An old discipline with a new twist: the course "Logic in Action"

Johan van Benthem
University of Amsterdam, Stanford University and Tsinghua University

Abstract

What are the basic logical notions and skills that all beginning students should learn, and that might stay with them as a useful cultural travel kit for their lives, even when an overwhelming majority will not become professional logicians? The course "Logic in Action" http://www.logicinaction.org/ tries to convey the idea that logic is about reasoning but also much more: including information and action, both by individuals and in multi-agent settings, studied by semantic and syntactic tools, and still confirming to the standards of precision of an exact and mathematized discipline. Viewed in this way, modern logic sits at a crossroads of academic disciplines where interesting new developments occur every day. In this light introduction, I explain the main ideas behind the design of the course, which combines predicate logic with various modal logics, and I lightly discuss its current manifestations and dialects in Amsterdam, Beijing and the Bay Area, as well as its future as an EdX pilot course.

1 History of the course

There is a thriving international market of new on-line logic courses today, witness the many projects presented at the successive TTL conferences [1] and the links there to earlier conferences in this series. Roughly speaking these endeavors fall into two kinds. Sometimes the new technology is used to create high-tech versions of largely standard fare in the traditional curriculum with, say, sophisticated graphics interfaces for classical natural deduction proof systems, like a Latin Mass with rock

I thank the organizers of the Conference on Tools for Teaching Logic, Rennes 2015, for giving me an opportunity and a forum for reflecting on the course "Logic in Action". I also thank the members of the core LiA development team for the course as well as the users that we know of, and finally, I am grateful to the two referees for this paper for providing very useful critical comments.

[1] See the website http://ttl2015.irisa.fr of these conferences.

guitars.[2] But sometimes also, there is ideological fervor behind the effort: the course designers have a special research agenda with their own view of logic, modifying or changing existing curricula, and they want to export their revolution by by-passing the academic colleagues and instead of that, influencing the youth.[3]

The course Logic in Action falls in the second activist category, and we will put our cards on the table in a moment. The course arose in the education group of the Spinoza Award project "Logic in Action" (1997–2002; http://www.illc.uva.nl/lia/) of the Dutch Science Organization, and it received a crucial further push by a grant from the Dutch Ministry of Economic Affairs in its program Creative Technologies meant to improve the national information infrastructure.

2 The general idea: a broader scope for logic

Traditional logic courses emphasize the study of correct inference patterns as the core business of logic, with propositional and predicate logic as paradigms of the methodology for doing so. Students are trained in basic skills which typically include translating natural language sentences into formulas, performing validity tests such as truth tables and tableaux, and often also, calculi for formal deduction.

Some problems with traditional courses In our view, this traditional agenda is not neutral: it instills a large number of attitudes, often as hidden presuppositions. Let us identify a few of its subliminal messages.

First, inference is made the central concern of logic – but this move seems quite debatable. Inference or proof is just one topic in logic, and just as important are two other main themes: definability and computation, a point made already in the seminal Beth 1963 reflecting on the history of logic as well as its modern branches of proof theory, model theory and recursion theory.

Next, there is little reflection on what intellectual assets are actually activated by training in formula translation or formal proof. It is unclear whether there is any transfer to broader reasoning skills, and it may be significant that research logicians themselves never seem to use them in their meta-theory. Criticisms of this didactic kind have in fact occurred throughout the last century: a modern study of transfer

[2] This is how I would view, e.g., the popular and very well-designed course "Logic & Proofs" at Carnegie Mellon University, http://oli.cmu.edu/courses/free-open/logic-proofs-course-details/.

[3] This activist stance is what I see in the Stanford course "Language, Proof and Logic" (http://online.stanford.edu/course/language-proof-and-logic) inspired by situation theory, and in the more logic-programming and resolution-based open-domain CS course "Introduction to Logic" (https://www.coursera.org/learn/logic-introduction). But their designers may feel very differently!

of skills also involving experimental cognitive studies is Haskell 2000.[4]

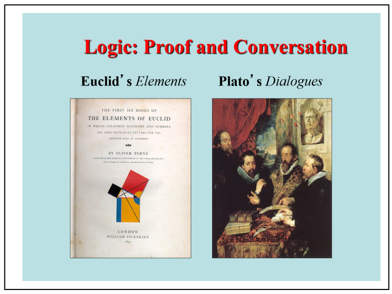
Next, the usual emphasis on formal proof somehow suggests that mathematical activities are the highest point of logical intellectual skills, a claim as debatable as thinking that the best test of someone's moral fiber is her behavior in church. Reasoning in down-to-earth practice, with its open universes of relevant considerations, tells us much more about what logical rationality a person can bring to bear.

Finally, the standard emphasis on teaching complete logical systems as the locus of logic is a very peculiar methodology, different even from the problem solving skills taught in mathematics and science courses. One comes for a logical formula or two in the store (just as we learn a few crucial and generally helpful algebraic equations), hoping that it will help us through some crucial steps in a problem-solving argument. But instead, one finds that one has to buy a system, a huge infinite supply of valid patterns, and worry about their staying fresh for years.

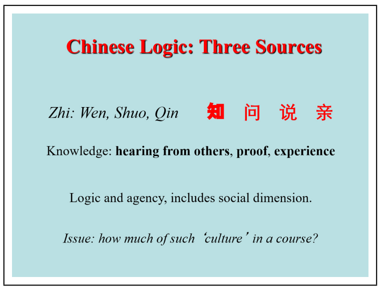
Broadening the scope Raising the preceding concerns does not mean that there is something inherently wrong with the traditional curriculum in logic, as far as it goes – only that the discipline of logic has much wider scope than what this standard agenda of topics might suggest. The major aim of the course 'Logic in Action' is conveying this broader picture from the start as being much more true to what logic is today and what its range is across the university and elsewhere. If we do not get this across at base level, students will either not see what logic is really good for, or, they will develop a narrow conception of the field which then keeps them locked afterwards into biased philosophical or mathematical conceptions.

Logic as information handling One way of achieving this mind-opening is by shifting the emphasis from inference alone to the study of a much broader range of informational activities as the subject of logic. Besides inference, such logical activities also include making observations and doing experiments, asking questions and processing answers to them, and engaging in communication generally. Therefore, the course 'Logic in Action' treats two realms on a par, purely deductive inference, and intelligent conversation, as highlighted to our students in the following picture of Euclid's "Elements" versus Rubens' painting 'The Philosophers':

[4]An emphasis on isolated formal activities need not be harmless, it may even make enemies. I have often observed this in interdisciplinary circles where colleagues from other fields who went through a logic course became firmly convinced of the Scholasticism and irrelevance of our discipline.

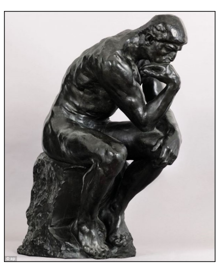
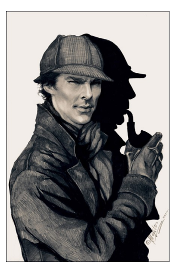


Interestingly, our themes are already present in ancient Chinese logic, witness a key dictum in the Moist School (500–300 BC; cf. Graham 2003) that knowledge comes from three sources: hearing from others, demonstration, and experience.



Histories As it happens, while not neglecting the essential Greek origins, this quotation is highlighted in our course with a side purpose: also make it clear to students that by learning logic, they become part of a worldwide cultural stream, not just ancestor worship of Greek Antiquity. The course has many such historical sidebars, all aiming at installing some more general erudition.

But we also emphasize that inference and observation are information sources on a par in modern science, where we need the two in tandem to understand our world. And in more playful mode, to the classical lonely thinker with eyes closed and ears shut, we juxtapose the detective Sherlock Holmes whose success shows that, far from the usual view of logic as organized pedantry, logical skills are not just duties that we perform, but also talents that we appreciate and that even give us pleasure.

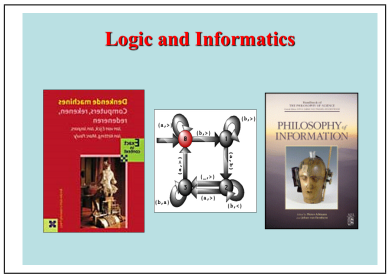



Two strands: structure of the world, structure of human activity Even so, the course presents no criticism of other views. One general way of thinking about what is said here goes back to a pervasive feature of logic throughout its history, and something that even surfaces in many hardcore textbooks. One can think of logic as describing the most general structure of reality and its inventory of atomic, negative, or disjunctive facts, individual and general facts. In that metaphysical sense, logic would be there even if there were no human beings at all, as on the cold and lonely planets we see in astronomical documentaries. One can soften this perspective a bit in terms of objective information available about and in the world (another view of logic that can be found in prominent textbooks, cf. Devlin 1991), but again this information would be there even if there were no human agents picking it up.

But there is also another stream, right from the ancient Greek origins of the discipline with Aristotle and Plato (but also prominent in the Chinese tradition), of logic as manifesting itself in activities of conversation, dialogue and debate, whether cooperative or competitive. On this agency view, logical laws are about moves and strategies that agents have toward winning in dialogue games, and the very logical constants now correspond with structured actions in argumentation or conversation. On this second view, then, communication and strategic interaction are crucial to logic, and the patterns described by logical systems may just as well be forms of rational behavior as forms of language as patterns forming the grooves of our world. 'Logic in Action' emphasizes the second view as much as the first. [5]

An interdisciplinary cross-roads This view comes with a broad canvas of disciplines that modern logic interacts with. While students in many disciplinary courses taught today, be they mathematicians, philosophers, or linguists, may be told that logic is typically 'theirs' (with only rumors of lapses into other fields), the reality of the field today is that it interacts with, feeds into, and is inspired by contacts with the old interfaces of philosophy and mathematics, but just as much with computer science, linguistics, and in recent years also some cognitive science. Probably most logic research today takes place in computer science, including some of the most innovative frontiers. Thus, in this course, computation in a broad sense is highlighted as a core concern of logic, and a running theme next to proof or definability.

[5] Of course, the two views are not in conflict. In the end, structured activity that does not fit the structure of the world may not have much of a chance from an evolutionary perspective.

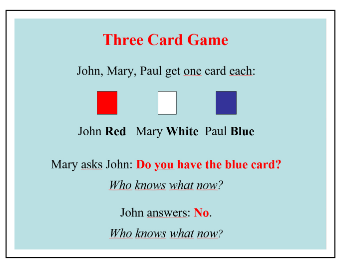


This is the intellectual environment that we convey to students in this course. Logic is one's ticket to broadmindedness, not to one particular disciplinary lifestyle.

3 And so: teaching a broader range of logical skills

In terms of paradigmatic logical acts, then, the basic repertoire to be taught gets extended. Say, a question is as basic a logical act as an inference. And likewise, an interactive strategy is as important as a proof, say, as a way of guiding communication or argumentation. But how do we make all this concrete to students?[6]

New standard example: Three Cards An appealing aspect of this multi-agent interactive view is that set pieces of logical reasoning to be taught now become much more interesting and appealing to students (and adults) than the usual simple syllogisms about Socrates' mortality or Boolean inferences about which box the keys are in. Here is a typical challenge, somewhat of a classic by now. Much of our basic reasoning in daily life is not just about the facts, but it also crucially involves what we know about what others do or do not know. Here is a scenario that was once played out with real children in the Amsterdam science museum "NEMO".



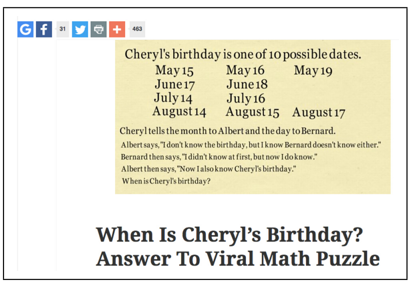
"The Cards". Three cards 'red', 'white', 'blue' are given to three children: 1, 2, 3, one to each. This fact is common knowledge in the whole group.

[6] A stream of research on 'dynamic-epistemic logic' forms the backdrop to this line in the course: cf. van Ditmarsch, van der Hoek & Kooi 2007, van Benthem 2011, and van Benthem 2014.

> The children see their own cards, not those of the others. The actual distribution over 1, 2, 3 is 'red, white, blue' (written **rwb**. Now a conversation takes place. Child 2 asks 1: "Do you have the blue card?" Then 1 answers truthfully: "No". Who knows what during this conversation?

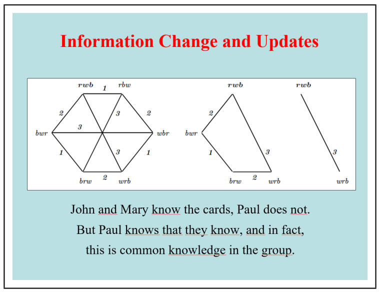
This scenario always generates classroom interaction, including mistaken claims. Here is the logical answer. Assuming that questions and answers are sincere (not unrealistic with children), 2 indicates that she does not know the answer, and so she cannot have the blue card. This tells 1 at once what the deal was. But 3 did not learn, since he already knew that 2 does not have blue. When 1 says she does not have blue, this now tells 2 the deal. 3 still does not know the deal; but since he can perform the reasoning just given, he knows that the others know it.

Humans often go through this sort of reasoning, with different knowledge for different agents acting as the driving force for communication. Indeed, puzzles like this pose challenges that people worldwide find interesting, witness the discussion of the solution of the 'Cheryl Birthday Puzzle',[7] a knowledge problem that went viral in the spring of 2015 after having appeared on a talk-show in Singapore.



A new feature: modeling skills This is logic in action at a challenging level, including inferences, questions and answers. And it involves a further important skill not usually taught in introductions to logic, namely, the ability to model a given scenario in a concrete semantic manner. Indeed, it is not hard to make students see that we can model the initial situation for the Three Cards as a set of six alternatives (the possible deals of the cards), related by easily drawable labeled uncertainty lines for players, as in the leftmost diagram of the following sequence:

[7]See https://en.wikipedia.org/wiki/Cheryl27s_Birthday for details.



With this direct visual structure, child 2 cannot tell **rwb** and **bwr** apart if she finds herself in either of these deals, but when in those same situations, child 1 and 3 can. The information flow in the preceding example can then be made very concrete in terms of updates, leading to the next two diagrams in the picture:

> 2's question removes **rbw**, **wbr**, reducing the range to four options. Then 1's answer removes **bwr**, **brw**, and we are left with a final diagram **rwb, wrb**, in which it is directly visible that 1 and 2 know the cards, 3 does not, though 3 does know that the others know. The last fact is non-trivial information in itself, of a more social interactive nature.[8]

Extended desiderata What skills and insights do we expect students to learn in the wider world of this course? Certainly, we do not want to give up on classical topics, since propositional and predicate logic with their standard agenda are still at the core of the field. Also, there is of course nothing wrong with the traditional virtues of logic education that come with this, such as increasing precision, appreciating the architecture of logical systems, and acquiring a sense of the beauty of abstract mathematical formulations. Indeed, such learning experiences also have to be, and can be, supplied for the further tasks mentioned here. This includes an understanding of the systematic theory behind the examples we have given.

But in addition, we want new topics that reflect the wider world of informational activities that we sketched, dealing with the logic of information, update, and interaction. And didactically, this set of topics requires modeling skills beyond the usual core. For instance, we do not want routine 'translation' of the natural language text of the Three Cards scenario into formulas, the way we drill students in a standard course to become little text processors. Such translations mix details of syntax with essentials for the task at hand – and true logical ability consists, more creatively, in

[8]Teaching unusual material like this challenges students in new ways. Recently, one observed that Child 1 does not even need to answer the question, but only has to say that he now knows the cards, and then Child 2 will know the cards as well. This then raised interesting general discussion in class about how epistemic information can replace factual information in communication.

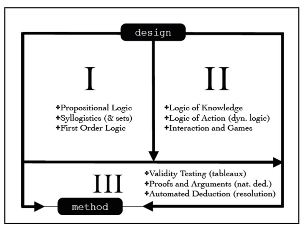
picking out the important features only. In brief, we want a paraphrase into essential formulas, the way we also use just a handful of mathematical equations to model physics problems. And preferably, we want a semantic model or diagram for the setting, and based on that, an understanding of the relevant information flow.

And finally, in an information society like ours, the world of human reasoning is entangled ever more with computing technology, whose origins go back to logic in other historical channels. Accordingly, in terms of preparing them for life, we want the students to understand some basics of the computational structure and complexity of the informational processes that form the topic of this course.

Next, we say a bit more about the course resulting from all these desiderata.

4 Contents and chapter structure

How can we teach the above enlarged set of themes and skills? Perhaps the most obvious approach is to merely extend today's standard curriculum. In a way, our course has that feature. 'Logic in Action' has the following two main parts, with a third as a supplement for a more ambitious version.



Part I The first part of the course contains the basics of propositional logic, then the syllogistic as a first, historically but also systematically important, extension toward reasoning about objects and predicates, and finally, full first-order logic with quantifiers. These systems are presented as progressively richer ways of describing the world, be it physical space or conceptual space. The way we do this has a few new twists (see the description of our recurrent chapter structure given below), but we largely follow the standard agenda of basic topics. This part covers the descriptive dimension of logic that we mentioned in Section 2. Next, we turn to the activity dimension that we saw as a complementary view of what logic is about.

Part II The second part of the course is then devoted to the main ingredients of information-driven agency. A first chapter on epistemic logic focuses on semantic modeling of information, including knowledge that agents have about facts and about knowledge of other agents. Next to get at the dynamics of the actions involved in communication, and agency in general, a chapter on dynamic logic of programs, and structured action generally, gives a standard base logic of structured computation. Finally, the two strands of information and action are brought together in a chapter on logic and games, as a grand finale where preferences come into the picture, as well as the fundamental notions of strategy and equilibrium.

Available materials This brief survey article is not the place to give precise details of these six chapters, for which we refer the reader to the public-domain website

http://www.logicinaction.org/

and the free textbook "Logic in Action" and further download materials there:

http://www.logicinaction.org/docs/lia.pdf.

Part III There is also a third optional part in the course, with technical material on major methods for proof and computation: semantic tableaux, natural deduction, and resolution. This is meant for students or teachers who have time to spare, or who just cannot let go of traditional themes. We also envisage adding a chapter on basic meta-theory offering acquaintance with proving important facts about logical systems, both classical and epistemic-dynamic. This material is more traditional again, emphasizing once more that we have no quarrel with standard curricula, and that the new systems in Part II still fall under a standard methodology.

Extension implies pruning In all this, a choice had to be made in setting ambitions. If we keep the usual content of the first standard chapters the same, then a course like this will become top-heavy, and also, we miss an opportunity to remove historical clutter from the old curriculum. But if we rethink things more radically, then hard and perhaps controversial choices must be made. Do we still teach translation from natural language to formulas, with the usual drill? Do we teach formal deduction in detail, despite legitimate concerns about its broader transfer value to reasoning skills, or its adequacy as a model for what mathematical proof really is? If we stick to the standard course size, something has got to give. [9]

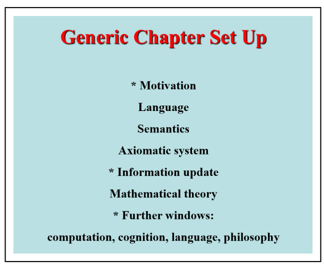
In our course, we have economized mainly on extensive translation drill, and on proof skills, though they are not gone completely. In particular, we have kept some axiomatic calculi to at least familiarize the students with the important intellectual idea of a symbolic uninterpreted systems view of deduction. Moreover, precisely

[9] This pruning may also have a positive value. People often forget that dropping worn-out topics from a curriculum can yield as much progress in a field as adding new ones.

because axiomatic proofs may involve surprising twists and shortcuts via lemmas undreamed of in more placid proof search environments like tableaux or sequent calculi, these pose more creative challenges to students. We have also economized on the usual formal set-theoretic presentation of model-theoretic semantics for first-order logic, which is often a stumbling block for students anyway, and which can also be questioned on technical logical grounds (Andréka, van Benthem, Bezhanishvili & Németi 2014). This set-theoretic garb also has the disadvantage of making first-order truth, which students already understand intuitively, look weird and exotic.

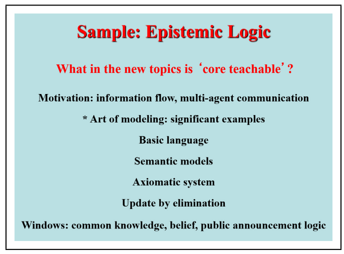
Note that the course does not become easier in this way, since the content structure for these topics in Part I now carries over to the new topics of Part II.

Coherence and chapter design Our broader agenda does have a didactic down side. The expanded set of topics runs a risk of incoherence and incongruity since its scope is so wide. Hence, to increase a sense of uniformity for the student, all chapters, no matter how different their topics, have been set up in a similar manner:



As illustrated in the displayed picture, each chapter repeats the same pattern of sections – called Motivation, Language, Semantics, Axiomatic System, Update, Mathematical Theory, and Further Windows, where the latter are illustrations oriented toward the broader intellectual environment of logic in computation, cognition, language, and philosophy. Let us describe the generic structure of a few chapters, with less or more standard topics, to illustrate how this set-up works.

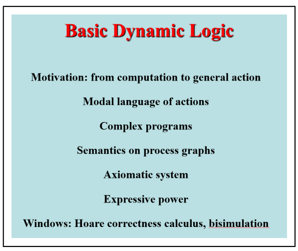
Chapter 1 In the chapter on propositional logic, 'motivations' are classifying of structure in the world as well as finding patterns in argumentation, 'language' introduces the idea of abstract symbolic syntax as a major historical achievement, and 'models' are of course the evergreen of truth tables. For an 'axiomatic system' we teach some Hilbert-style formula manipulation, which also gets students used to idea that finding proofs is not trivial. A new feature is teaching 'update' where new information decreases a current range of options, and where we show how some puzzles can be solved naturally either by deduction or by update to one single remaining option. This shows the semantics at work in a way that students find appealing, while the harmony of semantics and proof theory also features concretely. Next, in a section on 'mathematical theory' we introduce definability of connectives, as well as the notions of soundness and completeness for logical systems. Finally, 'further windows' in this case are toward the usual logic puzzles, but beyond that, mainly toward computation: networks for Boolean algebra, and complexity, including the $P = NP$ problem. After all, propositional logic is deeply connected with the emergence of computer science. Of course, the chosen illustrations in such windows can, and will touch on different disciplines in other chapters.

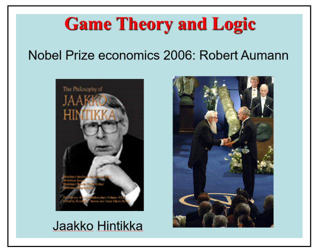


Chapter 4 Now the very same structure is also used, say, in the chapter on epistemic logic. We motivate the issues by means of simple informational scenarios concerning questions and answers that students immediately find appealing.[10] Introducing a language with knowledge operators allows them to state significant things about the agents involved in such scenarios in a concise manner, and finding models for this language that match a given intuitive scenario then turns out to be an attractive non-trivial task. Thus, instead of routine drill, we now emphasize the 'Art of Modeling'. Axiomatic systems such as modal S5 now stand for significant (if often controversial, and always discussion-generating in class) properties of knowledge, and making concrete deductions shows surprising connections. Update is the way of solving puzzles like the Three Cards, discussed earlier, in a satisfying systematic manner. Mathematical theory includes again completeness, or, more ambitiously qua abstract ideas, an introduction to the notion of bisimulation as an invariance between information or process models. In terms of further outlooks, epistemic logic is well-suited to discussing basic themes in philosophy (say, adding belief, and then discussing the surplus of real knowledge over belief) and cognitive science, where interactive social 'Theory of Mind' is considered a typical human skill.

[10]In particular – referring to the first picture displayed here – normally, my asking you in a Beijing street whether the structure depicted is the ceremonial Central Gate of Tsinghua University tells you several important epistemic social things: (a) I do not know the answer, (b) I want to know the answer, and (c) I think that you may know the answer.

Chapters 5 and 6 In a similar manner, we structure the next chapter on dynamic logic as a stream-lined abstract modal version of the basic Hoare Calculus of structured programs and actions, and at the same time, as a natural companion to the epistemic logic chapter for the purpose of describing information dynamics. The perspectives of Chapters 4 and 5 then come together once more in the chapter on games, along two lines. We introduce logic games for earlier tasks of formula evaluation or proof, and we define game logics as revealing basic structures in reasoning about, and inside, social interaction. We also show some mathematical background such as Zermelo's Theorem and broader connections with game theory.





Windows and the range of logic As for the intended interdisciplinary range discussed in Section 2: our windows at the end of these chapters include topics such as computational content of logics (say, satisfiability checking as computation), information and the internet, natural language (for instance, generalized quantifiers are a window after the chapter on the syllogistic), cognitive science (the Wason Card Task and difficulties in actual reasoning, confronting logical systems with 'natural logic' in cognitive architecture), and some history of logic in other cultures, especially in China. Finally, we keep emphasizing the value of the mathematical aspects of logic, none of which are meant to be endangered by this course: precision in formulation, abstraction, systematicity, and the beauty of meta-theory. [11]

Having concluded our description of content and structure, let us now look at some issues of didactic implementation and concrete practical experiences with the course 'Logic in Action'. Does the above really work?

[11]Of course we cannot cover every technical aspect. For instance, most modal logics of Part II can be systematically translated into (decidable fragments of) the first-order logic of Part I. But even though, technically, this generates further coherence to the course, we feel that this translation theme would probably only confuse students at this early stage of their logical education.

5 The spirit and the letter of the course

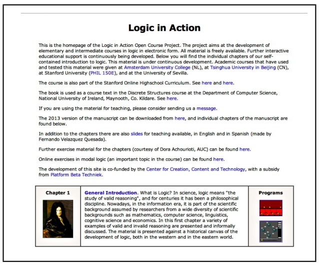
The spirit There are various ways of looking at this course. Our educational goal is to teach the students modern ideas and skills they may find helpful in further academic professions, or even beyond in society. We try to strike many chords in doing so. At a basic level, we try to show that logic is fun, using classic puzzles as well as newer items such as Sudoku or the Cheryl Birthday Puzzle. It is just a simple fact that many people enjoy exercising logical thinking skills, and students are no exception. Next, we try to teach the students what we genuinely think are the core topics of the field: deduction, computation, information, and interaction, using a broadened set of topics that we hope will become standard. To us, an example like the Cards puzzle is as genuinely logical as worrying about Socrates' mortality. In addition, we try to convey an appealing picture of logic as a broad and lively evolving field that connects between many disciplines, or put more negatively: we try to combat widespread narrow exclusive views of logic by opening interdisciplinary and cross-cultural windows. In doing so, we also try to convey that logic still has a great future ahead of it, given that so much has kept happening over the last century. Finally, perhaps more silently, we also hope to convey a less utilitarian idea to the students: that logic has a cultural value in itself that enriches them.

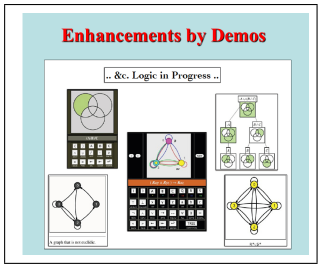
The letter These are the high-sounding ideals. In subsequent sections we will discuss what happens when these meet educational practice. But right here, let us also state another perspective: if you wish, 'the letter' of this course, that seems to be what remains on many working colleagues' radar when they use the material presented here. Take away the above ideals, and just look at what has to be taught, the bottom-line of all courses in academic reality. One way of describing our curriculum is simply this: we add modal logic to the traditional topics of propositional and predicate logic. The rationale for this terse description is that modal logic is indeed the technical core underlying our added chapters on epistemic and dynamic logic. While this mathematical formulation is an outrageously one-dimensional projection of what is contained in the course, and a misleading one in several ways, it does have the virtue of being short and intelligible. Moreover, since the connections of modal logic to classical systems are well-understood, the addition fits very nicely, so hard-bitten illusion-free teachers can just see this as their task.

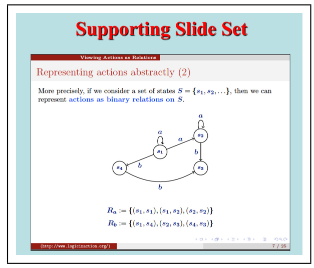
6 The internet dimension

As stated at the start, the original impetus for making this course happen (and a major motivation for its funding) was an initiative toward creating free courses available on the internet, and supported by new technology. Where do we stand?

On what there is Our material is freely available on our public website mentioned above: http://www.logicinaction.org/, in the form of a textbook, slides supporting class sessions, videos, and exercises from various sources with worked-out answers.







Overreach? Still, the ambitions in our team were much higher when the project started. We wanted to create a complete e-book with live links to background material, applets for specific tasks or demonstrations, and clickable windows for stepping right into the field of logic, from interfaces with automated deduction systems to more theoretical sources. A few chapters of this sort are indeed available on the above website, drawing on the innovative material developed by Jan Jaspars, a pioneer in computer-supported logic teaching in The Netherlands – for more samples, see, e.g., this website of the Dutch Open University:

https://www.ou.nl/web/logica-in-actie

Ideally, this electronic paradise would allow for complete self-study of 'Logic in Action' by worldwide users of the course, helped along by equally automated self-tests after chapters, without any interaction with human designers or teachers, except perhaps in the form of filmed lectures or video clips. In 2014, a more modest pilot version of this course, taught at Stanford University, was indeed formatted for the EdX platform in a preliminary way.[12]

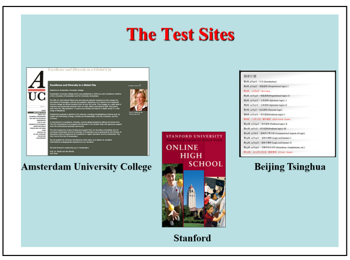
None of this broader internet agenda has materialized seriously so far. We will discuss in Section 8 why this is so, and how much of a bad or good thing this is.

[12]See the material at http://explorecourses.stanford.edu/search;jsessionid=1uudpox4o4m9v13p6nh1froldi?q=PHIL+150E%3A+Logic+in+Action%3A+A+New+Introduction+to+Logic&view=catalog&filter-coursestatus-Active=on&academicYear=20132014.

7 Experiences so far

This course has been taught in since 2008 in various classroom versions, mostly at an undergraduate level, at universities in Amsterdam, Beijing, Berkeley, Maynooth, Seville, and Stanford. Moreover, shorter versions of 'Logic in Action' have been taught occasionally elsewhere for more diverse audiences, including the 2011 ESSLLI Summer School in Ljubljana. An adapted version is also a standard part of the curriculum of the Stanford On-Line High School.

This fits the intended range as originally envisaged for this course material: from advanced high school level onward to lower university levels.



Except for the usual short-term student evaluations, there has been no systematic pedagogical evaluation yet of 'Logic in Action', which would have to involve a longer-term study of the intended lasting effects qua skills and attitudes.

Instead, what follows here are just a few more anecdotal quotes from teachers of the course about their didactic experiences.

Dora Achourioti (Amsterdam University College). " 'Logic in Action' is not a conventional logic text-book. The conventional introduction to logic would teach the technical material first and then study its applications (if applications are at all meant to be part of the picture). In LiA, logic rarely features in its own, outside of the real life practices where it is most naturally embedded. For the teacher, this presents a challenge. The conventional road is straightforward. But this one is not clear how to follow. How do you make sure to reach the mathematical precision that you do not want to compromise? How do you make sure that by complementing the material on the technical side you do not thereby take away from the richness and breadth of the subject and its various connections with other disciplines as highlighted in the book? It is important to work with a text that allows questions to be asked and teaching to develop, rather than enforcing a rigorous attitude that leaves no room for flexibility and hence no room for improvement. At AUC we have tried to make the most out of this flexibility, using the book more as a rich source of inspiration, rather than a book of instructions on how to do logic."

Wesley Holliday (University of California at Berkeley). "The last time I taught with 'Logic in Action' was in the Spring of 2012 at Stanford University. Nothing from that experience seems in conflict with any of the written impressions in this article. Since then I have used the 'Logic in Action' text as my go-to recommendation for students in my modal logic course and my first-order meta-theory course who want another text for review or to strengthen their understanding. (Incidentally, my text for modal logic is "Modal Logic for Open Minds", and my text for first-order meta-theory last time was Chiswell and Hodges' "Mathematical Logic", plus selections from Enderton, van Dalen, and Hodges' "Elementary Predicate Logic.") Student evaluations have been very positive. My plan is that when I am assigned the introductory logic course at Berkeley (with about 100 students), I will use 'Logic in Action', and then I will have a lot more to say."

Tomohiro Hoshi (Stanford On-Line High School). "The material that 'Logic in Action' provides matches the pedagogical spirit of the Stanford Online High School very well. We believe that active and live engagement of our students is essential for learning processes and have tried to represent this spirit in our online environment. We often feel that some of the most technologically advanced materials with lots of automated support for students do not fit the above goals. By contrast, 'Logic in Action' makes its material accessible to a wide variety of our students, not only by having the text and associated supplementary material free online, but also by grounding technical materials that are often challenging to students of our age groups to fields of study that they can more readily relate to, while still providing great opportunities for our students to experience what we believe is a true learning experience by "getting their hands dirty" with the material they are provided."

Fenrong Liu (Tsinghua University Beijing) "I have used the textbook 'Logic in Action' at Tsinghua, for undergraduate teaching over several years now. It is a one semester course, 48 hours in total. I usually cover propositional logic, first-order logic, epistemic logic and dynamic logic, and sometimes a bit of logic and games. The message of logic as a interdisciplinary subject is well received: this is also confirmed by the structure of the audience, as my students are from mathematics, computer science, philosophy, physics, and engineering. The students found the traditional part of first order logic still rather difficult, but get very excited when we start epistemic logic and dynamic logic. They can easily connect what they learned in class with how they reason with information in real life."

These statements from hands-on teachers largely speak for themselves. Even so, in the following section, I identify some further difficulties as I see them.

8 From plan to reality: difficulties

Self-study is a bridge too far In the confrontation of this new type of course with reality, several things can be noted. First, there is a big gap between a course taught at institutions by teachers interacting with students and an internet course for pure self-study. Simply put, apart from a few scattered positive reactions from visitors to our website, the second goal does not seem to have been realized at all.

So, let us consider experiences in more standard academic environments. Here, too, much can be noted that leads to serious questions about realizing the intended goals as explained in the above. We list several difficulties, though these do not mean that the 'Logic in Action' spirit is not appreciated!

Emergence of dialects One thing that is very noticeable is the immediate divergence in the way the course has been used, depending on the teachers' experiences, or their own views on the subject. It seems fair to say that 'Logic in Action' has as many dialects as it has geographical locations. One striking phenomenon is an urge to just add new material to old courses, retaining all the old standard topics such as natural deduction, so that the course loses its more radical character, and rather becomes the addition of, say, some epistemic logic to a relatively standard logic course. Two major emerging dialects that can be discerned are as follows: teach a sequence 'propositional logic, modal logic (in a more formal style), first-order logic', or teach things in the order 'propositional logic, first-order logic, modal logic'.

There may be various reasons for this minimal modus operandi, in whatever order it is done. Perhaps teachers are happy with the standard material in logic introductions, but do not object to adding a few topics to round it out, or make it more up to date. Some teachers have also complained that the course does not provide enough abstract mathematical material and training, which they consider the backbone of logic education: technique first, erudition and broad-mindedness later. Perhaps also, student audiences want more focus, finding the wide spread of topics disorienting. Living in a wide open world is not for everyone.

The target audience It may also be the case, and this is a perennial issue with introductory logic teaching, that broad audience courses do not work as well as specialized courses catering to the needs, and prejudices, of students from specific disciplines. Moreover, there may still be a perceived bias in our material, despite the intended broad scope. Anecdotal responses to the course have been that it is too much computer science oriented, and too little toward, say, philosophy. Somewhat ironically, a traditional very formal skills-oriented logic course may generate less resistance from specific disciplines. Since these skills do not apply to anything in particular, such a course treats everything equally, having no favorites.

But also, to continue with an earlier observation, university students fall into very different categories. There are 'open-system types' who like flexibility and change, and 'closed-system types' thriving only in well-defined communities with strict norms for what is 'good' and what is not (the 'bad' is often: what is done in other disciplines or paradigms). This division is clearly observable in graduate schools, where one has to cater for the sensitivities of both types of student – and it may well be that a course like this, with its broad range of topics and open windows to the university at large, will rub closed-systems types exactly the wrong way.

Supporting training But beyond these larger perspectives, there are also simpler down to earth issues with teaching the material in its current form. One difficulty is finding good exercises that test understanding of new topics and new skills. Traditional logic courses have had at least a century of honing test questions in their main fare, while in a new course like this, we need to find a new repertoire to train and test students in understanding the working of questions and other informational acts. This is a serious creative challenge requiring additional investment.

Likewise, our recurrent computational thread raises issues: should not this involve real training in programming or other hands-on computational skills? Some members of our team think so, and therefore, it should be noted that the 'Logic in Action' webpage also has a Part IV, still under development, with concrete programming materials. However, other teachers find this emphasis alienating for students who want a general logic course, not one biased toward computer science.

ICT form or good old content? As for the intended transformative internet and technology aspects of the course when it started, our main experience has been that this is not a decisive factor in the success of the course as taught. It may be an asset for some students, but given the level of sophistication in the world of education today, a course like this does not offer any creative technology that would give it an advantage over any other. To get ahead in this race, presumably, huge development efforts would be needed. But it is very unclear right now what realistic and desirable goal would justify such an effort (see also Section 9 on this issue).

Practical reasoning and social impact Finally, returning to the ideal of a self-study logic course with benefits for everyone, it seems clear by now that 'Logic in Action' really functions as an upper-level high school or under-graduate-level university course, and one that is directed mostly toward logic in its academic form. One could also have the goal of improving actual thinking and argumentation practice, but this would require an effort that we have not made. In fact, it is not clear yet if there can be a happy mixture of the abstract intellectual approach in this course and hands-on courses on argumentation theory or critical thinking.

This is not to say that striving for practical impact of logic courses is an endeavor without value. Even more traditional logicians like Evert Willem Beth, a founding father of the Amsterdam *ILLC* environment, explicitly stated his ideal that logic should improve the level of argumentation and reasonable interaction in our society. But realizing such an ambition seems a challenging separate task.

9 Conclusion: where to go from here

We conclude with a few thoughts on where the course 'Logic in Action' might go.

Given the above observations, our current thinking has become more moderate and laissez-faire. The material that we have produced seems a natural and coherent set. Beyond that, it may not be a good idea to impose much ideological uniformity on a course like this, and in any case, enforcing it across the globe is impossible in practice. Moreover, given the fast developments in the academic role of logic, flexibility is needed to accommodate further changes.

The material for a broad logic course in the style described here remains available in the on-line textbook, which will be updated periodically. In addition, we will add teaching tools as they come our way, including course slides and new exercises. We are also thinking of adding a 'best practices forum' where users of the website can meet. Finally, our team is thinking of 'teaching the teachers', offering courses at suitable venues for people considering to use this course.

As for the internet ambitions, it turns out that no harm has been done by procrastinating. The world of education actually seems to have reached a phase where, worldwide, initial expectations about slick on-line courses have been downgraded to much more realistic levels. The current trend toward 'blended learning' (cf. Bersin 2004) emphasizes the indispensable educational role of real teacher-student interactions, over and above what a textbook or website can give. Our course material can help with blended learning, but trying to 'can the course' will not work.

To go further, and find out what really happens with users of our course, we may also consider creating a 'logic garden' – on the analogy of the innovative website 'math garden' created by Han van der Maas at the University of Amsterdam:

http://www.rekentuin.nl/

This would be a site where a wide variety of visitors can experiment with the material presented here, leaving traces that we can use to improve our course, and learn more about what it is to learn logic.

But all these desiderata do not detract from what we see as our main contribution. The course 'Logic in Action' was designed to enrich what students learn in their first encounter with logic. In addition to content of any introduction to a field, there is also a spirit: a modus operandi and even an intellectual value system gets transmitted. Ours has been to make the scope of logic broad, and in line with that, also the students' view of its position in the university arena. While we are not expecting a revolution, given our material and teaching experiences so far, we do believe in the power of small steps in creating large beneficial attitude changes.

References

[1] H. Andréka, J. van Benthem, N. Bezhanishvili & I. Németi, 2014, 'Changing a Semantics: Opportunism or Courage?', in M. Manzano, I. Sain and E. Alonso, eds., *The Life and Work of Leon Henkin*, Birkhaüser Verlag, 307–337.

[2] J. van Benthem, 2011, *Logical Dynamics of Information and Interaction*, Cambridge University Press, Cambridge UK.

[3] J. van Benthem, 2014, *Logic in Games*, The MIT Press, Cambridge MA.

[4] J. Bersin, 2004, *The Blended Learning Book*, Pfeiffer and Company internet publishers.

[5] E. W. Beth, 1963, 'Konstanten van het Wiskundige Denken', *Mededelingen van de Koninklijke Nederlandse Akademie van Wetenschappen*, 26, 231–255.

[6] K. Devlin, 1991, *Logic and Information*, Cambridge University Press, Cambridge UK.

[7] H. van Ditmarsch, W. van der Hoek & B. Kooi, 2007, *Dynamic Epistemic Logic*, Cambridge University Press, Cambridge UK.

[8] A.C. Graham, 2003, *Later Mohist Logic, Ethics and Science*, The Chinese University, Hongkong.

[9] R. Haskell, 2000, *Transfer of Learning: Cognition, Instruction, and Reasoning*, Elsevier Science Publishers, Amsterdam.

Received \jreceived