIT is able to provide students with solutions by using its tutoring knowledge, which consists of a set of 90 constraints. A constraint is defined by a relevance condition, a satisfaction condition and some feedback messages. KERMIT uses such a knowledge to represent the ideal solution for each problem in its repository, and the solution is compared against the student's one where entities have been tagged properly. This comparison is made for testing the student's solution for syntax errors too. The KERMIT knowledge base enables the system to identify

solutions provided by the students that are identical to the ones provided by the system. Moreover, such a knowledge allows the system to provide alternative correct solutions.

The Pedagogical Module generates appropriate feedback messages for the student, and selects new practice problems. Feedback messages are presented to users when a constraint is violated. There are are six levels of feedback: correct, error flag, hint, detailed hint, all errors and solution. When the student gets a new problem, the feedback level is at a correct default value. This level is incremented with each submission until it reaches the detailed hint level. The system also gives the student the freedom to select the level of feedback manually, thus providing a better feeling of control. When selecting a new problem, the student model is examined to find the constraints that have been violated most often. This simple problem selection strategy ensures that the user gets the most practice.

If we regard KERMIT as an instance of the general cognitive architecture, it's easy to devise the Interface and the Pedagogical Module as the counterparts of the Perception Manager because they are related with dialogue and feedback to users. The Constraint Based Modeller can be mapped onto the Controller because drives the actual tutoring process, while Knowledge Module is represented by the repositories containing problems and students solutions. Finally, the Constraints repository can be regarded as the actual Memory Module in KERMIT. Figure 9 represents correspondences.
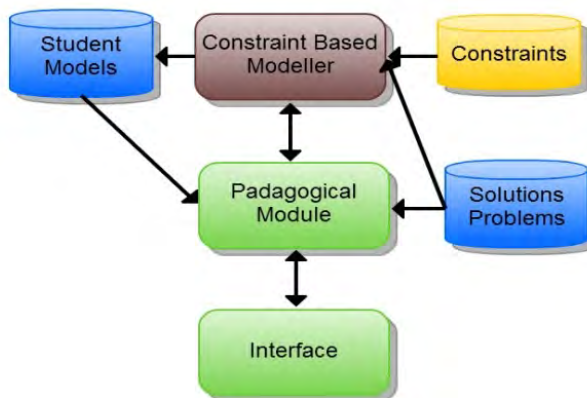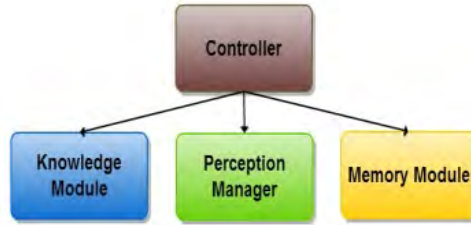
Fig. 9. KERMIT represented as an instance of the general cognitive architecture

3.5 Learning by teaching

Often, a student can profit from teaching others. The final effectiveness of such a learning process is uncertain. A student could learn nothing from a tutor that is learning too. To investigate this topic, many researches have been carried out by using teachable agents. A teachable agent is a peer learner that can be tutored by a student.

SimStudent [13] is one of the most significant examples of teachable agent. It is a pedagogical machine-learning agent, developed as a tool to investigate learning by teaching. It is based on the "programming by demonstration" paradigm developed through inductive logic programming. SimStudent is able to learn cognitive skills inductively from examples or through tutored problem-solving.

In the first case the user provides examples to the system. Only positive examples are presented. In fact, the analysis is made considering a closed world assumption. A positive example of a particular skill K implicitly has to be considered as a negative example for all skills other than K. The system tries to formulate hypotheses represented as production rules. The user provides a feedback by either accepting or rejecting hypotheses.

When learning by tutored problem solving, the system tries to solve a collection of problems. The system conjectures some possible solutions to each problem. A solution can be made up by a sequence of steps. For each step, the user provides a feedback.

When this feedback is negative, the system tries to correct the proposed solution. Sometimes, when it is not able to find a solution, it can ask the user for a hint. After collecting examples, the system generalizes them inductively

using background knowledge, and generates a set of production rules to represent the learned skills. The main difference between SimStudent and other teachable agents is that it is able to model the human modality of learning. In particular, it is useful to model human errors due to inappropriate inductions.

Betty's Brain Betty's Brain [11] is a computer-based learning environment inspired to the learning by teaching paradigm. The student has to tutor a computer agent named Betty. To this aim, it has to draw a visual representation of the learnt subject through a concept map. During this task, the agent emphasizes the involved cognitive and metacognitive abilities used by the student. The system can be used by a single student, or by an entire classroom. In the second case, drawing the concept map is a cooperative task.

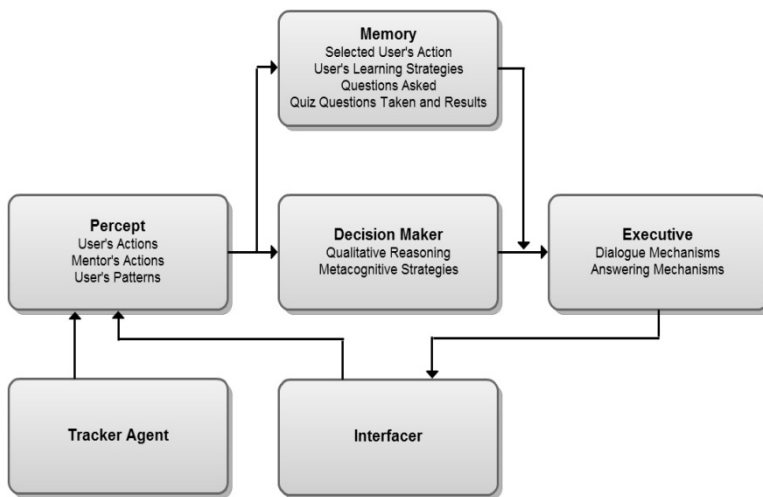The architecture of the system is reported in figure 10.

Fig. 10. Betty's Brain architecture

Creating the concept map allows the student to share his/her knowledge with the system. The student can monitor, assess, and reflect on his/her own learning. For example, he/she can pose questions to Betty, and observe how the system replies. The system was implemented as a Java client/server architecture. Betty can use qualitative reasoning methods to reason through chains of links for answering questions and explaining its reasoning.

Occasionally, the system can detect possible incoherencies in the map thus alerting the student to the problem so as she can correct the map. In this way, the student can reflect about what and how he/she is teaching. Students can reflect on the answer of Betty. If it is wrong, the student can modify the map to improve the performance of the system.

This approach stimulates self regulated learning. The student has to define goals related to the learning materials, to plan learning strategies, to monitor how learning evolves, to revise knowledge and strategies for reaching the goal. The system can involve also a human teacher in the interaction. This functionality could be used in a classroom. In this case, the teacher can coordinate the process of authoring the shared concept map as the result of merging distinct concept maps produced by each single student. The system allows to compare different concept maps. In this case, the user can assess such maps, and observe how different models of a same domain can modify the replies of the system.

As many other similar systems, Betty's Brain has been developed as a research tool to be used for investigating the role of cognitive and metacognitive skills in learning by teaching. In particular, the system offers many different functionalities to collect and analyze interaction data.

Looking at figure 10, the Interfacer, the Tracker Agent, and the Percept component of the Betty's Brain architecture can be mapped to the Perception Manager in the general cognitive architecture because they are related to managing the communication with the user. On the other side, the Decision Maker, and the Executive component can correspond to the Controller such as the Mentor module in the most recent version of Betty. Decision Maker includes the strategies for planning qualitative reasoning, so the part that includes the rules for such a process can be regarded as the Memory. The Memory in Betty can be mapped to the Knowledge component because it contains the knowledge generated in Betty's Brain during the learning process. Figure 11 represents the whole correspondence to the general cognitive architecture.
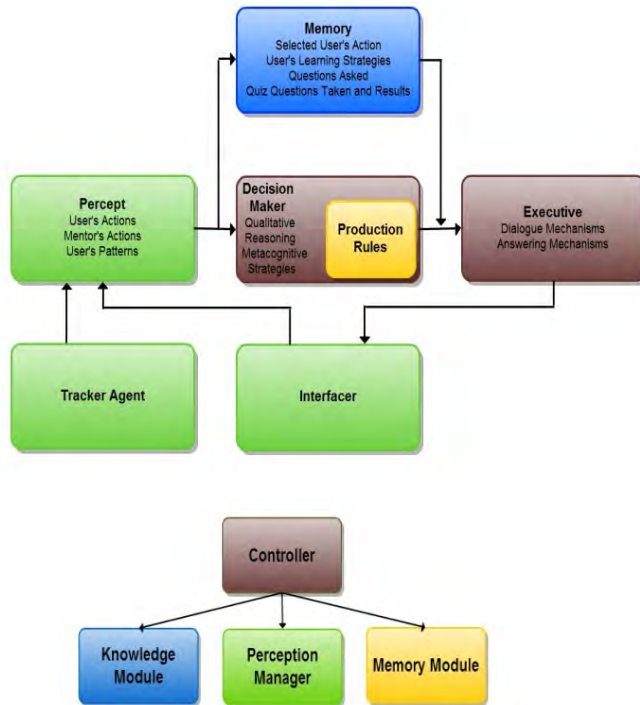
Fig. 11. Betty's Brain represented as an instance of the general cognitive architecture

4. Conclusions

The main aim of this chapter was to provide a review of the most widespread ITSs in the literature form an AI oriented perspective. Intelligent Tutoring Systems are one of the main application fields to build artificial agents. In particular, the most well established paradigm to cope with such a task is to use cognitive modeling. An Intelligent Tutor is definitely a cognitive agent; it has to accomplish the following functions:

- perceiving the surrounding environment, i.e. the actions performed through the GUI, the statements produced by the learner, the learning materials that have been accessed, and the affective status of the user (i.e. posture, eye movements, facial expressions);

- estimating the student's mental state as regards both cognition and metacognition: some internal representation of such a state has to be available; moreover the agent has to build the representation of the learning domain to enable assessment of the student, and to select suitable learning strategies;
- acting properly to elicit both cognitive and metacognitive abilities in the learner, thus modifying the surrounding environment.

Following this assumption, the chapter presented a review of the main cognitive models in the literature, and proposed a simple general cognitive architecture, which abstracts all the differences, while focusing on the macro-functions shared by all the models: perception, memory, control, knowledge.

The main ITSs have been described next, and a comparison with the general cognitive architecture has been carried out for each of them.

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3. Data Mining in Education

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Introduction

The traditional methods of turning data into knowledge relies on manual analysis but as computerisation has become wide spread the amount of data available from which knowledge can be gained exceeds what can be done manually. So the new field of data mining (DM), and the related field of knowledge discovery in databases, have developed as computer based process of discovering interesting and useful patterns within data [1]. It is a field that combines various tools and techniques from statistics and artificial intelligence with data management to analyse large data collections to discover new or previously unseen correlations within the data to create a deeper understanding of the information. DM has been successfully utilized in a wide variety of fields such as business, scientific research and governmental security [2].

Within the educational sector large repositories of data are accumulated. Data comes from the processes of formal education, such as student performance records, achievements and library records. It is all generated through students' and staffs' participation or lack thereof within virtual learning environments and learning management systems provided by the education provider (for example universities and schools). With the generation and retention of this data there is an opportunity for utilizing DM to understand students' and staffs' a great deal about both staff and students involvement in the educational process.

An early example of this is the use of DM in a traditional educational set-

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ting to understand the student enrolment [3]. However as the use of electronic environments for learning has become more popular there has been an increasing interest in using DM to obtain understanding of the student learning experience, which is otherwise very difficult to obtain. In conventional face-to-face teaching educators are accustomed to being able to obtaining feedback as part of the direct interaction with students and so are able to evaluate the teaching program continuously [4].

The results from the DM processes are most commonly used by human tutors to understand the learners, however these results can also be used by automated processes within the system. Recently a lot of research has gone into creating adaptive and "intelligent" educational systems that attempt to adapt to the learning of students by building models of goals, preferences, knowledge and content for each individual student to target the needs of the individual rather than the group, and thereby create an artificially intelligent tutoring system [5].

1. Main applications

The vast amount of data produced by courses with an online element provides a rich source for DM that is relevant to a range of target groups, including educators and instructional designers, and different levels of use, that can be related to pedagogical approaches and decisions, and to organisational needs. Most easily accessed data is that emanating within in a given environment (i.e. LMS, VLE) in the context of blended and distance education. There is potential for including the use of sources of data coming from the web, however the complex socio-technical interaction is largely as yet unexplored, although certainly it will be the subject of future research.

According to Romero and Ventura [5], the relationship between educational tasks and DM techniques can be categorized into eleven areas, namely:

	Cluster	Users	Reasons (educational task)
A	Analysis and visualization of data	Educators Course administrators Teachers, tutors, (Students)	To highlight useful information and support decision making; to analyse the student's course activities and usage information to get a general view of a student's learning
B	Providing feedback for supporting instructors	Authors Teachers Administrators	To provide feedback about how to improve student's learning, organise instructional resources, etc. To enable the target group to take appropriate proactive and/or remedial action
C	Recommendation for students	Students	To make recommendations directly to the students with respect to their personalised activities, links to visit, tasks to be done etc.
D	Predicting student's performance	Teachers Tutors	To estimate the unknown value of a variable that describes the student (performance, knowledge, score, or mark)
E	Student modelling	Teachers Tutors Instructors	To develop cognitive models of human users/students including modelling of their skills and declarative knowledge
F	Detecting undesirable students behaviours	Teachers Tutors Counsellors	To discover/detect those students who have some problems or unusual behaviours, such as: erroneous actions, low motivation, playing games, misuse, cheating, dropping out, academic failure, etc.
G	Grouping students	Instructors Developers	To create groups of students according to their customized features, personal characteristics, etc.

	Cluster	Users	Reasons (educational task)
H	Social network analysis	Students Teachers Tutors	To study relationships between individuals, instead of individual attributes or properties
I	Developing concept maps	Instructors Educators	To help instructors/educators in the automatic process of developing and constructing concept maps
L	Constructing courseware	Instructors Developers	To carry out the construction and development process of courseware and learning contents automatically To promote the reuse/exchange of existing learning resources
M	Planning and scheduling	Teachers Tutors Students	To enhance the traditional education process by planning future courses, helping with student course scheduling, planning resources allocation, helping the admission and counselling processes, developing curriculum etc.

Table 1. Categories proposed by Romero and Ventura (Romero and Ventura 2010) and their description (adapted)

At a different level, all these actions support learning: (D), (G), (L), (M) are more directly related to the organisation of learning, resources, grouping of students, to students to organise their schedules, etc.; (A), (B), (D), (E), (F), (H), (I) are of advantage especially of tutors, teachers and educators, even if for example (H) social network analysis and (A) Analysis and visualisation of data may be useful for the students too, who may wish to promote self-reflection and self-regulated learning. Finally, (C) is addressed to students only.

In this work, we focused our attention on the topics that we consider particularly relevant in distance learning, where the relation between educators and students takes place in virtual environments, and where the educators should put in place different strategies from the ones apllied in the face to teaching/learning context to learn about students, and to distinguish their

trajectories in the learning pathways. We therefore focused our analysis on students' performance (D), students modelling (E), and detection of students behaviour (F). These three interrelated categories can significantly impact both in learning support and in students management, and the advancements in these areas might highly impact on intelligent tutoring improvement.

The DM techniques used in any situation are varied and although broad they can be classified in a variety of ways. Fayyad, Piatetsky-Shapiro and Smyth [1] state:

> "Data mining involves fitting models to, or determining patterns from, observed data…
> Most data-mining methods are based on tried and tested techniques from machine learning, pattern recognition, and statistics: classification, clustering, regression, and so on. The array of different algorithms under each of these headings can often be bewildering…"

While Tan, Steinbach and Kumar [36] explain data mining tasks as generally divided into two major categories:

- Predictive tasks including classification and regression.
- Descriptive tasks including association analysis, cluster analysis and anomaly detection.

Roiger and Geatz [34] similarly state:

> "…data mining strategies can be broadly classified as supervised or unsupervised"

where supervised is equivalent to predictive and unsupervised to descriptive.

Romero and Ventura [13] identified that within an educational context studies could be classified as using DM approaches: Association, Classification, Clustering, Outlier detection, Prediction, Sequence pattern, Statistic, Text mining, Visualization. Stratifying these into broad categories of: Statistics (including statistic and visualization) and Web mining (the remainder), their Statistics category is based upon simple analysis and visualisation of usage statistics. While Web mining encompasses techniques from artificial intelligence to discover deeper knowledge about educational use.

In table 2 we classify the DM techniques used in different work as: Predictive, Descriptive, or both; and we use free format to identify the methods used by the authors.

There are many ways to identify research literature in particular fields including: chaining from known references [35]; following known resources [39] structured searches of databases such as undertaken in [38]. Here we adapted the approach used by [40] in which "Relevant research was retrieved through a series of search efforts, and eligible research meeting the selection criteria was identified."

As an initial criteria, we focused on the review of the works carried out in education and training for young adults and adults (higher education, training and adult education), who are the primary target of distance education: we discovered that research is carried out mostly in higher education settings. This is probably due to the availability of data, and to the permission to access them.

As additional criteria, we selected only research with experimental validation in real settings (with real datasets).

We focused our attention particularly on the articles published by the Journal of Educational Data Mining (JEDM), supplemented by scientific journals and books on Artificial Intelligence and Computer Science . We consulted abstracts and selected articles published after 2010 only: the work of Romero and Ventura valuably describes the state of the art of EDM until June 2010. The following classifications are based on reading and re-reading the articles identified and classifying the DM techniques used on the basis of the categories and sub-categories from Romero [13] as summarised in Table 2.

1.1 Student performance

Analysis of students performance is a source of feedback for educational staff on the effectiveness of their teaching, and a source of information to understand if specific characteristics of the student lead or hinder educational attainment. The use of these EDM results can be of a great advantage of the educators and tutors to recognize and locate students with high probability of poor performance in order to arrange focused strategies to support them. In facts, student performance is a key area of EDM, and much work has been done in this domain.

Recent research focused on prediction of final marks [6], [7], responses [8], performance [9] [24], and proficiency [10].

1.2 Student modelling

In general terms, student modelling involves the construction of a qualitative representation that accounts for student behaviour in terms of existing background knowledge about a domain and about students learning the domain, "student modelling is the construction of a qualitative representation, called a student model, that, broadly speaking, accounts for student behaviour in terms of a system's background knowledge. These three – the student model, the student behaviour, and the background knowledge – are the essential elements of student modelling, and we organize this section around them" [11]. Therefore, modelling encompasses representation of skills (in a given domain), knowledge about learning (meta-cognition) and behavioural constructs (motivation, emotional status etc.). Student modelling is a relevant area for EDM and generally ITS, and in recent years there have been remarkable advancements in educational data mining methods in this field [12], [13].

More recent research on student modelling focused on the tracing of student's sub-skills and latent skills[1] [14], on cognitive models identification and comparison [16]. [33], and generally on learning behaviours [18], [19].

1.3 Detection of students behaviour

Students' behaviour analysis can be a useful source to detect earlier problems in learning and/or unusual behaviours such as erroneous actions, playing games, misconceptions and above all disengagement. Pedagogical actions of human tutors are often related to the ability to understand how being effective in providing tailored strategies to support students, and then to anticipate potential school failures: learning is a complex process interrelated with all aspects of development, including cognitive, social and emotional development, that should be all taken into consideration in the pedagogical action. The effective characteristics of students are in this respect of high interest, social behaviours of online students may enhance the potential of artificial intelligence to support effective learning. In online learning as in the classroom, the ability of the tutor and of the teacher to analyse and understand behaviours is crucial to provide individualised learning and possible in-time remedial actions.

Detecting undesirable student behaviours in online learning environments by means of automated tools can also have a relevant impact in avoiding drop-out of students, especially at an academic level [22].

2. Technological implications

Data mining is a broad field within computer science with many available different techniques and methods. They range from simple statistical tools to complicated rule modelling tools and artificial intelligence techniques. New methods are still being developed and through that new possibilities are becoming available. This makes this field an interesting field for a technologist, however it presents problems for educationalists, who more likely than not do not have the knowledge and skills to use these techniques effectively, if at all. To utilise these methods effectively there is a need for more user-friendly EDM tools aimed at educationalist. Some educational tools, such as Blackboard and Moodle, provides statistical tools that can be used to study student's behaviour which are relatively simple to use, however the "depth" of knowledge that these provide for the users are mostly limited compared to what more elaborate data mining techniques might provide. It is this next level of knowledge possibilities that are difficult to generate currently without a Computer Science degree.

A more fundamental problem within the educational area is access to data. A diverse pool of data is generated within educational institutions, from Primary schools to Universities, but it can be problematic to gain access to it.

There is a multitude of systems that store the data, and there is not necessarily a clear connection between the systems. In the world of business there is an incentive to perform data mining to increase sales and value, thus business utilise the methods and make sure that different systems get connect. However it is not as clear within educational institutions. Different departments within a University might be protective of the data they possess to ensure that there are no mistakes made or privacy is not violated. For instance it is not as clear to the financial department or the exam's office that it is a good idea to open their databases to data mining with data from the teaching and learning department's virtual learning environment in order to spot possible drop out students.

Serious obstacles might have to be crossed before data mining becomes possible and big questions might have to answered, e.g. do we violate student's privacy and the rules that govern privacy by introducing the new data mining methods? Can we use minors' data in our analysis?

Before these issues are investigated and a solution has been found within the institution, data mining should not be performed, no matter how useful the results might be.

3. Pedagogical implications

The relationship between technology and pedagogy is neither neutral nor unbiased: technological decisions can greatly impact on the use of a new tool in educational settings, and pedagogical instances can also impact on the correct use – even on the up-taking – of new tools or services.

Educational data mining has a great potential to support learning and education beyond the already mentioned organisational settings of educational institutions and e-learning instructors, EDM can answer pedagogical needs especially in distance learning.

This potential can be exploited

- For tutors, teachers, trainers: by providing representations of the students online behaviour, both individually (i.e. consulted documents, results achieved, contribution in forums etc.) and of the online classroom/learning group (i.e. by means of social network analysis, analysis and representations of interactions; by highlighting 'deviant' behaviours, for instance misconceptions, recurrent errors, playing games, for an early intervention; by keeping updated on the scheduled activities and on the students respect of deadlines; by providing representations of available resources for a given subject, and cross the data between students modelling and suitable resources.
- For students: by positioning the student within a group, by means of representations of the classroom achievements (e.g. using social network analysis) or representation of intermediate (individual) achievements in a learning pathway, thus develop gaming aspects into learning, i.e. gamification of learning, by supporting the student in finding alternative and additional learning resources on a given subject; by helping with organisation of learning, scheduling of activities, respect of deadlines.

In general, EDM has therefore a great potential particularly in supporting the effective management of the students, including improvement of individualised learning and early interventions in challenging cases, and in fostering self-regulated learning (SRL).

Research shows interesting advancements in the use of EDM to promote SRL. What characterizes self-regulated learners is their active participation in learning from the metacognitive, motivational, and behavioural point of view [25]: according to [26], "self-regulated learning (SRL) concerns the application of general models of regulation and self-regulation of cognition, motivation/affect, behavior, and context to issues of learning, in particular, aca-

demic learning that takes place in school or classroom contexts". Further research [27], [37] analysed SRL strategies activated within hypermedia environments [27] and suggested to "design learning environments that contain the necessary instructional supports to accommodate skills that have yet to develop, are in the process of developing, or are in the process of being automated with additional practice" [37].

As a matter of fact, learning environments are the main contextual factor that can both foster or constrain learning, research has suggested that even efficacious students may experience decreases in their self-efficacy as they learn with environments that are too challenging to use [28]. In addition, hypermedia environments offer a wide range of information represented in different media, which is structured in a nonlinear fashion and therefore requires, in comparison to non-hypermedia environments, a higher deployment of SRL strategies [37]. The online student deals with a greater availability of resources: if the role of educators is also to prepare scaffolding in order to facilitate the students in an appropriate use of multimedia resources, automated agents could efficiently guide the students to access and use these resources – then promoting SRL. Likewise educators can take advantage of automated mechanisms in organising learning materials and individualise learning pathways.

The classroom dimension seems to being less explored by the research community, while learning and pedagogical theories agree on the principle that interaction – with teachers, with peers, with environment – play a fundamental role in the learning processes [29] [41] [42]. Social and contextual elements are therefore of remarkable impact in learning outcomes, particularly engagement and motivation in learning can be affected in a significant manner by social dimension and contextual settings. To this respect, specific reference for the use of EDM techniques in helping the individual student to compare his/her learning progress in comparison with peers, may offer additional motivation. Didactical approaches as peer monitoring, peers assessment, along with the natural tendency of the students to assess themselves in relation to peers (not only in relation to their personal learning goals), suggest the opportunity to better explore the use of EDM techniques to offer for instance though visualisation of a learning group data to the student. At the best of our knowledge, analysis and visualization of data tools are at present made available and tailored for teachers, instructors, and administrators, but rarely for students.

We believe that the capability of EDM to answer effectively pedagogical needs depends especially on two main elements:

1. **The user**. Most of the research carried out so far has a limited integration with the user perspective and with the users generally, at least until the testing phase or the release of the tool. On the contrary, the direct involvement of the users from the beginning of the design stage would allow (a) to provide tailored research; (b) to avoid mistakes in programming. The user, who can be the teacher, the tutor, the student, knows better the parameters, the meaning and the values of the settings; (c) to provide usable tools: the educational players are not programmers, or researchers, and they need friendly interfaces and easy reading of data. Development approaches such as rapid prototyping, extreme programming, and other agile methods with involvement of users in testing cycles might aid the development of these tools.

2. **The e-learning systems**. Online learning is already a reality in education, and what is already in use should be taken into consideration by the researchers for further development. The works carried out on Moodle, which is among the most popular Learning Management Systems, are very promising in this respect [23], [32], as well as the studies on Blackboard Vista [30], [31]: developing tools dealing with these learning management systems might impact on a huge number of users and support significantly teaching and learning.

Conclusions

Educational Data Mining is a very promising field of development both for computer science and pedagogy. Recent research and trends show an incremental interest on the application of automatic analysis and of the discovery of unseen correlation between data in education and learning settings. In this chapter we reviewed recent publications in EDM, and we highlighted the general trends and the main subjects that are worth of consideration in further exploiting the potential of EDM.

We identified as main topics to be considered in further research:

- Privacy issues are crucial in the use of educational data, and they require agreements and decisions at institutional level;
- The user perspective (of all players of the field, from teachers to students) should be integrated in the development of new services and tools, ideally from the design stage;
- EDM research should focus on existent and in-use learning environment to foster its up-taking within educational and learning settings;

- Forecast trends in distance education, included the use of social technologies, should be considered by researchers.

Generally, the establishment of an improved dialogue between the educational field (at organisational level, pedagogical level, didactic level etc.) and the computer scientist would remarkably enhance the future of this emerging discipline.

Author	Title	Technique	Focus
Akinola, Akinkunmi and Alo 2012	A Data Mining Model for Predicting Computer Programming Proficiency of Computer Science Undergraduate Students	Predictive. Artificial Neural Networks	Student performance
Behesheti, Desmarais and Naceur 2012	Methods to find the number of latent skills	Predictive. Singular Value Decomposition	Student modelling
Bergner et al. 2012	Model Based Collaborative Filtering Analysis of Student Response Data: Machine Learning Item Response Theory	Predictive. Collaborative filtering.	Student performance
Bouchet et al. 2012	Identifying Students' Characteristic Learning Behaviors in an Intelligent Tutoring System Fostering Self-Regulated Learning	Descriptive. Clustering	Student modelling
Gonzalez-Brenes and Mostow 2012	Dynamic Cognitive Tracing: Towards Unified Discovery of Student and Cognitive Models	Predictive. Bayesian network	Student modelling
Koedinger, McLaughlin and Stamper 2012	Automated Student Model Improvement	Descriptive. Learning Factors Analysis, statistical.	Student modelling

Author	Title	Technique	Focus
Lopez et al. 2012	Classification via clustering for predicting final marks based on student participation in forums	Descriptive and predictive. Clustering and Classification	Student performance
Mccuaig and Baldwin 2012	Identifying Successful Learners from Interaction Behaviour	Predictive. Decision Trees	Student performance
Obsivac et al. 2012	Predicting dropout from social behaviour of students	Descriptive. Social Network Analysis and entropy	Detection of student behaviour
Peckham and McCalla 2012	Mining Student Behavior Patterns in Reading Comprehension Tasks	Descriptive. Clustering	Student modelling
Tsai Ching-Fong 2011	Data mining techniques for identifying students at risk of failing a computer proficiency test required for graduation	Descriptive and predictive. Clustering and Decision Trees	Student performance
Yadav et al. 2012	Data Mining: A Prediction for Performance Improvement of Engineering Students using Classification	Predictive. Decision Trees	Student performance

Table 2. Classification of Educational data Mining (JEDM) 2012
http://www.educationaldatamining.org/JEDM/

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Note

1   http://www.educationaldatamining.org/JEDM/

2   For comparison of methods to for tracing multiple subskills see (Xu and Mostow 2012)

4. User Profiling in Intelligent Tutoring Systems

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Introduction

A user profile is a sort of description of the individual that uses a particular software application. It contains pieces of information about the basic characteristics and habits of the user. Discovering these individual peculiarities is vital to provide users with a personalized service. This customization has different meanings depending on the particular context in which it is applied. In e-commerce, for example, the consumer profile is used to offer the best offers in relation to the preferences of the buyer or to suggest a product that presumably could be of interest. The case of an Intelligent Tutoring System is different, because the purpose of the reconstruction of a user profile is to allow the design of a learning environment and of a guide for the student, that could be the more possible coherent with the personal particularities of each individual.

Changing the type of customization that the profile allows, it varies also the content that the profile includes. If, for example, we would like to customize the use of an online newspaper, the user profile should contain information on the type of news most analyzed from the reader or those relating to his/her reading habits. The information contained in the profile, in addition, may be collected in multiple ways, even different depending on the context in which we use it. In some cases it would be sufficient to consider just the information provided explicitly by the user, but in other cases, as in relation to ITS, it is necessary to use intelligent agents able to infer characteristics of the user even if they are not directly explicated.

Over the last twenty years there have been several investigations in order to design and test the most effective way to build and use profiles designed specifically to customize online learning environments. The information gathered from these profiles, and how to retrieve and process information vary according to different research hypotheses.

One of the first factors which the researchers have analyzed is the level of knowledge possessed by the student in relation to a specific domain. This element is considered essential in order to provide suitable assistance and to adapt the content of the courses according to the specific situations. For this reason, various procedures have been analyzed to build profiles that represent the user's knowledge in different ways.

1. User profiling in ITS

According to the creators of ANDES [1] one of the most sensitive functionality of an Intelligent Tutoring System should be the ability to respond effectively to the requests of its users. This operation requires an adequate understanding both of the knowledge that the individual possesses in relation to a specific domain, and of the solution path that the person is supposed to follow. To resolve that question ANDES uses a model that can infer both the student's knowledge and his/her objectives. For this purpose the system evaluates, in a probabilistic way, three types of information:

- the general knowledge of the student in relation to the field of physics;
- the specific knowledge of the student in relation to a specific problem;
- the path that the student intends to pursue in order to solve that problem.

At the University of Missouri-Columbia [2], in order to create greater personalization within an intelligent learning system, called IDEAL, an intelligent agent has been designed and tested to build user profiles useful to measure skills possessed by the students or developed during the course of study.

The authors of IDEAL start from the consideration that the student actively involved into the learning process can have better possibilities to reach personal success. In order to gain such implication, the system they produced pays a lot of attention to the interaction between the student and the ITS and customizes the learning process to the needs of individual students.

Students are very different because they have different personalities, learning experiences, backgrounds and skills, and they will also change over time. IDEAL represents a multi-agent system, whose intelligent agents realize different activities and functionalities. One of these agents is in particular designed to build users' profiles able to select and summarize the most important information. Such information are used by the system to select, organize and present learning materials in a different way, depending on the specific student, thus supporting a most active learning.

According to IDEAL's authors, an efficient profile should not record just what a student knows, but it also must take into consideration his/her behavior and characteristics. Despite this, analyzing in particular the way in which the profiles are constructed inside IDEAL, there seems to be a discrepancy between their beliefs and what the system achieves in practice. Inside IDEAL, in fact, the profiles are designed to measure, in a probabilistic way, how well some skills have been learned by the student, placing them along a scale (Novice, Beginning, Intermediate, Advanced, Expert).

In IDEAL the topics are presented in a graph, where links represent the relation among other topics. Each topic includes its prerequisites, co-requisites, related and remedial, that are to be learned just in some cases. Each topic is subdivided into subtopics, that allow to reach a finer understanding of the topic. The content of the subtopic are generated dynamically, according to the data recoded in the student's profile. Students can pass from a topic to another just when they can demonstrate that they have sufficiently learned the first one. The performance of the student on a topic is determined following three factors:

1. Quiz performance: the administration of a quiz relative to each topic can give the most direct information about the student's knowledge. Every next quiz is created dynamically for each student, thanks to the information recorded in his/her profile.
2. Study performance: it represents the way students interact with the materials of the courses, so it measures how much time the student spends on a topic and whether he/she uses multimedia materials.
3. Reviewed topics: it is based on how many times a topic is reviewed by a student and what kind of materials he/she consults more than once.

The path just described summarizes the way in which IDEAL models the learning environment according to the user's characteristics taken into consideration within the profile.

According to Xu, Wang and Su [3], in order to improve intelligent learning systems it is important to focus the attention on the personalization of the learning environment. Personalization is necessary to stimulate the motivation of the students, that is considered as the key of a successful learning process. Different people need different way to be stimulated. Students, in fact, have different personalities, backgrounds and learning experiences. In order to stimulate their motivation in a meaningful way, it seems to be fundamental to know the characteristics of the students we are referring to. This is just the aim of the creation of a student's profile. This is the reason why they presents a profiling system able to make a complete description of students' needs. The agent that creates this kind of profile is included into a multi-agent systems, composed by five sections with different functionalities:

1. Student profile: it stores learning activities and interaction history. It is created by an applications which is able to store both static information, as the previous course followed by the student, and dynamic information, as the learning activities that the student is doing.
2. Student model: the student model represents the abstraction of the data recorded into the student's profile.
3. Content model: it contains the definition of each topics and the relationships among topic.
4. Learning plan: based on the student model and the content model, the system creates a personalized learning plan.
5. Adaptive interface: it involves materials, quiz and advise that are personalized according to the characteristics of the student.

The cooperation among these intelligent agents is presented as an efficient way to personalize and improve intelligent learning systems.

Another example of an intelligent agent designed to make an online learning environment, that is addressed to students of engineering, is e-Teacher [4]. This system observes user behavior while participating in online courses to build their profiles automatically. The profiles include general information about the subjects' performance, such as exercises done, topics studied, exam results, but focus primarily on identifying the particular learning style that characterizes the student. All these elements are then processed by the system to effectively assist the student, suggesting personalized lines of action, according to the profile identified, that could support them during the learning process.

As in the case of e-Teacher, there are additional examples of intelligent agents that build profiles inferring the particular learning styles of individuals. SE-Coach is a learning module, inserted in ANDES, designed to assist students in the understanding of written instructional materials. To obtain such assistance, the system uses an adaptive interface that encourages the students to provide self-explanations while they are reading, even when they are not naturally used to carry out such operations. Nevertheless, according to the authors of this interface, it is essential that the system should intervene only when students can really benefit from the suggestion. In fact, constantly asking to all type of user to make explicit their thoughts, the system could also damage those who do this work spontaneously, without the need of a suggestion. It could also compromise their motivation. Therefore, to determine when to intervene, SE-Coach can count on a probabilistic model that assesses student attitudes and student learning styles. In this way the system can infer when and how to intervene.

Niesler and Wydmuch consider the adaptability to the needs of the user of an Intelligent Tutoring System as an issue of great importance. However, they point to the fact that there is a gap between theory and practice, as there are a lot of researches about it, but few solutions have been created in practice. The reason for this situation lies in the fact that characterize the human factor in a definitive way is very difficult, especially because of the psychological components involved.

According to the authors, the learning process depends primarily on a series of psychological conditions, which are different from individual to individual. These conditions are called personal predispositions and are linked to three factors: memory, understanding and content association. A good activity of user profiling is the key to having a good communication between the user and the ITS. Personal predispositions represent very important kind of information, so an efficient profile should be able to select them. People are often not aware of their predispositions, therefore they are not able to know what works best for them. For this reason, the profile should infer this information in an automatic way, analyzing their behavior.

But a profile that only includes personal predispositions is not a complete profile. Another very important factor is related to the user's preferences, that are linked to the particular type of personality. In order to define personality types the authors use one of the most popular methods, the Myers-Briggs Type Indicator (MBTI). The method is based on the description of a series of mental functions:

- attitude towards outer world;
- processing information;
- making decisions;
- organizing life.

These factors represent dichotomies on bipolar scales and they constitute the opposing preferences:

- Extraversion – Introversion
- Sensing – Intuition
- Thinking – Feeling
- Judging – Perception
- Personality type derives from the combination of all four criteria.

In order to summarize, we can say that, according to Niesler and Wydmuch, the psychological aspect plays a crucial role in learning process. User profiling should involve at least two factors: personal predispositions and user's preferences.

During the last ten years, research on user profiling has begun to examine new aspects considered essential for the reconstruction of students' profiles even more effective. For this reason, researchers have introduced new elements of analysis, such as affective states. Initially, the investigations were focused on the types of emotions involved. They started with more general models, which included general emotions such as fear, happiness or anger, and then they moved to more complex models, specifically designed according to the context of education, which include specific emotions such as uncertainty, frustration and boredom. Subsequently, on the basis of these considerations, several systems have been designed to detect these emotions in students using educational software.

One of the first work in this direction is that of Conati [5] which aims to detect the emotions of subjects while interacting with an educational game. For this purpose, the authors use a combination of physical sensors and the analysis of aspects related to the monitoring activity.

Mota e Picard [6] develop a model able to understand the interests of users from their postures. Forbes e Litman [7] create a system useful to measure the level of uncertainty in individuals from the analysis of audio files. D'Mello [8], experiments a system to detect affective and cognitive states even more specific in relation with the educational contest. Chaouachi e Frasson [9] use sensors to infer the attention level of users.

Those mentioned above are all examples of researches that have revealed interesting results and possibilities, but they all share an element that could limit their application: the use of sensors. Precisely from such a consideration, D'Mello [**10**], proposes an alternative to his previous system, which does not require the use of sensors. Arroyo and his team, proposes to use at school a suite of sensors relatively cheaper and more comfortable [**11**].

2. Conclusions

Users profiles are built using different learner models and focusing on various characteristics and habits of the user. Advances in educational data mining allows to implement these models and to use them to predict the learner behavior and to describe his/her knowledge and skills. Implementing these models effectively requires understanding the nature of the data, the assumptions inherent to each model and the methods available to fit the parameters. Recent research shows growing interest on the application of different types of analysis especially to detect affective and cognitive states with and without the use of physical sensors.

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5. The role of Instructional Design and Learning Design in Intelligent Tutoring Systems - A Review -

Dénes Zarka ◗ Annarita Bramucci

Introduction

Before going in detail we have to define the title, as both words: Artificial Intelligence (AI) and Instructional Design (ID) may be used in slightly different ways. One obvious temptation is to regard all tuition machines, and programmed learning applications where learners are instructed by machines as intelligent tuition machines, or intelligent tutors. Of course they are intelligent in the sense that designers built them in logics and structures helping learners to learn more effectively. But they are not using artificial intelligence as it is defined in the literature. In this chapter we do not call traditional machine instruction AI, as most of the software applications we use nowadays are "intelligent" but are not meeting the requirements of artificial intelligence.

Artificial Intelligence was defined earlier in this book, so we concentrate to the other term: instructional design. We take here the most common definitions of it.

1. Instructional Design. Classical approaches

There is a broader and a narrower sense definition.

The narrower sense definition is less broad in nature and mostly focus on analysis and design, thus normally goes into much more detail, especially in the design portion. Many similar descriptions are existing, one can be quoted here:

ID is the practice of creating "instructional experiences which make the acquisition of knowledge and skill more efficient, effective, and appealing." [1]

A more sophisticated definition is: "Instructional Design is the systemic and systematic process of applying strategies and techniques derived from behavioural, cognitive, and constructivist theories to the solution of instructional problem." [2]

It can be contrasted here with Instructional Science, which Builds upon Learning Sciences (Psychology of Learning, Sociology of Learning, Systems Science), and consists of theories, models and methodologies for Instruction and for Research on Instruction. The focus of studies in Instructional Science is the interrelationship between four classes of variables:

- instructional situation,
- subject-matter,
- instructional outcomes, and
- instructional strategy variables.

[16]

2. Instructional Systems Design

The broader sense of Instructional Design is also called Instructional Systems Design (ISD) and it deals with the construction of the whole model of the instructional process. A model is a mental representation of something else, an object or a process required, because of a dissatisfaction for status of real things. Therefore an instructional model describes an instructional experience required, imagined and patterned in the design. Consequently also an instructional pattern can be defined a cognitive artifact, because it is a real object designed and constructed for a problem solving.

2.1. ADDIE

The first and classical model, from which the most of ID patterns come, is ADDIE. It can be considered, for this, a meta-model. The ADDIE model was initially developed during the World War II by the U.S. Army and resumed in 1975 by the Center for Educational Technology University of Florida [3]. This model, based on a behavioural learning perspective, has

been created to ensure a process of effective learning that might do without the teacher action, so it's a meta-model also because it categorizes the various phases and sets in a scheme the pillars of design.
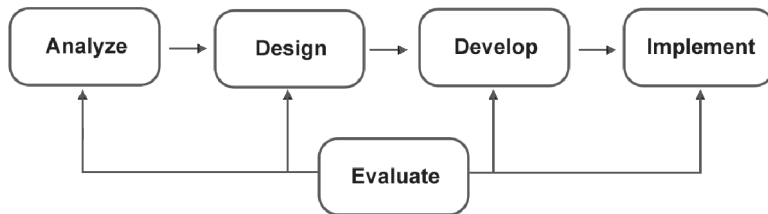
ADDIE is acronym of five phases about a particular instructional initiative:

A - Analysis is the process by which what will be taught is defined. It clarifies the instructional problem, establishes the aims, the instructional goals, the learning environment and identifies learner's existing knowledge and skills.

D - Design is the process by which how the instructional action will be is defined. The design phase deals with learning objectives, assessment instruments, exercises, content, subject matter analysis, lesson planning and media selection. These phase should be systematic and specific.

D - Development is the process by which materials are created and produced. In this phase, the instructional designers and developers create and arrange the content assets that were designed in the previous phase. Storyboards are created, content is written and graphics are designed.

I - Implementation is the process by which training devices in the real context are installed; devices should cover course curriculum, learning outcomes, method of delivery, and testing procedures.

E - Evaluation is the process by which the impact on education is identified. The evaluation phase consists of two parts: formative and summative. Formative evaluation runs throughout the entire process of ADDIE.

Analysis	Design	Development	Implementation	Evaluation
To define the needs required by the educational process	To translate the goals of the course in results and objectives.	To decide types of activities and materials.	To produce materials that will be used by both teachers and students.	To draw up plans for the student assessment.
To define the cognitive , affective and motor target	To define topics or units that must be addressed and the time devoted to them.	To prepare drafts of materials and activities	To provide help and needed supports	To draw up plans for the evaluation of the system.
	To put in sequence learning units with a focus on the objectives of the course.	To experiment activities and test materials within a group of users		To draw up plans for the periodic review of the course
To analyse needed time and available resources.	To detail the units, identifying of the main objectives of each of them			
	To define lessons the activities related to each of them.	To produce additional materials to train the teachers		
	To provide guidance for evaluating the students' learning.			

Because of the limits shown by the ADDIE model a plurality of subsequent models were born. Limits are about teaching and design methods. For example ADDIE presents a linear structure and it is a "waterfall" model: each phase affects and determines the next step.

2.2. Patterns derived from ADDIE

From 1970 to date, many ISD models were built on ADDIE and they were born from the need to overcome the limits of the meta-model which often cannot describe more complex systems because of its simple and reductive structure. In 1972, twenty-three significant models have been developed; in 1980, about forty, in 1994, a few hundred. Some of these will be described in this paragraph.

Gustafson and Branch [18] considered in their model that a non-linear and recursive structure may be more suitable to describe a complex system as the teaching-learning process. Recursion is provided at different stages of the path: in example, the Instructional Analysis needs a previous Situational

Assessment and a continuous dialogue with the Instructional Goals and Performance Objectives. Therefore, a part of process presents a non-linear but comprehensive scheme including Performance Objectives, Instructional Strategies, Media Selection and Formative Evaluation.
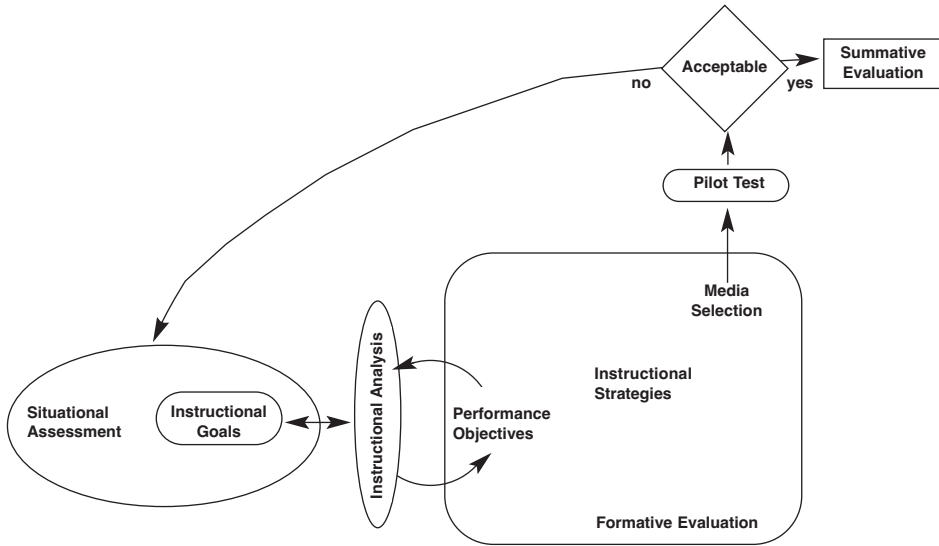

Figure 1. Gustafson model. From: Gustafson, Branch (2002)

A design pattern is closely linked to the context of teaching, and a model built on real experiences is the model of Gerlach and Ely [19]. This model is an example of the design of teaching in the school. From their experience, the authors found that often teachers start the learning design from the content: for this reason, they included as an initial stage both the specification of content (1) and of the objectives (2). Further steps include the evaluation of incoming students' behaviour (3), and then resources (8), space (7), time (6), organizing groups (5) and strategies (4) are analysed simultaneously. Since these elements are examined together, each choice affects the other.
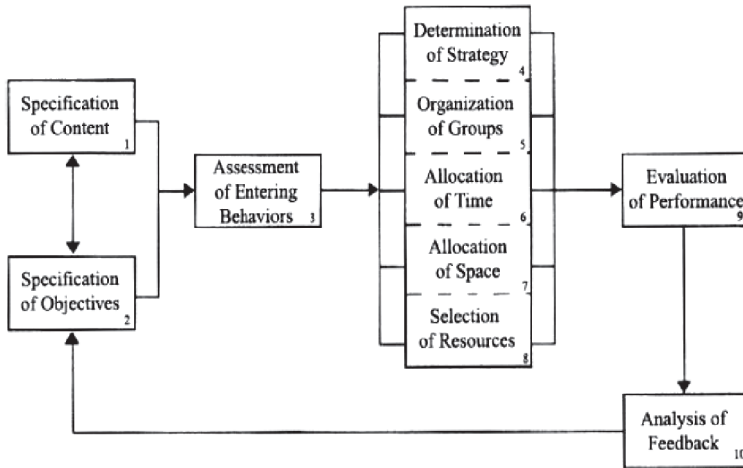
Figure 2. Gerlach and Ely model
From: http://sarah.lodick.com/edit/edit6180/gerlach_ely.pdf

ASSURE, the model of Smaldino, Heinich, Molenda e Russell [20], is used in many U.S. schools. The first step of ASSURE, *Analyze*, requires to examine some students' characteristics, particularly those easily and objectively assessable as the level of education, technical vocabulary, etc. The definition of the objectives in specific and measurable terms follows, and the selection of media and materials, along with a compulsory description of the use of the chosen materials. Then, strategies are defined, as well as organization of space and time, group activities and aims to actively involve students. The model closes with the evaluation and feedback phase. The evaluation has two values and it is addressed both to students' learning and the process as a whole.

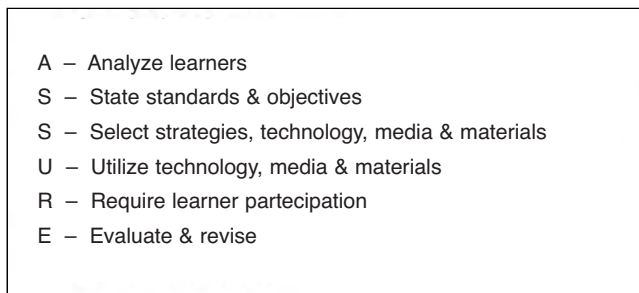The model MRK proposed by Morrison, Ross and Kemp [21] is very dif-

A – Analyze learners
S – State standards & objectives
S – Select strategies, technology, media & materials
U – Utilize technology, media & materials
R – Require learner partecipation
E – Evaluate & revise

Figure 3. ASSURE model of Smaldino, Heinich, Molenda and Russell (2004)
From: http://www.instructionaldesign.org/models/assure.html

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ferent from the previous ones, since it does not plan any linear process: the phases are indicated, but the order of them is defined by the teacher on the basis of the context. The model is in fact depicted by an oval, as in figure 4. The outlines define dimensions of the learning project in a concentric connection. The innermost circle includes aspects closely related to development of the educational process. The outer circle includes evaluation (formative and summative) and revision. The more external line includes the final phases as planning, implementation, project management, support services.

Figure 4. MRK model:
http://insdsg619-1-f11-beith.wikispaces.umb.edu/MRK
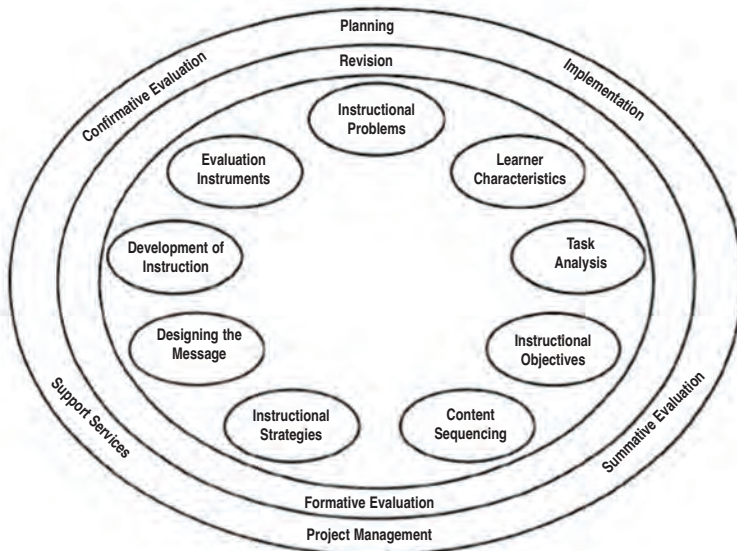
The Dick, Carey and Carey model [22] is described for the relevance attributed by the scientific community, and because of this it is considered a kind of benchmark. The design starts from the needs analysis, in order to identify the goals. This element distinguishes the model of Dick, Carey and Carey from the others. The results of the needs analysis are not called into question anymore in the further steps of the model, therefore it should be carefully carried out. There are two parallel activities: the Instructional Analysis and the analysis of the context and students. The Instructional Analysis aims at defining cognitive, affective and motor abilities. Then, the following steps are undertaken: definition of objectives, development of

assessment tools, and identification of strategies, with particular attention to individualization, and choice of materials. Finally, the evaluation closes the model. Each step of the process involves a revision.
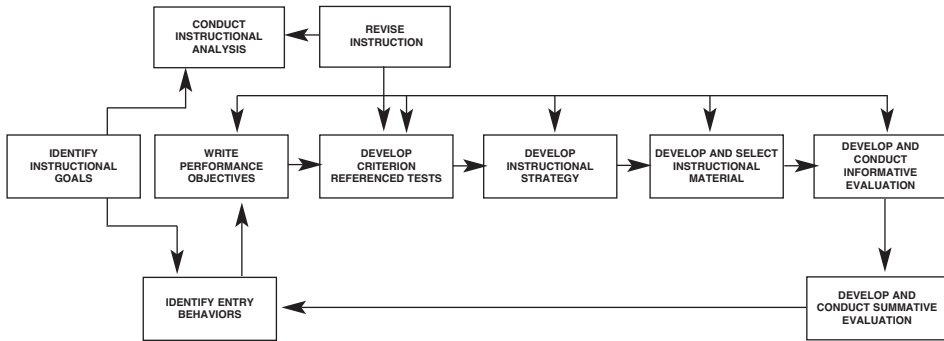

Figure 5. Dick, Carey and Carey Instructional Design model
From http://www.instructionaldesign.org/models/dick_carey_model.html

2.3. Models criticizing ID and overcoming the basic logic of ADDIE

In past ten years, ID has been largely criticised: Gustafson and Branch [18] pointed out the rigidity of the ID models, that are particularly binding for teachers. A sharp criticism came from Gordon and Zemke [23], who highlighted the following elements:

- ISD produces a bureaucratic approach, that takes too long time that is subtract to real teaching;
- Teaching is an art more than an exact science: the application of ISD models risks to focus more on the course perfection than on the results, which are related to learning;
- The inflexibility of the models are not suitable for learning processes and paths, that are by nature dynamic and driven by many variables;
- Creativity is undermined in the ISD models, that are based on the assumption that the students are low skilled and incompetent, and that they need guidance and help. This is not always the case.

Therefore it is impossible to have a single model and it is necessary to manipulate in practice different models, according to the needs and the contexts.

The prescriptive ID models seems to simplify the formative process, and then facilitate learning by reducing complexity. The result, however, turned to be monotonous, with poor activation of student's interest and motivation, and poor professionalization of the teachers, who don't acquire design skills and who have little space for reflection.

Reflection is a must for the teacher in order to be able to properly apply methods, to create new methods and finding creative solutions. Reflection on the context is embedded in action, and requires a continuous and recursive assessment of the ongoing situation. Teachers should master theories and be able to adapt themselves and their work to the context and the learner, therefore to deploy theory in practice. Reflection and reflexivity should thus lead design and instructional process.

If learning cannot be designed, however, it is important to design for learning. The design becomes a *boundary object* [24] that interacts with the context and with the subjects. The approach changes according to constructivist views, by involving the construction of an environment that provides participants with tools to manage the process for connecting materials, ideas and resources to innovate, or to build new objects and materials, and to reflect on their own paths.

Jonassen Model [25] suggests a broad design, addressed to a provision of a rich scaffolding and environment, more than on a fixed pathway. Assuming that knowledge cannot be transferred, teaching becomes facilitating learning processes by preparing appropriate and contextualised learning materials, a learning environment with appropriate tools to support cognitive processes, and by offering to learners the management of their own learning process. Furthermore, Jonassen proposes to engage the student in the solution of open problems and activities project at different levels of complexity (*question-based, case-based, project-based, problem-based).*

Model and modelling (M & M) is defined by Lesh and Doerr "beyond constructivism" [26].

The two authors are of particular concern to teaching of mathematics, but many elements of their theory have a broader application and meaning beyond the specific discipline. The focus of the M & M is the model and the modeling activities. The overcoming of constructivism is determined by the attention to the model as both a product and a process.

Kehle and Lester [27] have used a linguistic metaphor. Taking the semiotics of Pierce, Kehle and Lester they distinguish three forms of inference: deduction, induction and abduction.

- Abduction starts from experience and produces representation, a "sign" that in this case is a model.
- Deduction follows and consists in the manipulation of the sign, in compliance with syntactic rules that characterize it.
- Induction applies the sign system to experience, to verify whether the experience subsumes the system signs.

The model core is neither the object (condition of things), nor the model, nor the interpretant, but the semiotic process and the teacher who connects the three processes and ensures the unity of the path alternating abstraction and interpretation processes.
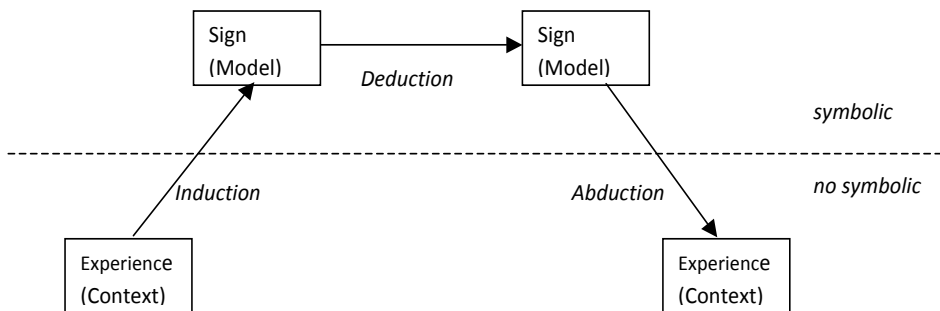
Figure 6. Linguistic metaphor of modeling. Kehle, Lester [27]

2.3.1. Rapid Prototyping

The Rapid Prototyping model introduced by Tripp and Bichelmeyer [28] and later taken up by Wilson, Jonassen and Cole [29], was created from the need to bridge design model with the context. Also it has been created to overcome the limit of information that the designer has in the initial step.
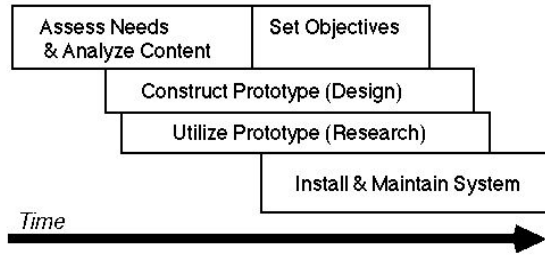
Figure 7. Rapid Prototyping Design
From: http://studio.coe.uga.edu/seminars/rpmodel.html

Botturi, Cantoni, Tardini and Lepori [30] take up the Rapid Prototyping with ELAB (Figure 8). The authors criticize the classic ID models not only for behaviourist roots and the linear structure, but also because they are based on two assumptions: 1. all the necessary information are available to designer from an early stage and 2. designers can govern the process without making mistakes.

The model ELAB wants to bring together three perspectives: linear, heuristic and constructivist, proposing a method to organize, in short steps, development of a physical reification of discussion, the prototype. The main aim is to have a model suitable for each project, but also sufficiently structured and time and cost acceptable.

Originality of the approach consists in considering prototyping as a catalyst process for communication of the project team. The discussion of team focuses on the prototype, avoiding a debate on theories and technologies of learning.

Prototyping process is divided into two concentric circles: in the first and internal *product cycle*, the prototype is developed, in the second and external *process cycle*, thanks to prototype, the final product is implemented. The prototype is a pattern that also allows to explore reality and carry out a pre-figuration of the system.
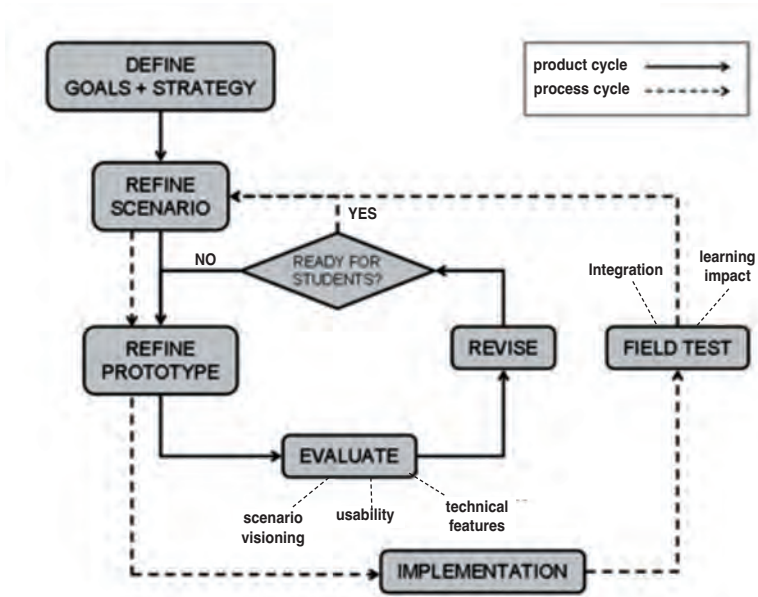
Figure 8. eLab Model
From: http://tecno08.pbworks.com/w/page/20362003/progettazione

2.3.2. FVP

FVP model (Rossi and Toppano, 2009) [16] retrieves some elements of the FBS model of Gero [31], [32] and the ELAB cycle of Botturi and colleagues [30]. It has been intended to design teaching for school, university and other areas of training.

It has three dimensions: aims (F), didactic variables (V) and path (P).

The aims dimension (F) defines teleology of the project, prefigures "the future city", detailing why it is made and indicates the direction and the meaning of the education act that is being planned.

The didactic variables dimension (V) indicates behaviour of the model, detailing the final state that's wanted to get according the aims. The variables include:

a) the objectives,
b) the epistemic nodes to be developed,
c) the didactic situations that describe the frame of the path,
d) the constraints of project as time, space, resources.

The path dimension (P), finally, describes the structure of the process, components and their relationships. It outlines the script and the structure of the components of the process according to the rules of education technology.

FVP is a dynamic model, animated by several steps of process.

Process 1: from F to Vd. Abduction

The design process starts, in theory, with the aims explicitation (F). Starting from the aims, through a process abductive, V is identified; namely Desired Variables (Vd) are located and describe the final state of desired things. After variables definition, it is possible to articulate the path using a synthesis process.
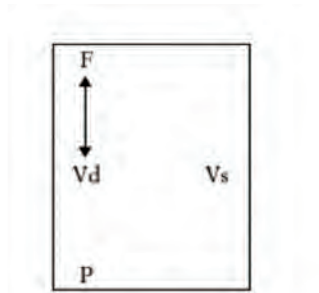

Figure 9. Process 1: from F to Vd. Abduction

Process 2: from V to P. Synthesis

V can be defined as a *boundary object*. On the one hand, communicates with F and, in this sense, there is a strong link between aims and variables, including disciplinary epistemology and selected nodes, but also V interacts with the path.

From Vd definition we get to the construction of the path with a synthesis process that allows to articulate script. In all levels, the internal structure of the components and the connections between them are the focal elements that require knowledge of syntactic and grammar rules for their proper implementation. The synthesis process is therefore driven by technology education.
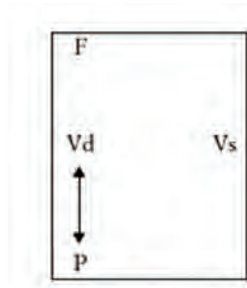
Figure 10. Process 2: from V to P. Synthesis

Process 3: P Vs Simulation

In the process 3, the teacher mentally simulates the path. He/she tells himself as if he/she was living, develops through a narrative process and thereby assumes the final state and provides the value that the variables may assume (Vs, where s stands for "simulated") to end of the path. The teacher, according to experience, simulates the path and analyzes all problems that may arise during development. He/she knows class, the operating procedures of the students, the resources available and their skills. With this knowledge he/she can prefigure the final situation and variables state obtained by simulation (Vs). He/she will try to predict achievable goals, situations put in place, the acquired disciplinary cores; seek to imagine the reactions of the students, problems they encounter, difficulties in classroom management.

The described process is similar to the "as if" proposed by Schön [1983], and in general it's very common in the planning processes of teachers and professionals paths.

In the simulation phase the teacher adopts a different approach from that one put in place to pass from the Variables to the Path; he/she takes the point of view of the students and the class seeing himself in action.
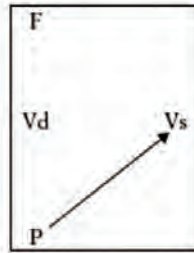
Figure 11. Process 3: from P to Vs. Simulation

Processes 4, 5: comparisons and descriptions

In the process 4, the teacher compares Vs (expected result based on simulations) with Vd (the desired result) to verify the acceptability of P, or proximity between Vd and Vs. If Vs is acceptable, it passes to the final realization of the artefact and three descriptions are built (process 5). The aspects that cause the difference between Vs and Vd must be identified and then the reformulation phase can start.
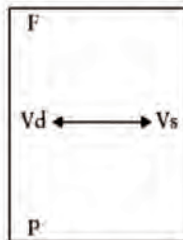

Figure 12. Processes 4,5. Comparisons and descriptions

Processes 6, 7, 8: reformulations

If the result of the comparison between Vs and Vd is not satisfactory, the reformulations are processed. The reformulations aren't a simple feedback, but they are an evaluation of the process with different perspectives and choices. The review follows three different changes:
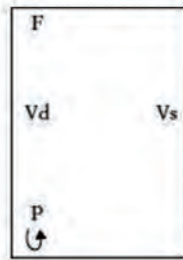
▶ in the Path;

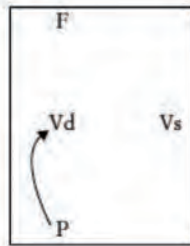Figure 13. Reformulation of Path. Connection Analysis

▶ in the Variables;

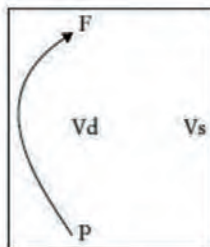Figure 14. Reformulation of V. Cohesion Analysis

▶ in the Aims.

Figure 15. Reformulation. Coherence Analysis

FVP is not a model for a path, but it is a model for the design.

3. Categories of ID

There are many possible categorizations of ID. To our scope of examining the roles of AI in ID we have to distinguish three settings:

- student-only;
- teacher-led;
- community-based settings.

Instructional design in its "pure form" can be observed in the student-only settings. Here the student is instructed by the machine. We do not observe the possibility of teacher intervention or the existence of other learners, who obviously affect the learning process. This approach is common in the literature, as Koschmann [34] describes. Since one-on-one tutoring is commonly considered the gold standard against which other methods of instruction are measured (Bloom, 1984) [35], the paradigm is founded on the proposition that education could be globally improved by providing every student with a personal (albeit machine-based) tutor (Lepper, Woolverton, Mumme, & Gurtner, 1993) [36].

3.1. Roles in ID

In the light of AI we have to define roles in computer enhanced (student-only) tuition, to narrow further the topic:

- Designer: The pedagogical or andragogical expert (or group) who is preparing the instructional program before the learning takes place. This role is typically the role of a teacher, but in many cases in larger Universities and Institutions that deal with distance education and on-line learning, it is already an exclusive role, already a profession.
- Tutor: There are many common definitions of tutor. We call tutor the andragogical process expert, who has a "working knowledge of the subject for discussion but they will also have a concrete knowledge of facilitation and how to direct the student to assess their knowledge gaps and seek out answers on their own." [5]. This knowledge in self-directed learning (student-only setting) is in most cases dealing exclusively with facilitating the self-learning path, by technically helping to work with the machine led instructional material and to help in detail by

pacing the material. Tutor's important role is to develop meta-cognitive skills, like discovering and understanding the consequences of the learner's learning style.

- Learner: Learner is in AI terminology the human who is following the programmed instruction.
- Machine: Program which is giving the instruction and processing learner input. This program can be itself the robot, or agent, but the machine can be designed by the author(s) with help of AI (authoring agent).

This chapter is dealing with Designer-Machine topics. This is the preparation, or planning (designing) phase of the self directed learning (or: distance learning, e-learning, technology enhanced learning... there are different trends and wages of terminology over time and educational sector, philosophy). The outcome of this phase is the learning program, which can be embedded in many applications (for example in learning management systems).

Other important role-pairs like tutor-learner, tutor-machine and machine-learner issues, are mostly discussed in the Intelligent Tutoring Systems chapter. Those relations can be used and observed during the learning process, when the program has been designed, and learner has started the self-directed learning.

This approach of Instructional design description is reinforced by other researchers. Individual learning, individual tutoring and asynchronous communication are typical features of a distance learning situation, with two main implications for distance learning systems: extensive macro- and micro-instructional design, and a strong student support system. Distance Learning and Instructional Design are intrinsically related (Bourdeau & Bates, 1996) [37].

4. Pedagogical agents

The problem of developing machines that intelligently teach has a long history. The research work started with pedagogical agents. The development of pedagogical agents appeared to be so complex that further research focussed on authoring agents. Authoring agents are not directly instructing learners but intelligently help authors do make effective instruction. The need for intelligent instructional systems emerged.

"Pedagogical agents are autonomous agents that occupy computer learning environments and facilitate learning by interacting with students or other agents. Although intelligent tutoring systems have been around since the 1970s, pedagogical agents did not appear until the late 1980s. Pedagogical agents have been designed to produce a range of behaviours that include the ability to reason about multiple agents in simulated environments; act as a peer, co learner, or competitor; generate multiple, pedagogically appropriate strategies; and assist instructors and students in virtual worlds" [6].

4.1 Layers

Lesgold [7] in '87 states already that there were mayor problems with existing architectures and defines three different knowledge of a pedagogical agent he calls "layers".

Curriculum knowledge (The Curriculum Goal Lattice Layer) - later content ontology

Lesgold states: "...the goal structure for the instructional system, it is, more or less, in control of the system. ... This kind of goal structure is exactly the sort of concept that Gagne was introducing his discussions (see above) of learning hierarchies. ... Clearly, if the structure of curriculum is simply a sub goal tree, we are well on the way to understanding how to develop such a tree." He and fellow researchers realized that there is no one exact solution to instruction sequencing: "It seems appropriate to advance, as a hypothesis for future research, that knowledge-driven instructional systems will work best and be most implementable for those courses which have more or less coherent, consistent, and complete goal structures" [7].

Representation of the knowledge (The Knowledge Layer)

"Such knowledge includes both procedures and concepts (i.e., both procedural and declarative knowledge)." He states, "that teaching the whole of a body of material is more than just teaching its parts; the goal for the whole includes not only the parts but also a specific focus on the ties between those parts" [7].

Meta-issues (The Meta-issue Layer) – later student model

Lesgold states: "Attending to a specific aptitude or some other meta-issue in shaping the activities represented for the trainee in any lesson is simply a special case of shaping a lesson according to a specific viewpoint. ... The meta-issue layer is simply the collection of goal nodes that are the origins of various viewpoint hierarchies embedded within the curriculum lattice."

Here we see an early theoretical basement of the standardized learning

object [8] (2002 by IEEE) leaded to IMS LO standard which is called the "Learning object" here. Lesgold states that their approach to the architecture of intelligent instructional systems is object oriented. (See also: object oriented programming.) So Lesgold changes the sequencing of instructions to a more structured thinking when objects send messages to other objects. When examining this Lesson object Lesgold states, that: "This requires that each object contain all the data and all of the methods needed to completely achieve the goal to which it corresponds." This is now the basic rule of SCOs in SCORM [7].

Lesgold already realized that subject ontology is much more complex that it seemed to be.

In later literature similar layers are described, directly citing them as ontology, like Meisel, Compatangelo and Hörfurter [9].

The Educational Modelling Language (EML) aims to provide a framework for the conceptual modelling of learning environments. It consists of four extendable top level ontology that describe:

- theories about learning and instruction;
- units of study;
- domains;
- how learners learn.

Pedagogical agents may be broken down in more specific agents. Rogers and colleagues discuss [10] the need of instructional design agents (IDA), and as a first step to this a taxonomy agent. Those agents are in the Goal lattice layer of Lesgold's system. IDA functions are defined also in [9] as the following requirements:

- Assist its user in the selection of appropriate teaching methods for a training and encourage the application of a wide range of available teaching methods.
- Instruct its user about particular Teaching Methods (TMs).
- Highlight errors in the design of a training.
- Those functions were developed in Concept Tool Ontology Editor. This idea is developed further in [12] by Mizogouchi and Bordeau.

For the description of IDA there are specifications, like **Instructional Material Description Language** (IMDL). IMDL considers instructional elements (i.e. learners or learning objectives) as pre-conditions and didactic ele-

ments (i.e. software components for the displaying of courses) as post conditions.

4.2 Taxonomy agent

The need for this kind of agent is described by Rogers, Sheftic, Passi e Langhan [10] "... devising the course outcomes, goals and objectives themselves (i.e., developing the mental model of the course) is a challenging task, and that perhaps the intelligent assistance agent should first aim to help the instructor articulate these preliminary building blocks. In order to accomplish this, our agent embodies Bloom's Taxonomy as an interactive design tool, which should help the instructor formulate an effective mental model of the course concepts, rather than just as a diagnostic tool for a pre-existing model".

Planned functions of the agent were:

- explicit taxonomy, where the instructor wishes to do the course development in the context of the formal objectives and outcomes, or
- transparent design, where the focus is on the content development, and the agent keeps track of objectives and outcomes "behind the scenes".

5. Intelligent Instructional Agents and Ontology Engineering

The problem of designing Intelligent Instructional Systems (IIS) is discussed in detail in [2] by Mizoguchi and Bordeau, by describing the problems of that kind of systems:

- There is a deep conceptual gap between authoring systems and authors;
- Authoring tools are neither intelligent nor particularly user-friendly;
- Building an IIS requires a lot of work because it is always built from scratch;
- Knowledge and components embedded in IISs are rarely sharable or reusable;
- It is not easy to make sharable specifications of functionalities of components in IISs;
- It is not easy to compare or cross-assess existing systems;

- Communication amongst agents and modules in IISs is neither fluent nor principled;
- Many of the IISs are ignorant of the research results of IS/LS;
- The authoring process is not principled.

There is a gap between instructional planning for domain knowledge organization and tutoring strategy for dynamic adaptation of the IIS behaviour.

Analyzing the problem, they summarise:

"Making systems intelligent requires a declarative representation of what they know. Conceptualization should be explicit to make authoring systems literate and intelligent, standardization or shared vocabulary will facilitate the reusability of components and enable sharable specification of them and theory-awareness makes authoring systems knowledgeable" [2, 110].

They propose a better Ontological structure to overcome some of those problems. They call it **Ontological Engineering.**

5.1 Computational semantics of an ontology

Level 1: A structured collection of terms. This level "provides a set of terms which should be shared among people in the community, and hence could be used as well-structured shared vocabulary. These terms enables us to share the specifications of components' functionalities, tutoring strategies and so on and to properly compare different systems" [2, 112].

Level 2: Formal definitions. This level is "composed of a set of terms and relationships with formal definitions in terms of axioms. … Thus, a level 2 ontology is the source of intelligence of an ontology-based system" [2, 112].

Level 3: Executable modules provided by some of the abstract codes.

5.2 Knowledge engineering of authoring

Mizoguchi and Bordeau summarise that: "authoring consists of "static knowledge" organization and "dynamic knowledge" organization. The former includes curriculum organization with instructional design and the latter tutoring strategy organization for adaptation to the learners" [2, 112].

They then try to outline the ontology of Instructional Design.

Requirements for an OLE typically are:

- to know about external learning events, both those planned and the ones that really happen,
- to be able to reason, make hypothesis and decisions based on both internal and external events and
- to be flexible in adapting instructional strategies based on culture or affects.

The roadmap outlined by Mizoguchi and Bordeau, to make ITSs more «real» to students,producing a better learning companion or tutor, is the following:

- the sharing among humans, and through computer technology, of the knowledge we have accumulated thus far,
- The sharing extended from among humans to among computers,
- The operationalization of this knowledge to support the building of IISs [2, 116].
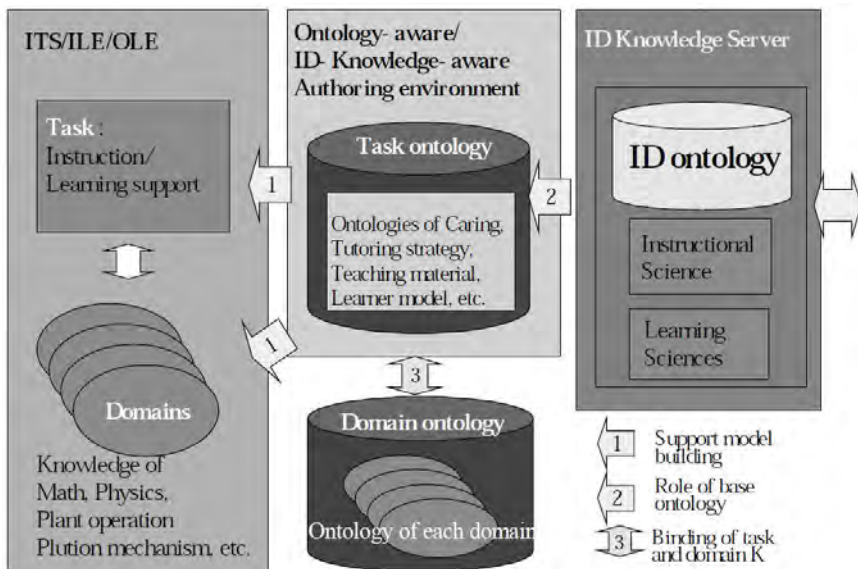
An ontological diagram of related systems with ID knowledge servers.

Design of IIS is discussed further by the same two authors [12] by refining the roadmap of theory-aware ITS authoring systems, and design a basic layer for ontological engineering based authoring systems. They also conclude with an Ontology Editor like [10] above.

5.3 Ontological engineering

Mizoguchi and Bordeau start the work by ID knowledge systematization. The necessary characteristics that systematized knowledge are expected to have are the following:
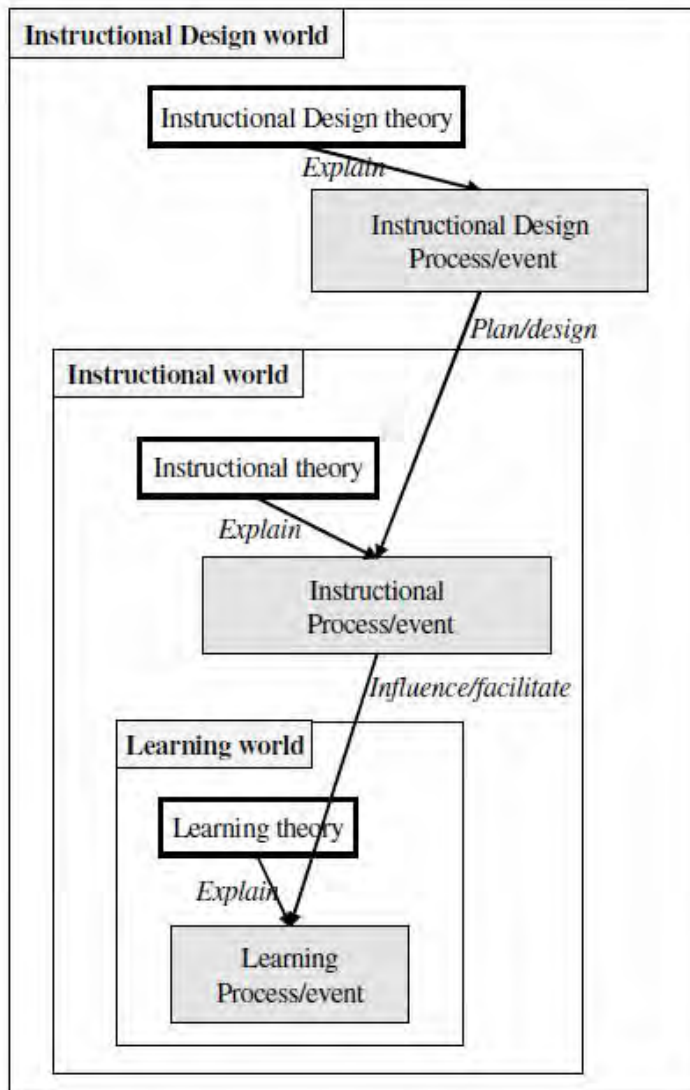
- Concepts found in all the knowledge are clearly defined;
- Concepts are organized in an is-a structure;
- Dependencies and necessary relations among concepts are explicitly captured;
- Each viewpoint used for structuring knowledge, if any, is made explicit;
- Ready for multiple access;
- Consistency is maintained.

They start the work with Level 1 ontology (deconstruction):

- Ontological categories
- actor (subject, thing which does actions),
- behaviour (verb, action, phenomena),
- object (thing being processed by actor),
- goal (state to be achieved),
- situation (context in which an action is done) and
- attributes (characteristics; of all of the above).

Authors distinguish two kinds of worlds to structure the ontology: Abstract and Concrete.

Concrete worlds (learning, instruction, instructional design) that we describe based upon the best possible approximation of what is existing, Abstract worlds (learning, instruction, instructional design) where we reflect existing theories with the best possible fidelity.

Instructional Design world

- Instructional Design theory
  - *Explain*
- Instructional Design Process/event
  - *Plan/design*

Instructional world

- Instructional theory
  - *Explain*
- Instructional Process/event
  - *Influence/facilitate*

Learning world

- Learning theory
  - *Explain*
- Learning Process/event

These are called Worlds of theories. The final internal structure of the ID ontology is the following:

Concepts:

world of learning	world of instruction	world of instructional design
learning activity, assignment, reading, interacting, problem-solving, learning phase, learning difficulties/remediation	instruction, learning, instructional strategies, teaching, tutoring, assessment of learning.	instructional design, instruction, learning, instructional scenario, learning environment, selection of methods, selection of media, selection of assessment methods.
world of theories of learning	world of theories of instruction	world of theories of instructional design
theory of learning, epistemological ground, taxonomy, learning, motivation, attention, comprehension, memory, cognition, meta-cognition, learning phase, learning difficulties/remediation	theory of instruction, theory of learning, epistemological ground, taxonomy, learning, instructional strategies, teaching, tutoring, assessment of learning	theory of instructional design, theory of instruction, theory of learning, epistemological ground, taxonomy, learning, selection of methods, selection of media, selection of assessment methods

This set of level 1 ontology can already be built in an ontology editor. (The Ontology Editor was developed at Mizlab, Osaka University).

The roles defined in this ontology are very similar to the roles that were described as a theoretical model of the whole chapter (designer, tutor, learner, machine). Here:

- Instructional designer;
- Instructor (tutor);
- Learner.
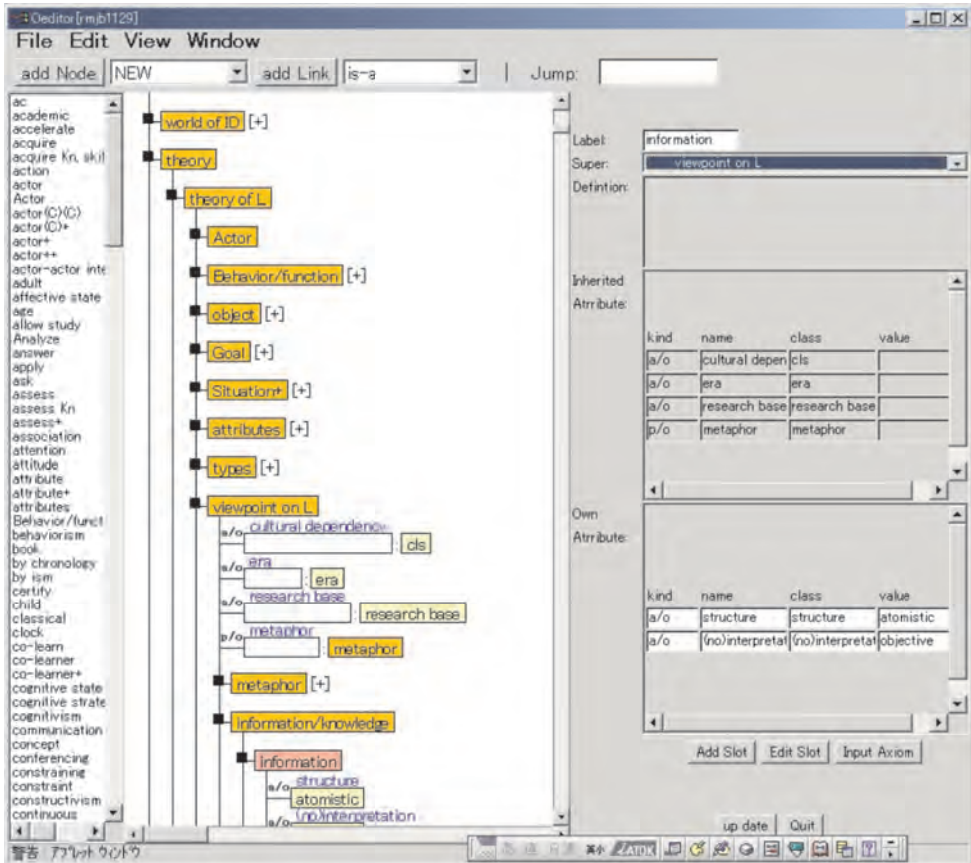
6. Semantic WEB and IIS

6.1 Core technologies

Another approach to IIS is the approach of Semantic WEB. In order to understand the structure of the content of the web based learning material, special technical solutions have to be used. Koper collects the core technologies [13]:

- Unified Modelling Language (UML) (Booch, Rumbaugh, & Jacobson, 1999) [38], (Fowler, 2000) [39]. UML provides a collection of models and graphs to describe the structural and behavioural semantics of any complex information system;

- XML and XML Schema's (XML, 2003), derived from SGML (ISO 8879). These are tools used to go beyond the fixed, page structure oriented vocabulary that HTML provides;
- RDF and RDF-Schema is the metadata approach from the W3C (RDF, 2003). It does not structure the syntax of the data, but defines semantic meaning for data on the web;
- Topic Maps (ISO/IEC 13250:2000), [41] provide an alternative technology to RDF. Topic maps define arbitrarily complex semantic knowledge structures and allow the exchange of information necessary to collaboratively build and maintain indexes of knowledge;
- OWL Web Ontology Language. According to Mc Guinness e Van Harmelen [40], ontology languages provide greater machine interpretability of Web content than that supported by XML, RDF, and RDF-Schema;
- Latent Semantic Analysis - LSA, (Landauer & Dumais, 1997) [42]. The approaches mentioned above require humans to provide the semantic meaning by using a machine interpretable coding scheme;
- Software Agents (Axelrod, 1997 [43]; Ferber, 1999 [44]; Jennings, 1998 [45]). One of the basic technologies that can exploit the coded semantics on the web are software agents.

It seems to me that for describing ontologies we need for IIS OWL will be the most suitable tool. Among many other possibilities that semantic web may offer, Instructional design can also benefit from that Devedzic describes: "Intelligence of a Web-based educational system means the capability of demonstrating some form of knowledge-based reasoning in curriculum sequencing, in analysis of the student's solutions, and in providing interactive problem-solving support (possibly example-based) to the student, all adapted to the Web technology (Brusilovsky & Miller, 2001 [46])" [14].

6.2 Standard vocabularies

Looking at issues that would be interesting in AI and ID, Devedzic explains:
"Authors develop educational content on the server in accordance with important pedagogical issues such as **instructional design** and human learning theories, to ensure educational justification of learning, assessment, and possible collaboration among the students. The way to make the content machine-understandable, machine-processable, and hence agent ready, is to

provide semantic mark up with pointers to a number of shareable educational ontologies" [**14**, 47]

He also highlights (like Mizogouchi and Bordeau [**12**]) the problem of ID ontology structures also from linguistic and structural differences point of view:

"One of the reasons why standard ontologies that should cover various areas and aspects of teaching and learning are still missing is the lack of standard vocabulary in the domain of education and instructional design. There are several working groups and efforts towards development of an official standard vocabulary. Examples include the IEEE Learning Technology Standards Committee – http://grouper.ieee.org/groups/ltsc/, Technical Standards for Computer-Based Learning, IEEE Computer Society P1484 – http://www.manta.ieee.org/p1484/, IMS Global Learning Consortium, Inc. – http://www.imsproject.org/, and ISO/IEC JTC1/SC36 Standard – http://jtc1sc36.org/. However, there is still a lot of work to do in that direction. Hence many structural, semantic, and language differences constrain reusability of applications produced by current tools" [**14**, 51].

He criticizes Murray [**47**], Mizoguchi and Bourdeau [**2**] because "Ontology-development tools that have resulted from these efforts have implemented a number of important ideas, but did not support XML/RDF encoding of ontologies and consequently were not Semantic Web-ready" [**14**, 52].

He lists then the possible standards that bring us closer to the solution:

"The statement of purpose of the project is very detailed, and includes issues like search, evaluation, acquisition, and utilization of Learning Objects, sharing, exchange, composition, and decomposition of Learning Objects across any technology supported learning systems and applications, enabling pedagogical agents to automatically and dynamically compose personalized lessons for an individual learner, enabling the teachers to express educational content in a standardized way, and many more. All of this is actually the essence of teaching and learning on the Semantic Web. P1484.14 supports P1484.12 by proposing and developing techniques such as rule-based XML coding bindings for data models. Finally, it should be noted that such efforts are related to more general standard proposals for ontology development. People involved with the IEEE SUO (Standard Upper Ontology) project 1600.1 (http://suo.ieee.org) are trying to specify an upper ontology that will enable computers to utilize it for applications such as semantic interoperability (not only the interoperability among software and database applications, but also the semantic interoperability among various object-level ontologies them-

selves), intelligent information search and retrieval, automated inferencing, and natural language processing" [14, 56].

Further development trends are envisaged by Devedzic [14] which might worth our attention: "An important research trend in the Semantic Web community that may support the idea of gradually evolving educational ontologies as well is ontology learning (Maedche & Staab, 2001 [48]). The idea is to enable ontology import, extraction, pruning, refinement, and evaluation, giving the ontology engineer coordinated tools for ontology modelling. Ontology learning can be from free text, dictionaries, XML documents, and legacy ontologies, as well as from reverse engineering of ontologies from database schemata".

6.3 A standardised Learning Ontology Editor

As an answer to the above criticism of Devedzic [14], a larger group of researchers together with Bordeau and Mizoguchi in [15] present a LD standard compliant solution for Learning Ontology as a continuation of the conceptualisation and development work presented earlier [12].

As a bridge they state: "Recently, in order to enhance and complete these representations, our work has been further inspired by the following: the Open University of the Netherlands' Educational Modeling Language (OUNL-EML) [8] and the IMS Learning Design [9] (IMS-LD) specifications" [15, 539].

The OUNL-EML aims at providing a pedagogical meta-model. It consists of four extendable models which describe:

- how learners learn (based on a consensus among learning theories);
- how units of studies which are applicable in real practice are modeled, given the learning model and the instruction model;
- the type of content and the organization of that content; and
- the theories, principles and models of instruction as they are described in the literature or as they are conceived in the mind of practitioners.

In IMS-LD Instructional design (ID) is called learning design (LD). Their integration (ontology engineering in e-learning standards environment) consists of the following steps:
- Analysis of the domain. This step was done by creating a glossary of terms.

- Conceptualization;
- Creating models of classes;
- Creating ad hoc property models;
- Formalization;
- Adding the subclasses in order to create taxonomies of classes;
- Adding predefined properties;
- Adding ad hoc properties;
- Adding comments (or annotations) if necessary;
- Adding axioms if necessary;
- Adding individuals;
- Evaluation;
- Documentation (OWL terminology);
- Creating a dictionary of classes. For each class, indicate the: identifier, equivalent class, super and sub-classes, individuals, class property;
- Creating a dictionary of properties. For each property, indicate the: name, type, domain, range, characteristics, restrictions;
- Creating a dictionary of class axioms: indicate boolean combinations;
- Creating a dictionary of individuals.

In EML meta-model the Unit of study was matched to learning design ontology. Authors present classes and properties in this ontology:

CLASSES	• **Theory:** theory of knowledge, learning theory, theory of instruction, ID theory; • **Paradigm:** Behaviourism, Rationalism, Pragmatism-Sociohistoricism (EML); • **Learning Theory:** Piaget, Bruner, Vytgosky, other; • **Theory of Instruction:** Inquiry teaching, Socratic, Algo-Heuristic, other; • **Instructional Design Theory:** Component Display, Elaboration, other;
PROPERTIES	• A theory of knowledge **has** a paradigm as one of its parts; • A theory of learning, instruction, and instructional design **has** a paradigm as an attribute; • A theory of learning, instruction, and instructional design **has** the following parts: theorist, concepts, principles, paradigm, content domain, reference, date; • Theories of learning, instruction, and instructional design **rely on** a theory of knowledge; • Models issued from a theory are **extracted from** a theory; • Models emerging from practice (eclectic) are **extracted from** practice; • Learning Designs are **inspired by** models.

UML representation of the Theories:
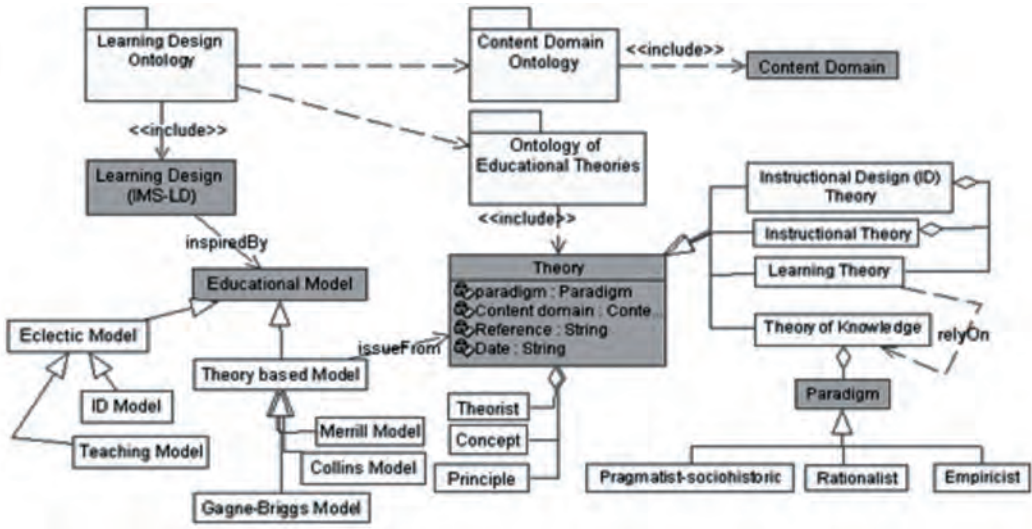
Finally the whole ontology system was implemented in HOZO Ontology Editor to make it operational (Ontology Agent).

7. Authoring tools for ITS

Murray [11] gives a review and categorization of ITS authoring systems. In this chapter we focus on authoring systems that are relevant for Instructional design. We see here seven categories of authoring systems, out of which four are ID related pedagogy oriented systems:

▶ **Curriculum Sequencing and Planning** (Systems: DOCENT, IDE, ISD Expert, Expert CML).
  Murray defines this category: they "organize instructional units (IUs, or "curriculum elements") into a hierarchy of courses, modules, lessons, presentations, etc., which are related by prerequisite, part, and other relationships. … These systems are seen as tools to help instructional designers and teachers design courses and manage computer based learning" [11, 102].

▶ **Tutoring Strategies** (Systems: Eon, GTE, REDEEM)
  Here we find similar approach as above, but "these systems also encode

fine-grained strategies used by teachers and instructional experts. ... Instructional decisions at the micro level include when and how to give explanations, summaries, examples, and analogies; what type of hinting and feedback to give; and what type of questions and exercises to offer the student" Murray states [11, 102].

▶ **Multiple Knowledge Types** (Systems: CREAM-Tools, DNA, ID-Expert, IRIS, XAIDA).

Murray describes this category in detail. "Facts are taught with repetitive practice and mnemonic devices; concepts are taught using analogies and positive and negative examples progressing from easy prototypical ones to more difficult borderline cases; procedures are taught one step at a time. ... The pre-defined nature of the knowledge and the instructional strategies is both the strength and the weakness of these systems" [11, 104].

▶ **Intelligent/adaptive Hypermedia** (Systems: CALAT, GETMAS, InterBook, MetaLinks).

This type was differentiated by media (web based) but otherwise contains similar approaches as the first two categories. Media convergence nowadays does not require this kind of separation any more.

Murray categorizes all systems to have four main components:

- Student interface;
- Domain model;
- Teaching model;
- Student model.

For ID the Domain models are most interesting. Murray distinguishes:

- Models of curriculum knowledge and structures;
- Simulations and models and of the world;
- Models of domain expertise:
- Domain Knowledge Types.

Goals for authoring tools:

- Decrease the effort (time, cost, and/or other resources) for making intelligent tutors;

- Decrease the skill threshold for building intelligent tutors (i.e. allow more people to take part in the design process);
- Help the designer/author articulate or organize her domain or pedagogical knowledge;
- Support (i.e. structure, recommend, or enforce) good design principles (in pedagogy, user interface, etc.);
- Enable rapid prototyping of intelligent tutor designs (i.e. allow quick design/evaluation cycles of prototype software)

The methods for achieving those goals are the following:

- Scaffolding knowledge articulation with models;
- Embedded knowledge and default knowledge;
- Knowledge management;
- Knowledge visualization;
- Knowledge elicitation and work flow management;
- Knowledge and design validation;
- Knowledge re-use;
- Automated knowledge creation.

Summarizing the review: Murray shows trends toward the inclusion, if not integration, of four components: Tools for Content, Instructional Strategy, Student Model, and Interface Design.

7.1. Authoring agents: Learning Design Support Environment (LDSE)

Several times, in the previous chapters, we highlighted the presence of author module for next-generation-content free ITS. The bases of this research were set in the early 2000s, however in recent years, neither ITS research, nor the use of EML and LMS LD have spread, primarily because of the difficulties faced by teachers in the implementation.

Research for more sustainable solutions has therefore been developed, in order to value skills and knowledge of teachers. It is not possible here to provide a broad picture of the research and experience undertaken. We would like to suggest research developed by Diane Laurillard at the London Knowledge Lab, because the work of this center was discussed in the first chapter, in relation to the paradigm shift that the field of ITS is living in the past two years.

The educational scenario requires continuous changes in the adoption of educational models and tools. Diana Laurillard with collaborators is the project leader of Learning Design Support Environment (LDSE) and she designs the basic functionality and pedagogical input of LDSE [49].

This research discovers how to use digital technologies to support teachers in designing effective technology-enhanced learning (TEL). Teachers will be required to use progressively more TEL and the teaching community should be at the forefront of TEL innovation. Thanks to the use of TEL the development of new knowledge, in this case about professional practice, should be carried out in the spirit of reflective collaborative design. The same technologies that are changing the way students learn can also support teachers' own learning and teachers' design.

The LDSE project aims to fill the gap in research that currently exists between technology, design and learning for teachers. It has the following goals:

- Research the optimal model for an effective learning design support environment (the Learning Designer). What are appropriate ways of modeling the activity of learning design conceptually, so that it can be implemented within a digital environment?
- Embed knowledge of teaching and learning in the learning design software architecture.
- Achieve an impact of the LDSE on teachers' practice in designing TEL. What are the appropriate ways to represent learning designs so that they can be tested, adapted, shared and reused by teachers and lecturers?
- Identify the factors that foster collaboration among teachers in designing TEL. What kind of digital environment will enable teachers as a community of practitioners to lead innovation and carry out successful design for TEL? To what extent can we adapt existing approaches to user modeling to the complex activity of collaborative learning design?
- Improve representations of the theory and practice of learning design with TEL. What are the optimal forms of representation of knowledge about teaching and learning?

The researchers are working with practicing teachers to co-construct and to experience an interactive learning design support environment, the **Learning Designer**, to scaffold teachers' decision-making from basic planning to creative TEL design. The aim of this iterative research-design process is to support learning design during practice and not only, but also to build a

community of teacher who can collaborate further on how best to deploy TEL, and especially to approach the majority of them on good practice by others and to inform them by the findings of pedagogical research, thereby optimizing the benefits to their learners.

So far, researchers have experienced a basic way of modeling the activity of learning design representing the learning activities in the modules within which articulate single sessions how significant teaching and learning times.

LDSE is the result of early design-support tools: the London Pedagogy Planner [50], an interactive tool for designing teaching and learning at both the module and session levels, and Phoebe, which supports the design of individual sessions and incorporates a community-owned resource bank of learning designs. The aim, then, is to take this initial work forward into the construction and evaluation of an LDSE that makes TEL innovation a rewarding, creative, shared process for teachers in all sectors including, ultimately, schools.

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[49]   LSDE.

[50]   London Pedagogy Planner.

[51]   Phoebe.

[52]   Instructional-Design Theories.

••• Conclusions

▼

The I-TUTOR project, as said in the Introduction, has the objective of developing software agents able to deal with existent LMS used in at present to support teacher and tutor work, as well as accompany students in order to promote aware and reflexive learning.

Some elements are here highlighted to clarify why there is interest for ill-defined problems and for artefacts that are not dependent on disciplines, but that focus on pedagogical and didactical needs, such as: user profile, control of the variables established in the initial learning contract, attention to the didactical strategies, mapping of the concepts coming from the teachers' materials and the students' writings, support to reflexive processes, representation in real time of the systems' state of the art.

The parameters of the project are based on the specificity of the European scenario, and on pedagogical and didactical theories.

The European scenario is characterized by a strong fragmentation of languages and educational systems. These two elements implies the inability to adopt solutions for ITS, i.e. based on natural language, which could be usable by a large number of users – a larger audience would justify an higher cost of development. Furthermore, courses change year after year, and the preparation of the ITS for a specific course requires the intervention of a single teacher, who often does not have technical competences and who has a limited time to devote to the task.

Therefore, the following needs are identified

▶ to focus on textual analysis based on numeric and statistical models (language free models), more than on semantic approaches;
▶ to focus on ontologies related to pedagogical-didactical domains, therefore usable on different topics, and not related to disciplines.

The latter consideration comes from the need to overcome a strictly cognitivist approach, based on educational psychology only. The present research in didactic highlights the need to take into consideration values, the epistemology of disciplines, pedagogical/didactic strategies in the learning practices, in addition to the concepts coming from educational psychology and cognitivist approaches. This is also proposed by the *teachers' thinking* and *analise plurielle* approaches.

Taken in due consideration this background, the project concept on which the I-TUTOR prototype will develop its system are:

▶ to develop an accurate and intelligent monitoring system of the activities performed by the students within the online environment, able to represent in real time the trend of the class and of the single student; the outcomes of the monitoring should refer to quantitative, qualitative and relational aspects, and should give a feedback both to students, to teachers and tutors.
▶ to map, with automatic processes and statistical methods for language analysis, the conceptual domain underlying the documents, prepared by the teachers, and the knowledge produced by the students; the analysis of the materials and a few key words provided by the teacher at the beginning of the planning phase, allow the system to build maps on the meanings of the single didactical modules. These maps can be compared with the students' productions both in debates or blogs, and in the wikis and peer to peer relationships.
▶ to suggest, on the basis of a pedagogical/didactic ontology, several learning strategies. As stressed in the previous chapters, research on ill-defined domains showed how the passage from traditional ITS to new approaches pointed out the need to have learning strategies based on mediation, reflection and awareness. In this perspective, a pedagogica/didactic ontology may support teachers and tutors in designing and ongoing monitoring;

▶ to support reflexive and decisional activities of the students, in order to promote professionalization process. Experiences in past few years in online learning pathways managed by human tutors, verified the soundness of artifacts like e-portfolio and project work diary. These research have been carried out at the University of Macerata and compared with results coming from other universities. The reflective pathways are structured in questions allowing the students to reflect and review the planned project activities. If the student find difficult to carry out the self-reflexive process, he/she can ask support to human tutor. The tested models are close to research in the field of self-regulated learning, reflexive approach and of analysis of practice. The reflexive process, implemented in the I-TUTOR prototype, even if will not allow an articulate dialogue which would require semantic methods, focus on the attention of the students on reflexivity and ask for the tutor intervention only when the system is unable to properly support the student.

The fact that the initial design phase does not require a long time of planning and the fact the dialogue with students, being language free, does not use semantic methods, limits the potentials of the ITS, and build the system as support for the teacher. It therefore does not replace the relation teacher-student. This choice is based both on the need to respect European context, which is multilingual, and on the didactic choice to work on ill-defined domains, as well as on a non-deterministic vision of the relation teaching-learning, which always requires an ongoing adjustment. In this perspective, the produced artifacts are not replacing the human tutor and the relation between student and teacher, but are often fundamental for the quality of the decisions of the human tutor. In facts, the picture offered by the intelligent system is much more complex, articulated and complete than the picture coming from a human monitoring only, and can greatly improve the performance of the educational system. The human and automatic support are not alternative, but complementary, and they complete each other.

The I-TUTOR project recognises a logical evolution on authoring systems that support teachers and tutors in the design and planning phase. In this perspective, the project team is testing the Conversional Framework model, proposed by Diana Laurillard, and the related software LDSE (Learning Design Support Environment).

The ongoing monitoring of the pathway, the mapping of the domains and the reflexive support provide to the teachers tools to detect in-time problematic situations, or interesting modifications from the designed educational

path, and to the students a meaningful representation of their own learning pathway, which is needed to improve the own professional and personal identity.

Appendix
1. Intelligent Tutoring Systems in Ill-defined Domains Bibliography 2003-2012

◖ By courtesy of Philippe Fournier-Viger*

This pages lists main publications about ITS in ill-defined domains. They are ordered by years of publications in main conferences/workshops/journals and alphabetical order of first author last names. It was last updated: 2012/11/04. The list is not exhaustive.

2012

ITS 2012

1. M. Floryan, T. Dragon, B. Park Woolf (2012). When Less Is More: Focused Pruning of Knowledge Bases to Improve Recognition of Student Conversation. Proc. ITS 2012, pp. 340-345.
2. P. Fournier-Viger, R. Nkambou, A.Mayers, E. Mephu Nguifo & U. Faghihi (2012). Multi-Paradigm Generation of Tutoring Feedback in Robotic Arm Manipulation Training. Proceedings of the 11th Intern. Conf. on Intelligent Tutoring Systems (ITS 2012), LNCS 7315, Springer, pp. 233-242.
3. M. Sharipova (2012) Supporting Students in the Analysis of Case Studies for Ill-Defined Domains. Proceedings of the 11th Intern. Conf. on Intelligent Tutoring Systems (ITS 2012), LNCS 7315, Springer, pp. 609-611.
4. B. Nye, G. Bharathy, B. G. Silverman, C. Eksin (2012). Simulation-

Based Training of Ill-Defined Social Domains: The Complex Environment Assessment and Tutoring System (CEATS). Proceedings of the 11th Intern. Conf. on Intelligent Tutoring Systems (ITS 2012), LNCS 7315, Springer, pp. 642-644.

Journal papers

1. M. McCarthy (2012). Supporting Collaborative Interaction with Open Learner Models: Existing Approaches and Open Questions. Australasian journal of engineering education, 18(1), pp. 49-60 (pdf).

Other conference papers

1. S. Gross, B. Mokbel, B. Hammer, N. Pinkwart (2012). Feedback Provision Strategies in Intelligent Tutoring Systems Based on Clustered Solution Spaces. Proc. of Delfi 2012.

Book chapter

1. F. Loll, N. Pinkwart, O. Scheuer, B. M. McLaren, (2012). How Tough Should It Be? Simplifying the Development of Argumentation Systems using a Configurable Platform. In N. Pinkwart, & B. M. McLaren (Eds.), *Educational Technologies for Teaching Argumentation Skills*, Bentham Science Publishers (pdf).
2. C. Lynch, K. D. Ashley, N. Pinkwart, V. Aleven (2012). Adaptive Tutoring Technologies and Ill-Defined Domains. In P. J. Durlach, A. Lesgold, Adaptive Technologies for Training and Education.

2011

Journal papers

1. R. Nkambou, P. Fournier-Viger, E. Mephu Nguifo, E (2011). Learning Task Models in Ill-defined Domain Using an Hybrid Knowledge Discovery Framework. Knowledge-Based Systems, Elsevier, 24(1), pp. 176-185.
2. R. Noss, A. Poulovassilis, E. Geraniou, S. Gutierrez-Santos, C. Hoyles, K. Kahn, G. D. Magoulas and M. Mavrikis (2011). The design of a system to support exploratory learning of algebraic generalisation. Computers & Education (pdf).

AIED 2011

1. A. Weerasinghe, A. Mitrovic, D. Thomson, P. Mogin, B. Martin (2011). Evaluating a General Model of Adaptive Tutorial Dialogues. Proc. AIED 2011, pp. 394-402.

Others

1. A. d.S. Jacinto, J. M. P. d. Oliveira (2011). A Process for Solving Ill-Structured Problem Supported by Ontology and Software Tools. Proc. Third International ICST Conference, pp. 212-226.

2010

Book chapter

1. P. Fournier-Viger, R. Nkambou and E. Mephu Nguifo, E. (2010). Building Intelligent Tutoring Systems for Ill-Defined Domains. In Nkambou, R., Mizoguchi, R. & Bourdeau, J. (Eds.). Advances in Intelligent Tutoring Systems, Springer, pp. 81-101 (pdf).

ITS 2010

1. R. Gluga, J. Kay and T. Lever. Modelling long term learning of generic skills, pp. 86-95.
2. I. Goldin, K. Ashley. Prompting for Feedback in Peer Review: Importance of Problem-Specific, pp. 96-105.
3. H.Kazi, P. Haddawy and S. Suebnukarn. Leveraging a Domain Ontology to Increase the Quality of Feedback in an Intelligent Tutoring System, pp. 76-85.

ITS 2010 - posters

1. P. Fournier-Viger, R. Nkambou, E. Mephu-Nguifo and Andre Mayers, Intelligent Tutoring Systems in Ill-Defined Domains: Toward Hybrid Approaches, pp. 749-751 (pdf).

ITS 2010 - workshop "Intelligent Tutoring Technologies for Ill-Defined Problems and Ill-Defined Domain" (website / full proceeding)

1. K D. Ashley: "Borderline Cases of Ill-definedness and How Different Definitions Deal with Them".
2. P. Durlach: "The First Report is Always Wrong, and Other Ill-Defined Aspects of the Army Battle Captain Domain" (pdf).
3. R. Gluga: "Is Five Enough? Modeling Learning Progression in Ill-Defined Domains at Tertiary Level" (pdf).
4. A. Graesser: "Using a Quantitative Model of Participation in a Community of Practice to Direct Automated Mentoring in an Ill-Formed Domain" (pdf).
5. A. Graesser: "Comments of Journalism Mentors on News Stories: Classification and Epistemic Status of Mentor Contributions" (pdf).
6. N. Green: "Towards Intelligent Learning Environments for Scientific Argumentation".
7. M. Hays: "The Evolution of Assessment: Learning about Culture from a Serious Game" (pdf).
8. L. Lau: "What is the Real Problem: Using Corpus Data to Tailor a Community Environment for Dissertation Writing".
9. M. Mavrikis: "Layered Learner Modelling in ill-defined domains: conceptual model and architecture in MiGen." (pdf).

IJAIED special issue on ill-defined domains Vol. 19 Issues 3 and 4 (website)

1. C. Lynch, K. Ashley, N. Pinkwart, Concepts, Structures, and Goals: Redefining Ill-Definedness, pp. 253-266.
2. Amy Ogan, Vincent Aleven, Advancing Development of Intercultural Competence through Supporting Predictions in Narrative Video, pp. 267-288.
3. J. Kim et al., BiLAT: A Game-Based Environment for Practicing Negotiation in a Cultural Context, pp. 289-308.
4. H. Kazi, P. Haddawy, Expanding the Space of Plausible Solutions in a Medical Tutoring System for Problem-Based Learning, pp. 309-334.
5. E. Owen, Intelligent Tutoring for Ill-Defined Domains in Military Simulation-Based Training, pp. 337-356 Bratt, Stanford University, pp. 357-379.
6. A. Weerasinghe, A. Mitrovic, B. Martin, Using Weighted Constraints to

Diagnose Errors in Logic Programming – The Case of an Ill-defined Domain, pp. 381-400.
7. N. Pinkwart, K. Ashley, C. Lynch, V. Aleven, Evaluating an Intelligent Tutoring System for Making Legal Arguments with Hypotheticals, pp. 401-424.
8. M. Easterday, V. Aleven, R. Scheines, S. Carver, Carnegie Mellon UniversityConstructing Causal Diagrams to Learn Deliberation pp. 425-445.

FLAIRS 2010
1. N.-T. Le, W. Menzel and N. Pinkwart. Considering Ill-Definedness of Problems from the Aspect of Solution Space.

2009

AIED 2009
1. P. Fournier-Viger, R. Nkambou and E. Mephu Nguifo. Exploiting Partial Problem Spaces Learned from Users' Interactions to Provide Key Tutoring Services in Procedural and Ill-Defined Domains. (**pdf**).
2. M. Hays, H. C. Lane, D.Auerbach, M. Core, D. Gomboc and M. Rosenberg. Feedback Specificity and the Learning of Intercultural Communication Skills (**pdf**).
3. A.Mitrovic and A.Weerasinghe. Revisiting Ill-Definedness and the Consequences for ITSs (**pdf**).

AIED 2009 - posters
1. T. Dragon, B. Woolf and T. Murray. Intelligent Coaching for Collaboration in Ill-Defined Domains.
2. R. Hodhod, D. Kudenko and P. Cairns. Educational Narrative and Student Modeling for Ill-Defined Domains.
3. N. Pinkwart,C. Lynch, K. Ashley and V. Aleven. Assessing Argument Diagrams in an Ill-defined Domain.

ICCE 2009
1. R. Hodhod, S. Abbas, H. Sawamura and D. Kudenko. Teaching in Ill-Defined Domains Using ITS and AI Approaches (**proceedings**).

2008

ITS 2008

1. R. Nkambou, E. M Nguifo and P. Fournier-Viger. Using Knowledge Discovery Techniques to Support Tutoring in an Ill-Defined Domain
2. N. Pinkwart, C. Lynch, K. Ashley and V. Aleven. Re-evaluating LARGO in the Classroom: Are Diagrams Better than Text for Teaching Argumentation Skills? (**pdf**).

ITS 2008 - posters

1. A. Ogan, E. Walker, C. Jones and V. Aleven. Toward Supporting Collaborative Discussion in an Ill-Defined Domain.

ITS 2008 - YRT

1. M. Ringenbert and K. Van Lehn. Does Solving Ill-Defined Physics Problems Elicit More Learning than Conventional Problem Solving?

ITS 2008 Workshop on ill-defined domains
(**workshop website**, **full proceedings**)

1. P. Fournier-Viger, R. Nkambou and E. Mephu Nguifo. A Sequential Pattern Mining Algorithm for Extracting Partial Problem Spaces from Logged User Interactions (**pdf**).
2. G. Gauthier, L. Naismith, S. P. Lajoie and J. Wiseman. Using Expert Decision Maps to Promote Reflection and Self-Assessment in Medical Case-Based Instruction (**pdf**).
3. R. Hodhod and D. Kudenko. Interactive Narrative and Intelligent Tutoring for Ethics Domain (**pdf**).
4. C. Lynch, N. Pinkwart, K. Ashley and V. Aleven.What Do Argument Diagrams Tell Us About Students' Aptitude Or Experience? A Statistical Analysis In An Ill-Defined Domain (**pdf**).
5. S. Moritz and G. Blank. Generating and Evaluating Object-Oriented Designs for Instructors and Novice Students (**pdf**).
6. J. Pino, M. Heilman and M. Eskenazi. A Selection Strategy to Improve Cloze Question Quality (**pdf**).
7. E. Walker, A. Ogan, V. Aleven and Chris Jones. Two Approaches for Providing Adaptive Support for Discussion in an Ill-Defined Domain (**pdf**).

ICCE 2008

1. N.-T. Le and W. Menzel. Towards an Evaluation Methodology of Diagnostic Accuracy for Ill-defined Domains (**pdf**).

2007

AIED 2007 - YRT and DC

1. T. Dragon. Advancing the state of inquiry learning tutors for ill-defined domains (**pdf**).
2. G. Gauthier. Visual representation of the ill-defined problem solving process.

AIED 2007 - Workshop on ill-defined domains
(**workshop website**)

1. K. Avramides and R. Luckin. Towards the Design of A Representational Tool To Scaffold Students: Epistemic Understanding of Psychology in Higher Education (**pdf**).
2. I. Bittencourt, E.Costa, B. Fonseca, G.Maia and I. Calado. Themis, a Legal Agent-based ITS (**pdf**).
3. V. M. Chieu, V. Luengo, L. Vadcard and D.Mufti-Alchawafa. A Framework for Building Intelligent Learning Environments in Ill-defined Domains (**pdf**).
4. M. W. Easterday, V. Aleven and R. Scheines The logic of Babel: Causal reasoning from conflicting sources (**pdf**).
5. G. Gauthier, S. P. Lajoie and S. Richard Mapping and Validating Case Specific Cognitive Models (**pdf**).
6. C. Lynch, K. Ashley, N. Pinkwart and V. Aleven. Argument diagramming as focusing device: does it scaffold reading? (**pdf**).
7. A. Nicholas and B. Martin. Resolving Ambiguity in German Adjectives (**pdf**).

UM 2007

1. B. Martin, A. Nicholas. Studying Model Ambiguity in a Language ITS (**pdf**).

2006

ITS 2006

1. T. Dragon, B. P. Woolf, D. Marshall and T. Murray. Coaching Within a Domain Independent Inquiry Environment.

ITS 2006 - Workshop on ill-defined domains
(workshop website)

1. C. Lynch, K. Ashley, V. Aleven, and N.Pinkwart. Defining Ill-Defined Domains; A literature survey (**pdf**).
2. N.-T. Le. A Constraint-based Assessment Approach for Free-Form Design of Class Diagrams using UML (**pdf**).
3. M. Heilman and M. Eskenazi. Language Learning: Challenges for Intelligent Tutoring Systems (**pdf**).
4. A. Ogan, R. Wylie, and E. Walker. The challenges in adapting traditional techniques for modeling student behavior in ill-defined domains (**pdf**).
5. N.-T. Le. Using Prolog Design Patterns to Support Constraint-Based Error Diagnosis in Logic Programming (**pdf**).
6. V. Aleven, N. Pinkwart, K. Ashley, and C. Lynch. Supporting Self-explanation of Argument Transcripts: Specific v. Generic Prompts (**pdf**).
7. A. Weerasinghe and A.Mitrovic. Individualizing Self-Explanation Support for Ill-Defined Tasks in Constraint-based Tutors (**pdf**).
8. T. Dragon and B. P. Woolf. Guidance and Collaboration Strategies in Ill-defined Domains (**pdf**).
9. H.-C. Wang, C. P. Rosé, T.-Y. Li, and C.-Y. Chang. Providing Support for Creative Group Brainstorming: Taxonomy and Technologies (**pdf**).
10. I. Goldin, K. Ashley, and R. Pinkus. Teaching Case Analysis through Framing: Prospects for an ITS in an ill-defined domain (**pdf**).
11. A. Ogan, V. Aleven, and C. Jones. Culture in the Classroom: Challenges for Assessment in Ill-Defined Domains (**pdf**).

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1. Aleven, V. (2003). Using background knowledge in case-based legal reasoning: a computational model and an intelligent learning environment. Artificial Intelligence, 150, 183-237.

Before 2003

1. K.D. Ashley (1991) Reasoning with cases and hypotheticals in HYPO, Internat. J. Man-Machine Stud. 34 (6). 753-796.

Related works in Artificial intelligence

1. Simon, H. A. (1978). Information-processing theory of human problem solving. In W. K. Estes (Ed.), Handbook of learning and cognitive processes: Vol. 5. Human information.

2. ITS 2006
Workshop in Ill-Defined Domain

Intelligent Tutoring Systems have made great strides in recent years. Robust ITSs have been developed and deployed in arenas ranging from mathematics and physics to engineering and chemistry. Over the past decade intelligent tutoring systems have become increasingly accepted as viable teaching and learning tools in academia and industry.

Most of the ITS research and development to this point has been done in well-defined domains. Well-defined domains are characterized by a basic formal theory or clear-cut domain model. Such domains are typically quantitative, and are often taught by human tutors using problems where answers can unambiguously be classified as correct or incorrect. Well-defined domains are particularly amenable to model-tracing tutoring systems. Operationalizing the domain theory makes it possible to identify study problems, provide a clear problem solving strategy, and assess results definitively based on the existence of unambiguous answers. Help can be readily provided by comparing the students' problem-solving steps to the existing domain models.

Not all domains of teaching and inquiry are well-defined, indeed most are not. Domains such as law, argumentation, history, art, medicine, and design are ill-defined. Often even well-defined domains are increasingly ill-defined at the edges where new knowledge is being discovered. Ill-defined domains lack well-defined models and formal theories that can be operationalized, typically problems do not have clear and unambiguous solutions. For this reason ill-defined domains are typically taught by human tutors using exploratory, collaborative, or Socratic instruction techniques.

Ill-defined domains present a number of unique challenges for researchers in Intelligent Tutoring Systems and Computer Modeling. These challenges include 1) Defining a viable computational model for aspects of underspeci-

fied or open-ended domains; 2) Development of feasible strategies for search and inference in such domains; 3) Provision of feedback when the problem-solving model is not definitive; 4) Structuring of learning experiences in the absence of a clear problem, strategy, and answer; 5) User models that accommodate the uncertainty of ill-defined domains; and 6) User interface design for ITSs in ill-defined domains where usually the learner needs to be creative in his actions, but the system still has to be able to analyze them.

These challenges must be faced if the ITS community is ever to branch out from the traditional domains into newer arenas. Over the past few years a number of researchers have begun work in ill-defined domains including law, medicine, professional ethics and design. This workshop represents a chance to share what has been learned by those practitioners at a time when work in these domains is still nascent.

CALL FOR PAPERS

We invite work at all stages of development, including particularly innovative approaches in their early phases. Research papers (up to 9 pages) and demonstrations (up to 4 pages, describing an application or other work to be demonstrated live at the workshop) are welcome for submission. Workshop topics include but are not limited to:

▶ Model Development: Production of formal or informal models of ill-defined domains or subsets of such domains.
▶ Teaching Strategies: Development of teaching strategies for such domains, for example, Socratic, problem-based, task-based, or exploratory strategies.
▶ Search and Inference Strategies: Identification of exploration and inference strategies for ill-defined domains such as heuristic searches and case-based comparisons.
▶ Assessment: Development of Student and Tutor assessment strategies for ill-defined domains. These may include, for example, studies of related-problem transfer and qualitative assessments.
▶ Feedback: Identification of feedback and guidance strategies for ill-defined domains. These may include, for example, Socratic (question-based) methods or related-problem transfer.
▶ Exploratory Systems: Development of intelligent tutoring systems for

open-ended domains. These may include, for example, user-driven "exploration models" and constructivist approaches.

▶ Collaboration: The use of peer-collaboration within ill-defined domains, e.g., to ameliorate modeling issues.

▶ Representation: Free form text is often the most appropriate representation for problems and answers in ill-defined domains; intelligent tutoring systems need techniques for accommodating that.

The topics can be approached from different perspectives: theoretical, systems engineering, application oriented, case study, system evaluation, etc.

WORKSHOP

▶ Collin Lynch, Kevin Ashley, Vincent Aleven, and Niels Pinkwart (Carnegie Mellon University and University of Pittsburgh): Defining Ill-Defined Domains; A literature survey (**pdf**).

▶ Nguyen-Thinh Le (University of Hamburg): A Constraint-based Assessment Approach for Free-Form Design of Class Diagrams using UML (**pdf**).

▶ Michael Heilman and Maxine Eskenazi (Carnegie Mellon University): Language Learning: Challenges for Intelligent Tutoring Systems (**pdf**).

▶ Amy Ogan, Ruth Wylie, and Erin Walker (Carnegie Mellon University): The challenges in adapting traditional techniques for modeling student behavior in ill-defined domains (**pdf**).

▶ Nguyen-Thinh Le (University of Hamburg): Using Prolog Design Patterns to Support Constraint-Based Error Diagnosis in Logic Programming (**pdf**).

▶ Vincent Aleven, Niels Pinkwart, Kevin Ashley, and Collin Lynch (Carnegie Mellon University and University of Pittsburgh): Supporting Self-explanation of Argument Transcripts: Specific v. Generic Prompts (**pdf**).

▶ Amali Weerasinghe and Antonija Mitrovic (University of Canterbury): Individualizing Self-Explanation Support for Ill-Defined Tasks in Constraint-based Tutors (**pdf**).

▶ Toby Dragon and Beverly Park Woolf (University of Massachusetts-Amherst): Guidance and Collaboration Strategies in Ill-defined Domains (**pdf**).

▶ Hao-Chuan Wang, Carolyn P. Rosé, Tsai-Yen Li, and Chun-Yen Chang (Carnegie Mellon University, National Chengchi University Taiwan and National Taiwan Normal University): Providing Support for Creative Group Brainstorming: Taxonomy and Technologies (**pdf**).
▶ Ilya Goldin, Kevin Ashley, and Rosa Pinkus (University of Pittsburgh): Teaching Case Analysis through Framing: Prospects for an ITS in an ill-defined domain (**pdf**).
▶ Amy Ogan, Vincent Aleven, and Christopher Jones (Carnegie Mellon University): Culture in the Classroom: Challenges for Assessment in Ill-Defined Domains (**pdf**).

WORKSHOP PROGRAM COMMITTEE

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3.

Appendix

ITS 2008
Workshop in Ill-Defined Domain

Intelligent tutoring systems have achieved reproducible successes and wide acceptance in well-defined domains such as physics, chemistry and mathematics. Many of the most commonly taught educational tasks, however, are not well-defined but ill-defined. These include such domains as law, design, history, and medical diagnosis. As interest in ill-defined domains has expanded within and beyond the ITS community, researchers have devoted increasing attention to these domains and are developing approaches adapted to the special challenges of teaching and learning in these domains. The prior workshops in Taiwan (ITS 2006) and Marina-Del-Rey, California (AIED 2007) have demonstrated the high level of interest in ill-defined domains and the quality of ITS work addressing them.

Developing ITSs for ill-defined domains may require a fundamental rethinking of the predominant ITS approaches. Well-defined domains, by definition, allow for a clear distinction between right and wrong answers. This assumption underlies most if not all existing ITS systems. One of the central advantages of classical ITSs over human tutors is the potential for on-line feedback and assessment. Rather than waiting until a task is completed, or even long after, a student receives guidance as they work enabling them to focus clearly on useful paths and to detect immediately 'the' step that started them down the wrong path.

Ill-defined domains typically lack clear distinctions between "right" and "wrong" answers. Instead, there often are competing reasonable answers. Often, there is no way to classify a step as necessarily incorrect or to claim that this step will lead the user irrevocably astray as compared to any other. This makes the process of assessing students' progress and giving them reasonable advice difficult if not impossible by classical.

This workshop will provide a forum for presenting good work on all

aspects of designing ITSs for ill-defined domains. In order to build on the successes of the prior workshops in Taiwan and Marina-Del-Rey this workshop will focus particularly on the issues of how to provide feedback in ITS systems designed for ill-defined domains and how to assess such systems.

Paper topics of special interest are:

1. *Assessment:* Development of student and tutor assessment strategies for ill-defined domains. These may include, for example, studies of related-problem transfer and qualitative assessments.
2. *Feedback:* Identification of feedback and guidance strategies for ill-defined domains. These may include, for example, Socratic (question-based) methods or related-problem transfer.

Other topic of interest include:

1. *Model Development:* Production of formal or informal domain models and their use in guidance.
2. *Teaching Strategies:* Development of teaching strategies for such domains, and the interaction of those strategies with the students.
3. *Search and Inference Strategies:* Definition of suitable search strategies and the communication of those strategies to the students.
4. *Exploratory Systems:* Development of intelligent tutoring systems for open-ended domains. These may include, for example, user-driven exploration models and constructivist approaches.
5. *Collaboration:* The use of peer-collaboration within ill-defined domain for guidance or other purposes.
6. *Representation:* Free form text is often the most appropriate representation for problems and answers in ill-defined domains; AIED in this area needs tools and techniques for accommodating text.

WORKSHOP

▶ Introduction: Kevin D. Ashley (pdf).
▶ Two Approaches for Providing Adaptive Support for Discussion in an Ill-Defined Domain **Erin Walker, Amy Ogan, Vincent Aleven, Chris Jones** (pdf).
▶ Interactive Narrative and Intelligent Tutoring for Ethics Domain Rania Hodhod and Daniel Kudenko (pdf).

- A Selection Strategy to Improve Cloze Question Quality Juan Pino, Michael Heilman, and Maxine Eskenazi (**pdf**).
- Generating and Evaluating Object-Oriented Designs for Instructors and Novice Students Sally Moritz and Glenn Blank (**pdf**).
- A Sequential Pattern Mining Algorithm for Extracting Partial Problem Spaces from Logged User Interactions Philippe Fournier-Viger, Roger Nkambou and Engelbert Mephu Nguifo (**pdf**).
- What Do Argument Diagrams Tell Us About Students' Aptitude Or Experience? A Statistical Analysis In An Ill-Defined Domain Collin Lynch, Niels Pinkwart, Kevin Ashley and Vincent Aleven (**pdf**).
- Using Expert Decision Maps to Promote Reflection and Self-Assessment in Medical Case-Based Instruction Geneviève Gauthier, Laura Naismith, Susanne P. Lajoie, and Jeffrey Wiseman (**pdf**).

The topics can be approached from different perspectives: theoretical, systems engineering, application oriented, case study, system evaluation, etc.

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ITD 2010
Intelligent Tutoring Technologies
for Ill-Defined Problems and Ill-Defined Domains

At the 10th International Conference
on Intelligent Tutoring Systems in Pittsburgh. 2010

Intelligent tutoring systems, and intelligent learning environments support learning in a variety of domains from basic math and physics to legal argument, and hypothesis generation. These latter domains are ill-defined referring to a broad range of cognitively complex skills and requiring solvers to structure or recharacterize them in order to solve problems or address open questions. Ill-defined domains are very challenging and have been relatively unexplored in the intelligent learning community. They usually require novel learning environments which use non-didactic methods, such as Socratic instruction, peer-supported exploration, simulation and/or exploratory learning methods, or informal learning techniques in collaborative settings.

Ill-defined domains such as negotiation, intercultural competence, and argument are increasingly important in educational settings. As a result, interest in ill-defined domains has grown in recent years with many researchers seeking to develop systems that support both structured problem solving and open-ended recharacterization. Ill-defined problems and ill-defined domains however pose a number of challenges. These include:

▶ Defining viable computational models for open-ended exploration coupled intertwined with appropriate meta-cognitive scaffolding;
▶ Developing systems that may assess and respond to fully novel solutions relying on unanticipated background knowledge;
▶ Constraining students to productive behavior in otherwise underspecified domains;
▶ Effective provision of feedback when the problem-solving model is not definitive and the task at hand is ill-defined;

▶ Structuring of learning experiences in the absence of a clear problem, strategy, and answer;
▶ Developing user models that accommodate the uncertainty, dynamicity, and multiple perspectives of ill-defined domains;
▶ Designing interfaces that can guide learners to productive interactions without artificially constraining their work.

These challenges must be faced in order to develop effective tutoring systems in these attractive, open, and important arenas. A stimulating series of workshops has been held at ITS 2006, AIED 2007, and ITS 2008. Each workshop brought together a range of researchers focusing on domains as diverse as database design and diagnostic imaging. The work they presented ranged from nascent system designs to robust systems with a solid user base. While the domains and problems addressed differed from system to system, many of the techniques were shared allowing for fruitful cross-pollination.

Due to the success of those workshops and the growing interest in extending intelligent tutoring systems and learning environments to address ill-defined domains we feel a workshop at ITS 2010 is warranted. This event will allow researchers from prior workshops to share their lessons learned while allowing new developers to explore the this dynamic area.

Call for Papers:

We invite work at all stages of development, including particularly innovative approaches in their early phases. Full research papers (up to 8 pages) and demonstrations (up to 4 pages, describing an application or other work to be demonstrated live at the workshop) are welcome for submission.

Paper topics may include but are not limited to:

▶ *Model Development:* Production of formal or informal models of ill-defined domains, constraints or characteristics of such domains or important subdomains.
▶ *Teaching Strategies*: Development of teaching strategies for ill-defined problems and ill-defined domains, for example, Socratic, peer-guided, or exploratory strategies.
▶ *Metacognition and Skill-Transfer*: Identification of essential skills for ill-defined problems and domains and the transfer of skills across domains and problems.

▶ *Assessment*: Development of student and tutor assessment strategies for ill-defined domains. These may include, for example, qualitative assessments and peer-review.

▶ *Feedback*: Identification of feedback and guidance strategies for ill-defined domains. These may include, for example, Socratic (question-based) methods or related-problem transfer.

▶ *Exploratory Systems*: Development of intelligent tutoring systems for open-ended domains. These may include, for example, user-driven exploration models, simulations, and constructivist approaches.

▶ *Representation*: Free form text is often the most appropriate representation for problems and answers in ill-defined domains; ITSs in these areas need to accommodate and yet guide this free description.

The topics can be approached from different perspectives: theoretical, systems engineering, application oriented, case study, system evaluation, etc.

Collin Lynch: Welcome to IllDef2010

1. *Kevin D. Ashley:* "Borderline Cases of Ill-definedness and How Different Definitions Deal with Them".
2. *Paula Durlach:* "The First Report is Always Wrong, and Other Ill-Defined Aspects of the Army Battle Captain Domain".
3. *Nancy Green:* "Towards Intelligent Learning Environments for Scientific Argumentation".
4. *Lydia Lau:* "What is the Real Problem: Using Corpus Data to Tailor a Community Environment for Dissertation Writing".
5. *Manolis Mavrikis:* "Layered Learner Modelling in ill-defined domains: conceptual model and architecture in MiGen".

   Prof. David Herring: University of Pittsburgh's School of Law Aspects of instruction in Legal Reading and Writing.

6. *Art Graesser:* "Using a Quantitative Model of Participation in a Community of Practice to Direct Automated Mentoring in an Ill-Formed Domain".
7. *Matthew Hays:* "The Evolution of Assessment: Learning about Culture from a Serious Game".

8. *Art Graesser:* "Comments of Journalism Mentors on News Stories: Classification and Epistemic Status of Mentor Contributions".
9. *Richard Gluga:* "Is Five Enough? Modeling Learning Progression in Ill-Defined Domains at Tertiary Level".

Panelists: Vincent Aleven, Amy Ogan, Sergio Gutierrez and Hameedullah Kazi.

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Appendix

AIED 2013
International Conference
on Artificial Intelligence in Education

The 16th International Conference on Artificial Intelligence in Education (AIED2013) is the next in a longstanding series of biennial international conferences for high quality research in intelligent systems and cognitive science for educational computing applications. The conference provides opportunities for the cross-fertilization of approaches, techniques and ideas from the many fields that comprise AIED, including computer science, cognitive and learning sciences, education, game design, psychology, sociology, linguistics, as well as many domain-specific areas. Since the first AIED meeting 30 years ago, both the breadth of the research and the reach of the technologies have expanded in dramatic ways. The theme of AIED2013 therefore seeks to capture this evolution: *From education to lifelong learning: constructing pervasive and enduring environments for learning*. In line with this theme of expansion, AIED2013 will welcome the Industry & Innovation Track which seeks to capture the challenges, solutions, and results from the transition of AIED technologies into the commercial sector.

TOPICS

1. Modelling and Representation: Models of learners, facilitators, tasks and problem-solving processes; Models of groups and communities for learning; Modelling motivation, metacognition, and affective aspects of learning; Ontological modelling; Handling uncertainty and multiple perspectives; Representing and analysing discourse during learning.

2. Models of Teaching and Learning: Intelligent tutoring and scaffolding; Motivational diagnosis and feedback; Interactive pedagogical agents and

learning companions; Agents that promote metacognition, motivation and affect; Adaptive question-answering.

3. Intelligent Technologies: Natural language processing; Data mining and machine learning; Knowledge representation and reasoning; Semantic web technologies and standards; Simulation-based learning; Multi-agent architectures.

4. Learning Contexts and Informal Learning: Educational games; Collaborative and group learning; Social networks; Inquiry learning; Social dimensions of learning; Communities of practice; Ubiquitous learning environments; Learning grid; Lifelong, museum, out-of-school, and workplace learning.

5. Innovative and Commercial Applications: Domain-specific learning applications (e.g. language, mathematics, science, medicine, military, industry); Scaling up and large-scale deployment of AIED systems.

6. Evaluation: Human-computer interaction; Evaluation methodologies; Studies on human learning, cognition, affect, motivation, and attitudes; Design and formative studies of AIED systems.