eLearning with a Rule-based Tutor: Real-time Socratic Dialog

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Abstract. To generate real-time "intelligent dialog" as a core concept of good teaching, the CourseWare eLearning platform uses a rule based expert system. The aim is to provide an adaptive, fully interactive style of conditional multi-media course content delivery over the web, that engages the student, and adapts to the learners implicit (observed) and explicit (expressed) feedback. „Socratic“ dialog – a simulated intelligent tutor – uses embedded questions, challenges, assignments and tasks, on-line experiments, and external links and an ongoing, real-time evaluation and feedback based on observed student performance. Lectures are delivered by a real-time expert system as a conditional sequence of dynamically generated and thus personalized elements. Sequence and detail depend on student response, emulating a lecturer-student dialog. The intelligent tutor concept utilizes close monitoring and evaluation of the students' behavior (e.g., time spent on individual pages and units, tests, personal learning history), including any number of embedded small multiple-choice tests to monitor student comprehension, as well as the results from larger 'virtual laboratory' assignments that involve on-line model use. Additional feedback is provided by explicit on-line comments and questions by students. A wide range of supporting functions and tools provides extensive background literature, glossary, on-line models, a discussion forum for peer-to-peer communication and in fact learning, and continuous feedback on any students performance and standing in the “class”. Learning progress and ultimate success is measured in terms of continuously evaluated participation, direct student feedback as well as the comparison of before-and-after lecture tests together with assignments and term papers submitted for tutor and optional peer review in the class. Test applications in university courses and in an industrial context (technical training) concentrate on environmental management topics related to air, water, risk, energy and climate, urban and regional development. These are complex, dynamic, and distributed problem domains, that provide an ideal mixture of factual knowledge and analytical tasks, supported by simulation models, that can take full advantage of the interactive methodology.

1. Introduction

The concept of eLearning offers in addition to the obvious economic benefits of near unlimited cost-efficient scaling independence of location, timing, and individual speed of learning - that benefit both student and teacher- and innovative styles of instruction material. This flexibility should improve course delivery logistics and thus enlarge the possible user group substantially beyond classical and necessarily synchronized classroom teaching. At the same time, most eLearning platforms lack a key element of successful teaching, which is intelligent dialog between students and teacher, immediate feedback, and immediate adaptive response to learner behavior. Classical platforms simply provide download
facilities for “lectures”, notes or taped frontal deliveries, assignments and communication and discussion tools. While this improves the “synchronization” requirement of classroom teaching, it lacks true interaction, adaptive response in real-time, immediate feedback.

2. Dialog oriented learning

To provide better, more efficient and flexible, adaptive and "intelligent", intuitive, attractive and fun-to-use learning environments, the CourseWare prototype integrates key ICT technologies into an innovative eLearning platform for both university courses and continuing education and technical training applications:

- **Artificial Intelligence**, using rule based hybrid (forward and backward chaining) expert system technology to simulate a human tutor that adapts;
- A **virtual classroom** for social contact and group experience in eLearning;
- The **virtual laboratory**: web-based simulation models fully integrated with the lectures as "assignments" to study concepts and relationships experimentally;
- **Mobile dialog**: supports the students favorite toys as auxiliary communication channel.

These technical features and objectives are embedded in a new learning model based on a constructivist approach to experiential learning. Through the dialog, learners are encouraged to plan, experience, reflect and abstract lessons learned from experience both on a personal level and with peers through discussion in an on-line forum. Real-time interactions facilitate engagement, motivation (the tutor always listens and reacts), and an improved understanding of the complex concepts, relationships and associated analytic tasks as well as the development of the learner's own meta-cognitive competencies, learning to learn. Motivational support combines enhanced social presence in the virtual classroom and collaborative activity, discussion, and the competitive and gaming-like element of continuous evaluation and transparent student ranking.

The distributed client-server implementation is based on the concepts of Socratic Dialog, an interactive and exploratory learning style including guided self-discovery of learning objectives and peer-to-peer learning, that is customized based on an evolving "individual student model". The context sensitive and personalized lectures within a course framework are supported by a discussion forum, a virtual library for background reading, a virtual laboratory of simulation models, an ontology and glossary (participatory) that not only drives the course (the ontology) and links to the lectures (the glossary) but also provides supporting material for an additional learning stream of "didactic tokens", small factoids, questions, and challenges (in the Socratic Dialog style) designed for mobile clients. The support tools are also open for learner contributions.

The basic lectures introduce topics, basic concepts and methods, and include numerous challenges and questions (with simple, individual choices or symbolic answers easy to parse to more complex embedded multiple-choice tests and "assignments" for posting to the discussion board. The questions (and the student response) are designed to maintain the dialog, and guide the student towards critical thinking and self-discovery.

The basic concept is better adaptive and personalized content management and delivery in a more flexible real-time communication style: the integration of web browser, virtual classroom social environment, a rich assortment of background information in hypermedia format, fun-to-explore, a virtual laboratory for experimentation, and supplementary mobile communication to "keep in touch", truly mobile, 'anywhere, anytime'. A more intelligent, adaptive eLearning environment that itself "learns" should help to interest and seriously engage and actively students.
A further objective is to create an advanced eLearning platform that is cost efficient and easily scalable, re-usable. By automating communication, evaluation, feedback and course management tasks, the architecture supports arbitrarily scalable in terms of numbers of students and simultaneous interactions through parallel implementation.

2.1 Functional components

To “capture” the learners attention in an intelligent dialog, the platform integrates:

• *Artificial Intelligence*, a teaching dialog maintained by a real-time expert system (simulated tutor) with first order production rules, adaptive heuristics and machine learning concepts for an innovative interactive and personalized eLearning solution. Related AI tools include an ontology that serves both as a repository of learning objectives (as semantic net with functional extensions) and a part of the course material as a participatory, interactive glossary, that develop the terminology of the application domain as on of the “cooperative projects” of the learners (folksonomy).

• *Simulation models*, that provide an interactive laboratory to explore complex functional concepts in the main targeted application domain of environmental sciences and technical training;

• Support for mobile clients to maintain a continuous meta-dialog with learners, providing encouragement, reminders, feedback and challenges, including “didactic tokens”, a non-trivial pursuit for mobile engagement;

• *Distributed client-server architecture* that facilitates easy integration of courses and lecture from different sources and institutions without the need for a central data repository, maintaining distributed IPR, and thus ownership, responsibility, and maintenance and continuous update of content.

• *An advanced pedagogical framework*, that supports a new learning model based on a constructivist approach to experiential learning where learners are encourage to actively shape, experience, reflect and abstract lessons learned both on a personal level and with peers through discussion in an online forum. A meta-cognitive tutor supports critical reflection on experience so that specific meta-cognitive competencies can be developed and later may be transferred to the workplace. Other factors underlying learner performance are motivational support through enhanced social interaction (integrating concepts of social media in a dedicated implementation), collaborative activity and discussion. These pedagogically supported interactions facilitate engagement, motivation, and an improved understanding of the complex concepts, relationships and associated analytic tasks as well as the development of the learner’s own meta-cognitive competencies: *learning to learn more efficiently*.

• *Machine learning*: the concept of a meta-cognitive tutor can also be used at the course level, across any number of individual learners. Here we aim at analyzing reception of the lectures, reactions, comments, behavioral patterns and explicit feedback to continuously adapt and improve the course structure and content along the lines of the constructivist model, using machine learning concepts and the functional semantic net representation of the basic course ontology: *learning to teach more efficiently*.

CourseWare integrates browser based distance learning with a truly mobile, “anywhere, anytime” access and support. Forward chaining expert systems technology is used to implement a responsive tutor or lecturer for the “intelligent”, context sensitive and adaptive delivery of lecture content as dialog and discourse style (loosely based on Aristoteles, Socrates, and Foucault) within a course framework again managed by real-time rule-based
inference to provide apparent “intelligence” and adaptive response to the students observed behavior and expressed preferences.

The central engine for both course level and lecture level dialog is a rule-based real-time expert system, [1], http://www.ess.co.at/RTXPS. The basic rule syntax is simple and familiar. The forward chaining RULES are very similar to the first order production rules used in the backward chaining version of the expert system, XPS. The main difference is the action or consequence part: while in the backward chaining branch, this is always an ASSIGNMENT setting the value of a DESCRIPTOR, each forward chaining RULE executes one or more from a repertoire of FUNCTIONS in its consequence part.

RTXPS uses basic production RULES in first order logic.

The generic RULE syntax is:

\[
\text{IF } \text{CONDITION1 AND/OR CONDITION 2} \\
\text{..... AND/OR CONDITION i} \\
\text{THEN ACTION 1} [\text{optional}] \\
\text{AND ACTION 2} [\text{optional}] \\
\text{..... AND ACTION i} [\text{optional}] \\
\text{ELSE ACTION a} [\text{optional}] \\
\text{AND ACTION b} [\text{optional}] \\
\text{..... AND ACTION j}
\]

where CONDITION is short for CONDITION = TRUE, and a construct of the form:

\[
\text{IF TRUE} \quad \text{(unconditionally true, will always execute)} \\
\text{IF function()} \quad \text{arbitrary function call, using DESCRIPTORs as arguments or uses the dynamic Knowledge Base for its context/input, returns TRUE or FALSE} \\
\text{IF DESCRIPTOR OPERATOR VALUE} \quad \text{(direct comparison/evaluation see below, or triggering backward chaining inference tree of arbitrary nesting and number of RULES; alternative METHODS/branches and optional defaults guarantee completion of the inference with limited/lacking data)}
\]

where OPERATOR can be any one of the basic first logic operators: 
\(=, \neq, >, \geq, <, \leq\). For operations on symbols, literal or ordinal interpretation or interval arithmetic of the corresponding numerical ranges (where applicable for hybrid Descriptors with numerical ranges defined) is used. CONDITIONS represent student performance, feedback and learning history. The basic ACTION is the (conditional) composition and presentation of a web page, part of a lecture or specific tutor-to-student communication based on the evolving, dynamic status of the dialog, that reacts to the Knowledge Base with synchronous and asynchronous inputs from various data streams. The flexible ACTIONS make it possible to implement a wide range of heuristics for adaptive behavior [2].
2.2 The didactic concept: a simulated tutor

The basic principle is based on the Aristotelian Philosophy of Dialog and Discourse (and in its practical implementation, the Socratic Dialogue). Rather than providing predefined static content elements (frontal, unidirectional delivery of facts) to the student as lecture notes or taped (classroom frontal) lectures, learners are guided in dialogs of dynamically generated adaptive content to discover knowledge and further understanding. The dialog combines background information with embedded questions to measure comprehension but also facilitate knowledge discovery and understanding from the learners. Another “active” element, albeit asynchronous, is the possibility for the learner to submit a query, comment, suggestions, or “error report” at any point in the. Also, more units (individual “pages” in the hypertext content include links to the discussion board and the appropriate forum or topic within a forum.

This changes the perception towards empowerment of the learner and engenders ownership of the information (discovered rather than received by the student) replacing an unconditional acceptance of authoritative delivery with participatory knowledge discovery. The role of the (simulated, rule-based expert system) tutor is to maintain and adapt the dialog (the sequence and detail of content and questions) to the students’ comprehension and knowledge, by continuously analyzing student behavior and response.

Automatically measurable student response includes
  - the time spent on individual units (pages) in the course delivery;
  - the time used and correctness of the answers to the multiple-choice questions;
  - the answers generated by using the linked model tools as on-line laboratory experimentation, the evolving performance history,
  - all elements of participation, access, contributions
and in addition, provide the option, at every “page” of the user interface, to submit comments, reflections, suggestions for improvements, to a data base backend analyzed and maintained by the real-time expert system. Each post is the basis of yet another dialog (supported by eMail alerts), that the original participants can make public or keep restricted.

For each individual lecture unit, but also a course (set of related, interdependent lectures) as a whole, learning performance can be measured by comparing the results of a test (set of questions) given before and after the lecture, combining formative and summative evaluation concepts. The hypothesis to be tested here is that the test results after the lecture should be better (higher score) than the test results from the test given before the lecture, together with, on average a faster response. This provides easily embedded performance measures for automated monitoring and also formative evaluation feedback to improve the teaching program itself.

The adaptive tutor employs the latest applied research and teaching practices from the field of artificial intelligence and education, and from distance, networked learning. The expert system based tutor supports individual dialog about the particular learning tasks, (e.g. after use of a simulation, or after watching a video or reading about a topic), and adapt to the needs of the individual learner with a personalized customized delivery of dynamically generated content. The adaptive tutor also engages in a dialog with the learner about the learning experience and support individual reflection on that experience. Reflection through dialog creates meaning from experience [2] By supporting learning through reflection on experience, the adaptive tutor not only supports learning but also facilitates knowledge
creation, as it extends understanding of the area and enhances the potential for transfer of that knowledge to another context [4,5,6] Distance learning and collaborative activity enables the sharing of activities and discussion on activity leading to the creation of new knowledge and learner created resources. In order to assist learning and collaboration and create virtual classrooms, discussion fora such as MOODLE (https://moodle.org), SAKAI (http://www.sakaiproject.org), phpBB (http://www.phpbb.com) can provide support for student communication and peer learning where learners can discuss their course, task or project (even as an intrinsic part of seminars with posts being evaluated like explicit assignments), and where learner generated topics and material can potentially be a valuable learning resource as well, generating ownership and thus motivation.

2.2.1 The basic concepts: dialogue, discourse:
The concept of dialog in teaching is a few thousand years old (viz. Plato, Aristoteles, Socrates, Xenophon, Boethius, and a few more classics. Recent treatment (again more than numerous, refer to the very selective bibliography after the references) include, e.g., [7] and it is not beyond being re-invented at regular intervals, [8]. The basics, however, are comparatively simple: The “Socratic method” does not look for specific answers and the (rote) learning of facts, but seeks to broaden students’ views by helping them see multiple aspects involved in answering a question, which fits very well with the basic tenets of multi-attribute theory [9].

As a somewhat more modern, yet also more controversial notion, discourse is "an entity of sequences of signs in that they are enouncements (enoncés, [10]) An enouncement (or "statement") enables signs to designate specific and (within a discourse) fixed relations to objects, subjects and other enouncements. Discourse constitutes sequences of such relations to objects, subjects and other enouncements. A discursive formation describes the regularities, patterns and rules that produce such discourses. Foucault used the concept of discursive formation in relation to his analysis of large and diverse bodies of knowledge, such as political economy and natural history. Here we use it to describe the technology assisted teaching of environmental management. Discourse can be observed in (and used as a conceptual framework to describe) spoken, written and signed language and, in this case, multimodal and multimedia forms of communication, which includes any teaching applications of structured (rule driven patterns) forms of language via the Internet and mobile communication.

2.2.2 From Aristoteles and Socrates to expert systems:
The implementation of these basic concepts in a man-machine dialog is somewhat more restricted, yet the principle aspirations are the same: to guide the student or learner to self-discovery by a mixture of factual statements and (somewhat leading) questions, adapted to the students responses. These observations of the student reception and understanding of the course content offered, her responses to questions and tasks drives an adaptive, context sensitive and “learning” delivery mechanism to get closer to a human student – teacher dialogue. The third dimension or component is the communication channel, here represented by both the Internet and a web browser, and mobile clients such as SmartPhones or tablets, a modern equivalent of the Greek Gymnasium.

2.2.3 Motivation, learning objectives, evaluation, feedback:
A key element of successful teaching is to motivate the learner; we assume there is an “intrinsic” interest in the topic but also a more pragmatic one to get the credits for a course in the overall curriculum. The same interactive logic of the course content presentation is also used to maintain contact in distance learning: students are reminded and encouraged e.g., via email and SMS, if and when their activities “slow down” or lag behind schedule for any
one of the components of participation such as the on-line lectures, participation in the discussion forum with pending posts to be answered, access to the various support tools like the on-line library, or the submission of specific assignments. Encouraging and congratulatory messages acknowledging participation can be configured as positive reinforcement. Students actions and inputs (from login and time on-line, to going through lectures, material downloads, posts, test results, contributions to the glossary etc. are immediately rewarded with Brownie points that are publicly displayed (student ranking) with a detailed but only individually accessible breakdown – moving towards gaming.

![Fig. 1. Dynamically generated lecture web page](image1)

![Fig. 2. Student evaluation page with Brownie points](image2)

### 2.3 Application examples

The test cases (designed for lecture series, seminars and tutorials for complex software systems (i.e., intelligent interactive manuals for training on demand, on the job) deal with complex science topics (environmental geomatics, urban ecology, spatial planning, pollution control) that combine natural science, economic, and socio-political elements (for related projects and on-line course examples, see: [http://www.ess.co.at/TRAINING](http://www.ess.co.at/TRAINING)).

### 3. Discussion and Summary

Adding true interaction and intelligent dialog to eLearning provides a new quality for on-line instructions beyond taped lectures. However, the basic conditional ACTIONS of CourseWare can also play a video sequence (the classical taped lecture), but engage the learner in a dialog about the material afterwards. The interactive nature and the integration of SmartPhones in the overall communication and course management help to get student involved, making the course close enough to a game with elements of “edutainment” in the immediate feedback and collection (and comparative display) of a students evaluation, and ranking through the Brownie points assigned. However, it should also be noted that even with efficient on-line support tools, the design and implementation of lectures and courses that take full advantage of the possibilities of through interaction through a rule-based expert system are considerable.

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