Ten Years of Computer-Based Tutors for Teaching Logic 2000-2010: Lessons Learned

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Abstract. The First International Congress on Tools for Teaching Logic took place in 2000 and the second such congress took place in 2006. The third one takes place in 2011. In the ten years that separate the first and the third congress, the history of the tools for teaching Logic based on the paradigm of intelligent tutoring has been evolving significantly. This article provides a brief review of this history. It also presents a comparative study of 26 such tools and proposes a classification of existing tools with a specific methodology.

Keywords: Logic, higher education, e-learning, intelligent tutoring system, computer-based tutor, e-tutor, web-assistant.

1 Introduction

The First International Congress on Tools for Teaching Logic[1] took place in Salamanca in June 2000. The second such congress[2] took place in September 2006, also held in Salamanca. The third one will also take place in Salamanca in July 2011. In the ten years between the first and the third one, the development of information and digital technology has brought about great changes in the teaching of Logic. On the one hand, the Logic curriculum has been extended through new logics for that new technology and on the other hand, teaching itself has been transformed due to the general access to computers and the Internet.

Currently, opportunities and challenges arise from the onset of technology in educational practice [12]. Digital technologies such as computers, mobile devices, digital media creation and distribution tools, and social networking sites are transforming learning. Tensions between traditional models of schooling and the affordances of digital technologies are noted, while the initial promise of these technologies to shape a new system of education is being reviewed and many voices coming from the educational research area are claiming for the urgency of seeking a coherent model for the future of education in a technological age [8].

The tension between traditional and technology-driven learning can be summarized in the following four opposing positions:

[1] See http://aracne.usal.es/congress/congress.html
[2] See http://logicae.usal.es/SICTTL/

P. Blackburn et al. (Eds.): TICTTL 2011, LNAI 6680, pp. 131–140, 2011.

- Age uniform learning vs. life-long learning
- Teacher as expert vs. diverse knowledge sources for acquiring knowledge
- Standardized assessment vs. performance-based assessment
- Learning by 'absorption' vs. 'learning by doing'

Computer tutoring systems are being seen as the tools to provide customization, interactivity and performance-based assessment in e-learning environments. But what about the history and the position of those tools?

We can find a first review of the subject in [2] where the 10-year history of tutor development based on the advanced computer tutoring theory is reviewed. This early evaluation showed that students could achieve at least the same level of proficiency as conventional instruction in one third of the time. Empirical studies showed that the best tutorial interaction was one in which the tutor provides immediate feedback consisting of short and directed error messages; and those systems appear to work better if they present a nonhuman appearance rather than as emulations of human tutors. Computer tutoring systems were being built during the nineties following this framework: let students do as much as possible for themselves and provide them with error messages to tell them something useful about that error; providing also some extremely short help messages (even if they sound nonhuman). Thus the system becomes an Assistant that can deal with more routine learning problems.

In the context of Logic, academic research in the nineties was conducted in software designed to help computer science students to learn formal proofs (specially, natural deduction). The appearance of Tarski's World [3] was a milestone; it was considered not only useful for learning the syntax and semantics of first order Logic but also enjoyable. Another important tool was Jape [6] that enabled students to construct, revise and test formal proofs. At the Institute of Educational Technology of the Open University, some research focused on students' experience using the program to assist proof construction [1].

That was the theoretical situation when María Manzano promoted the First International Congress on Tools for Teaching Logic in 2000 and a number of logicians from different countries met to focus on the education of Logic. They reported interesting teaching experiences; some of them were works presenting the use of intelligent tutoring systems for teaching Logic at university level [19]: An *interactive proof Assistant* [10] to support teaching Logic and deductive reasoning (based on Tableaux); a *didactic tool* [17] to help in the learning of Natural Deduction; a *Logic tutor* [21] to help students of Logic in Computer Science; an *intelligent system* [24] for learning First-order Logic.

The Second International Congress on Tools for Teaching Logic (SICTTL) was even more successful. The presentation of software tools was a very important part of it. An outline of some of the tools was published in [25]. A wholly integrated tutoring system in a Logic courseware seemed to be an improvement in the paradigm of previous tutoring systems. Three of those new kind of systems presented in SICTTL were: Pandora [7], APros [23] and Organon [9].

Between 2000 and 2006, e-learning had become a reality and a new kind of tool was the step forward of the initial computer tutors. They were web-based, fully interactive and oriented in guiding students through activities.

Since 2006, life-long, distance and online learning have reached the college educational scenario. The intensive use of IT approaches traditional education to an e-learning model where the student and its activity have become the centre of the model [12] [8] [16]. One of its main challenges is the use of technology in customizing learning and assessment [22]. There has been a considerable amount of research showing that intelligent tutoring systems provide effective instruction for math and relative subjects in online scenarios [5]. What is the situation in 2011? In the next section, I will present a brief study of existing tools for learning of Logic.

This paper is organized as follows; Section 2 describes the basic characteristics found among current tools for learning Logic. Section 3 describes a possible classification of the current tools depending on which characteristics they possess. Finally, Section 4 presents some final discussion and conclusions.

2 Basic Features of Tools for Learning Logic

In 2011, a great variety of tools for teaching Logic can be found. In [26] there is the well known list of educational Logic software compiled by Hans van Ditmarsch. Today there are 46 entries with Internet links to their web pages and some information (a brief description on the functions, the platform, developers, and a book reference). In the proceedings of the First and the Second International Congresses on Tools for Teaching Logic [19,20], there are very interesting papers on some of the tools working at each moment. Visiting these sites one by one and studying each of the tools, it is evident that there is a wide variety among them, and it is also clear that they have evolved from the first ones until now. Some were left on the way, others were adapted to the times in its subsequent versions and other new ones have appeared. To understand the present situation, a comparative study of the current tools is presented here. To perform this study, a sample of 26 has been selected among the ones in use [3].

A careful study has been made with each of these selected tools. Each tool has been studied and has been used to know how it works, and its literature has been reviewed to know how it is used in learning and how it has been evaluated. Access to the tools has been unbalanced, as some are free and others are commercial, although among the latter there are demo versions or are better documented than those of free access. From this empirical study, a qualitative study was carried out to identify the specific characteristics that allow a comparative analysis and eventually a classification. The outcomes of this study below are the basic features of those tools, clustered for presentation in the following groups:

- Functional characteristics: the basic functionalities as a learning tool and the logical content being taught are considered.
- Technical characteristics: the year of birth and the current version, developer profile, platform, the type of license and the form of access are considered. Features such as the programming language, the type of database or information system were not taken into account for this study. Only significant characteristics from the point of view of users were discussed.

[3] See the list of the studied tools and web references of them in the Annex.

– Interaction characteristics: the type of interactivity, feedback, advice, help, and the introduction of logical symbols are taken into account.
– Assessment characteristics: the way to grade, the type of assessment and the statistics that the tool provides, if any.

2.1 Functional Characteristics

The central role of the tools is intended to be used for learning purposes and therefore we have not considered in our sample those systems that automatically perform tests without any educational objective. Regarding the educational function, a wide range of characteristics have been found: guide and help in the evaluation of sentences using a simple editor; guide students in the construction of a proof (with different levels of interaction), guide learners to construct semantic tableaux or help in making proofs or normal forms; guide building truth tables and checking unification programs; checking proofs to teach basic proof-writing skills, etc.

In relation to the logical content, most tools focus on Propositional and Predicate Logics, and in particular, in Natural Deduction and other proof systems. Truth tables and normal forms are also common. There are those that focus on semantics and there are also many tools that cover all the themes in an introductory Logic course. The latter is designed to fit snugly over a course's teaching materials or a particular book. Most of the tools studied are aimed at introductory-level college students.

As for the language, most of the 26 studied tools have a monolingual interface in English, with a few exceptions in German, Catalan, Spanish and Czech. In a very few cases, multilingual systems were implemented.

2.2 Interactivity, Feedback and Advice

Since the very beginning, interactivity has been the most fundamental characteristic of an intelligent tutoring system [2]. The main issue in subjects like Logic is that feedback could be calculated automatically by e-learning tools that support problem solving [11] and that students could interact with computer-based teaching systems in solving the problems [4]. Among the tools that they studied, the following characteristics are presented:

– Different levels of interaction, from simply verifying that the problem is solved right and delivering an error or correction message, to guiding, in a step by step process, in building the solution with different levels of feedback or assistance.
– The tool emits some kind of feedback after checking whether or not a step is correct. If it is correct, an asserting message is emitted. If it is not correct, an error message is usually given and possibly, information about the kind of error is provided.
– A hint after an error message is done automatically or when the student asks for it and this is only found in some of the studied tools.

Instructional software for Logic usually incorporates this kind of feedback and hints features [4]. In the studied tools, most of them are giving error messages and some kind of feedback about the work (17 of 26). A few of them give only error messages (6 of 26). Two of them only check the work and another only gives results. The kind of feedback after errors is immediate, sometimes only with simple information about the kind of error or detailed feedback about each proof or exercise. In some cases, there is specialized feedback depending on the mistake; or the tool gives students immediate feedback for both correct and incorrect actions.

Pandora, for instance, works in two modes. In the basic mode, at every attempt to apply a natural deduction rule, either a success or a helpful error message is found. In the mode with an enhanced support, hints and explanations are also provided [7].

Another example of high feedback is the Proof Lab of Carnegie Mellon University. It is a sophisticated application for constructing proofs that allows students to make logical forward and backward moves. The Lab also diagnoses errors and provides error-reports with links to instructional material related to the mistakes [23].

Another example would be that Organon provides both exercises for student practice as well as graded work. It shows (step by step) the example solution of the exercise and provides a relevant explanation. It also provides assistance through checking each step of a student's solution on completion, and alerting when a mistake appears as well as showing the mistake (if required by the student), giving hints for the next step or performing that step. In fact it corrects the student's solution when finished (not during the process of solving) and comments it in the same way as graded homework [9].

[18] In the IDEAS project at the Open University of Netherland, the tool is a logical exercise solver. It helps students to rewrite formulae from propositional logic into a disjunctive normal form using standard equivalences. At each step, the tool provides feedback which depends on the kind of mistake the student might have made: the error-correcting parser suggests a correction, the tool tries to find a plausible rule the student intended to use and gives a correct application of this rule.

In the case of the SELL project of the Open University of Catalonia the AELL tool is an assistant in the learning process [13,14], providing both practice and graded exercises, immediate feedback and hints in every step.

As for the introduction of the logical notation, which is usually a problem, the tools studied had two kinds of solution: either a keyboard window (web editor) or the introduction of symbols in plain text (ASCII), from the physical keyboard, equivalent to the Logic symbols.

2.3 Assessment, Statistics, Reports

Automatic grading and statistics of student activity is a characteristic to be found in almost half of the tools. This functionality requires that students access to the tool individually and be identified. In some of these cases, the tool has an evaluation module that manages the development and delivery of work, qualification and recording of continuous assessment.

In the case of Pandora, for instance, students are provided with exercises that they download from the web-based Continuous Assessment System and the first time they save a proof (usually when they have completed it), their identity is coded. Then the tool can produce a report for each student and a summary of results for their tutors with minimal human intervention [7].

The web tutor Organon also has an Assessment Module to administrate students' homework. It generates the exercises, facilitates the production as well as the delivery of the homework, manages to correct and grade the homework, stores the achieved results including a record of the exercise and gathers statistical data to provide feedback. There is always an automatic solving procedure associated with them. The resulting grades reflect not only whether the answer is correct or not, but also the whole procedure of solving because it is a proportion of how many mistakes the student has made, and how many stages he/she has completed successfully [9].

In the case of the AELL tool [14], the assessment module has been created to manage individual work of the students (both voluntary and compulsory work). There are two possible interfaces, one for each kind of user (student or teacher). Students are always identified while working with the tool and the logs produced are stored. For any kind of exercise, students can see the statistics of their voluntary work (completed, uncompleted, or pending exercises). Students are allowed to work on compulsory exercises until the deadline has expired. Continuous assessment tests are delivered with the tool and most of the grading is automatically calculated by using the associated solving procedure. From the point of view of the instructors, the assessment module is much richer. They have access to the individual or group statistics of many different elements: the average success of students, rules that were incorrectly introduced, frequencies of use, temporal distribution of the work, and as the system stores all the logs in a server of the university, many other statistics can be obtained.

The assessment characteristic, with grade reports and statistics has appeared recently in tools with the identification of student (especially in an online environment) and which provide learning for the majority of the content of the Logic course. It is the case in 8 of the 26 studied tools.

3 A Classification of Tools for Learning Logic

After establishing the fundamental categories for the study and classification of the different tools, the specification of the values in these categories has been assigned for each of them. The chosen categories have been 1) date of creation and last version, 2) platform (web, Windows, Appel, Linux), 3) developer's profile (university staff or not), 4) logical content, 5) student level, 6) language or languages, 7) functionalities, 8) introduction of logic notation (windows keyboard or plain text), 9) kind of interactivity, 10) kind of feedback, 11) help messages and advices, 12) license, 13) statistics and assessment, 14) identification of the user, and 15) the existence of a book or courseware reference.

Once the map of the values for each tool and each category has been made[4], the result allows the identifying of five groups, which are specified below.

- Provers. They are characterized by their automatism. In these types of tools, the user is totally passive. The system calculates and shows the solution of the exercise in an automatic way. It provides examples to the student. No interactivity at all. They are usually free licensed and of open access [Z].
- Checkers. They are characterized by the rather passive behaviour of the learner. The main activity is to verify deduction or formalization. The feedback of the tool

[4] A table showing the values in these categories for the different tools can be found in http://openaccess.uoc.edu/webapps/o2/bitstream/10609/6501/1/TableofToolsPaper.pdf

is restricted to find errors when the user requests explicitly the verification of the exercise being carried out. A message error is then sent, but with no more feedback or richer interactivity. Many of them are systems for practicing with Natural Deduction (ND) and other proof systems [U, W, Y]; others also include Truth Tables and Normal Forms [T, V, X]. They are usually free licensed and of open access.

- Assistants (also named constructors in [15]) are characterized by a higher degree of interactivity with the user. They provide menus and dialogues to the user for interaction purposes. This kind of tool gives the students the feeling that they are being helped in building the solution. They provide error messages and hints in the guidance to the construction of the answer. Many of them usually offer construction of solution in Natural Deduction proofs [K, L, M, P, Q] or other kind of proofs [R]. Others assist with Semantic Tableaux [N, O]. However they are not integrated in the rest of the logic courseware notation and contents. They are usually free licensed and of open access.
- E-tutors. They are characterized by the full integration with the rest of the resources of the Logic course. The tool inherits the central element of interactivity, feedback and hints also presents in Assistants. The difference is that it is totally related with contents, exercises, exams and occasionally assessment. Students are usually identified so the system can do statistics, grade reports or more complex assessment services. It is usually a web application, especially when the e-tutor is part of an online course in the university (the users are then usually the students and instructors of the course) [C, E, G, H]. Other kinds of e-tutors are provided with books offering a complete introductory course of Logic [A, B, D, F]; in that case, they are windows or apple platform with proprietary license. In this group, we can also find logic formulae in plain text (the older systems), but the trend is for Windows editors to introduce logic notation.
- E-tutorial. It is a tool having the characteristics of Assistants but integrated in a courseware. It does not offer assessment services, which is the main difference with E-tutors. We think that E-tutors are a development of those ones. We have found a free licensed one here [I] and a free tutorial to accompany a book [J].

The number of tools in each group and their relevance varies from group to group. There are 8 E-tutors, 9 Assistants, and 6 Checkers, while only 2 are E-tutorials and 1 is a Prover.

Among the E-tutors, 4 of them are web applications and 4 are Windows and Apple platforms. The web platform tools are related to specific courses and its tutorials are accessible only to students of the course, while non-web tools are associated with the commercialization of reference books under a proprietary license and with access for the users having the book. With respect to the introduction of logical notation, we find 50% using the Windows keyboard and the other 50% using plain text

Among the Assistants, the same distribution is repeated with 50% in each type of platform, all of them are using plain text to introduce Logic notation, and they are usually specialized in some logical content (5 of the 9 in Natural Deduction). Some of them also have a book of reference.

In the case of the Ckechers, there are again 50% in each type of platform, they use plain text to introduce notation, and they have a thematic similar to the Assistants, but without offering a high level of feedback and advice.

5 Conclusions

After this study of a large sample of current tools for teaching Logic, we can try to deal with the following question: what kind of computer-based tutor for teaching Logic is the one used in the 21st century? The first clear idea is that there is no standard kind of tool for teaching Logic. The way those tools have emerged, as research projects in many cases, may partly explain this variety. But perhaps the most obvious explanation is that the change in the type of teaching that requires the use of these tools is not standard yet. It is much easier to find them in online universities or as a component for self-learning of some introductory textbooks. This is the case of the E-tutors. Checkers and Assistants are commonly products of free access that could be used to support any part of the curriculum in face-2-face courses.

Students in a Logic course have to acquire a set of skills related with the complexity of logical reasoning. The immediate feedback and continuous assessment are very important in the learning process. In particular, intelligent tutoring systems could provide customized assistance and feedback to students. Moreover, in the context of e-learning, intelligent tutoring systems can help to overcome the absence of teachers while taking advantage of self-learning. There are many case studies of tools for learning logic [9,14,15,17,18,23] where Assistants and E-tutors seem to be the preferred kind of tools to help in the learning process of a subject like Introductory Logic.

In the lifelong-learning era, assessment usually occurs as the learner progresses through a computer-learning environment in order to provide support to carry out the tasks and determine whether the learner has accomplished its goals [8]. E-Assessment, which is most commonly known Computer-Assisted Assessments or On-line Assessment, has become a very integral part of study programs that are mainly conducted in an online environment. In face-to-face education, the use of E-assessments may help academics by reducing their workload of making large volumes of papers as well as by making the assessment-related administration task efficient. E-assessments can be categorized as Diagnostic, Formative and Summative assessments based on at which stage of the learning, the assessment is carried out. In particular, using a Virtual Learning Environment only for teaching and learning and then using a manual method of assessment is not very productive. Therefore in the e-learning paradigm it is needed to integrate the task of assessment. Both E-tutors and Assistants could then have a role in a model of e-assessment and in a model of continuous assessment as well. Furthermore, most of the evaluations of these tools confirm that students use them very little if they are not associated with the work being assessed.

It seems that E-tutors suggest a future for higher education in this context. Its integration in online courses has a clear meaning, covering all kinds of exercises with maximum interactivity, while acting as a guide in the learning process and, certainly, helping when the student requires. The time factor could also be a key element in the future, both for the opportunity to work individually in the allotted time, and in passing, this has to affect the current standard of school times. On the one hand mobile devices and accessibility of digital resources are important new trend in e-learning. On the other hand, knowledge technologies like the use of ontologies and the Semantic Web could help in building new intelligent tools for enriching the learning experience in subject like Logic.

Thus, an evolution of E-tutors to become more usable, ubiquitous, accessibility and intelligent tools could be the near future for computer-based tutors for teaching Logic.

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A List of Studied Tools

A. Tarsk's World, http://ggww2.stanford.edu/GUS/tarskisworld/index.jsp
B. LPL-software, http://ggww.stanford.edu/NGUS/lpl/www-csli/LPL/
C. MLT-PC, http://aracne.usal.es/congress/PDF/AntonioMoreno.pdf
D. Logic Daemon, http://logic.tamu.edu/,
E. CPT-AProS (Carnegie Proof Lab), http://www.phil.cmu.edu/projects/apros/
F. LogicCoach III, http://academic.csuohio.edu/polen/
G. Organon, http://www.kfi.zcu.cz/organon/index_aj.htm
H. AELL: Logic E-Learning Assistant, http://cimanet.uoc.edu/logica/aell
I. Logic Café, http://thelogiccafe.net/PLI/
J. Power of Logic, http://www.poweroflogic.com/
K. Pandora, http://www.doc.ic.ac.uk/pandora/
L. Jape, http://users.comlab.ox.ac.uk/bernard.sufrin/jape.html
M. Plato, http://www.utexas.edu/courses/plato/
N. Socrates, http://www.utexas.edu/courses/socrates/index.html
O. blobLogic, http://corinhowitt.com/blob/blobSplash.html
P. AND (Natural Deduction Assistant), http://www.dccia.ua.es/logica/ADN/
Q. DN-FN, http://patrice.bailhache.free.fr/dnfn/deductioneng.html
R. IDEAS, ftp://ftp.computer.org/press/outgoing/proceedings/csse08/data/3336i553.pdf
S. TPS and ETPS, http://gtps.math.cmu.edu/tps.html
T. Interactive Logic http://www.math.uwaterloo.ca/~snburris/htdocs/LOGIC/st_ilp
U. Bertie3, http://selfpace.uconn.edu/BertieTwootie/software.htm
V. Summa Logicae XXI Software, http://logicae.usal.es/
W. ProofWeb, http://proofweb.cs.ru.nl/login.php
X. Gateway to logic, http://logik.phl.univie.ac.at/~chris/gateway/formular-uk.html
Y. DC Proof, http://www.dcproof.com/
Z. Logic Animations, http://staff.science.uva.nl/~jaspars/animations/