Teaching Syllogistics Using E-learning Tools

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Abstract. This paper is a study of various strategies for teaching syllogistics as part of a course in basic logic. It is a continuation of earlier studies involving practical experiments with students of Communication using the Syllog system, which makes it possible to develop e-learning tools and to do learning analytics based on log-data. The aim of the present paper is to investigate whether the Syllog e-learning tools can be helpful in logic teaching in order to obtain a better understanding of logic and argumentation in general and syllogisms in particular. Four versions of a course in basic logic involving different teaching methods will be compared.

Keywords: Syllogistics · Argumentation · Learning analytics · Logical proofs · Deduction · Gamified quizzing · Logic teaching

1 Introduction

In this paper we discuss problems and teaching challenges related to courses in basic logic and argumentation offered to 2nd year students in "communication and digital media" (previously known as "humanistic informatics") at Aalborg University in Aalborg and Copenhagen. The present study is a continuation of previous studies and practical experiments cf. [6–9,11]. Data from the courses in 2012, 2013, 2014 and 2015 will be discussed. The general structure of these courses can be outlined in the following manner:

- Period 1. Lectures + homework: General introduction to logic and argumentation. Introduction to classical syllogistics.
- Period 2. Lectures + homework: Classical syllogistics (Euler diagrams, Venn diagrams, proofs) and propositional logic (truth tables, proofs).
- Period 3. Lectures + exercises in groups + homework: Proofs. Syllogistic validity.
- Period 4. Lectures + homework: Ideas of formal reasoning. The role of logic in everyday life and in scientific argumentation.

About 20 lessons are offered in the course. In addition the students have to do homework. The total number of students has been 150–200 each year. During

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2012–2015 courses with four different versions of Period 3 have been tested. The tests have focussed on syllogistic reasoning.

In order to test and measure the students' ability to do syllogistic reasoning the program Syllog has been developed. Syllog is implemented[1] as a Java-Applet running in the student's browser, developed using PROLOG+CG (see [2–5,12]). However, the system is not only useful in order to measure the students' ability to do syllogistic reasoning. Versions of the system can also be used in order to support the students in their process of learning the principles of logic.

In Sect. 2 we present the theory of Aristotelian syllogistics as a deductive system in the classical manner, and it is also explained how the deductive system can be presented in terms of controlled natural language. In Sect. 3 we present the use of the Syllog system in the study of the educational problems related to the courses in basic logic. We also discuss two Syllog tools which have been used during the courses. Finally, in Sect. 4 we compare the outcome of the studies of the four versions of the course.

2 Aristotelian Syllogisms as Deductive Structures

Aristotelian syllogistics has been an essential part of almost all courses in basic logic since the rise of the European university in the 11$^{\text{th}}$ century; cf. [1,10]. In modern logic teaching the classical (medieval) syllogistics is often presented as a fragment of first order predicate calculus. A classical syllogism corresponds to an implication of the following kind: $(p \wedge q) \supset r$, where each of the propositions p, q, and r matches one of the following four forms: $a(U,V)$ (read: "All U are V"); $e(U,V)$ (read: "No U are V"); $i(U,V)$ (read: "Some U are V"); and $o(U,V)$ (read: "Some U are not V").[2]

In this way, 256 different syllogisms can be constructed. According to classical (Aristotelian) syllogistics, however, only 24 of them are valid. The medieval logicians named the valid syllogisms according to the vowels, $\{a, e, i, o\}$, involved. In this way the following artificial names were constructed (see [1]):

1$^{\text{st}}$ figure: barbara, celarent, darii, ferio, barbarix, feraxo
2$^{\text{nd}}$ figure: cesare, camestres, festino, baroco, camestrop, cesarox

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[1] See http://syllog.sourceforge.net/ and http://syllog.emergence.dk/2015/.

[2] We may express these functors in terms of first order predicate calculus in the following way:

$a(U,V) \leftrightarrow \forall x : (U(x) \supset V(x))$ $\quad$ $e(U,V) \leftrightarrow \forall x : (U(x) \supset \neg V(x))$

$i(U,V) \leftrightarrow \exists x : (U(x) \wedge V(x))$ $\quad$ $o(U,V) \leftrightarrow \exists x : (U(x) \wedge \neg V(x))$

The four basic propositions can be related in terms of negation:

$i(U,V) \leftrightarrow \neg e(U,V)$ $\quad$ $o(U,V) \leftrightarrow \neg a(U,V)$

The classical syllogisms occur in four different figures:

$(u(M,P) \wedge v(S,M)) \supset w(S,P)$ (1$^{\text{st}}$ figure)

$(u(P,M) \wedge v(S,M)) \supset w(S,P)$ (2$^{\text{nd}}$ figure)

$(u(M,P) \wedge v(M,S)) \supset w(S,P)$ (3$^{\text{rd}}$ figure)

$(u(P,M) \wedge v(M,S)) \supset w(S,P)$ (4$^{\text{th}}$ figure)

where u, v, $w \in \{a, e, i, o\}$ and where M, S, P are variables corresponding to "the middle term", "the subject" and "the predicate" (of the conclusion).

3rd figure: darapti, disamis, datisi, felapton, bocardo, ferison
4th figure: bramantip, camenes, dimaris, fesapo, fresison, camenop.

In these names some of the consonants signify the logical relations between the valid syllogisms, and they also indicate which rules of inference should be used in order to obtain the syllogism in question from the four syllogisms which were considered to be fundamental (i.e. axiomatic): barbara, celarent, darii, ferio (see [1,4,8]).

An even more convincing representation of the deductive system of syllogisms than the one suggested in medieval logic, may be obtained using five fundamental deduction rules. These rules can be formulated symbolically in terms of the conceptual graph interchange format (CGIF) as it was suggested in [8]. However, the rules may also be formulated in terms of a controlled fragment of natural language:

(TRANS)	All Y are Z	(SUBST)	All Y are Z
	All X are Y		Some X are Y
	Therefore: All X are Z		Therefore: Some X are Z
(CONTRA)	All X are Y	(MUT)	Some X are Y
	Therefore: All non-Y are non-X		Therefore: Some Y are X
(EX)	All X are Y		
	Therefore: Some X are Y		

Note that we allow for negations of terms. The term non-X simply stands for all elements in the universe that are not instants of X. Clearly, non-non-X (i.e. a double negation) would be equivalent with X. It should also be noted that the e-proposition, "No X are Y", can be reformulated as "All X are non-Y". Similarly, the o-proposition, "Some X are not Y" can be reformulated as "Some X are non-Y". This means that in terms of the controlled natural language the number of types of propositions in syllogistic reasoning can be reduced from four to two, namely the universal propositions (i.e. "All ... are ..."), and the particular propositions (i.e. "Some ... are ..."). In combination with the option of term negation and the above inference rules we have everything that we need in order to evaluate all possible syllogisms in classical syllogistics.[3]

The above inference rules may be seen as an axiomatic system that makes it possible to derive the conclusion in a syllogistic argument from its premises if

[3] It should be noted that (TRANS), which is in fact short for 'transitivity', may in fact be read as the syllogism barbara in Fig. 1. Furthermore, by substituting Z by non-Z we get the syllogism celarent in Fig. 1. — Similarly, it is obvious that (SUBST), which is short for 'substitution', leads directly to the syllogism darii in Fig. 1, and if Z is replaced by non-Z we get ferio in Fig. 1. The three remaining rules are different from the first two in the sense that they only depend on one premise each. (CONTRA) — which is short for 'contraposition' — makes it possible to transform a universally quantified proposition, whereas (MUT) — which is short for 'mutation' — makes it possible to transform an existentially quantified proposition. (EX) — which is short for 'existence' — makes it possible to derive an existentially quantified proposition from a universally quantified proposition.

and only if the syllogistic argument under consideration is a valid syllogism. It is easy to present (TRANS), (SUBST), (CONTRA), (MUT) and (EX) in terms of Euler circles. In this way it can be made clear that the rules are intuitively reasonable.[4]

3 Teaching Syllogistics Using Syllog

The Syllog system generates syllogisms at random, and the user is supposed to evaluate them using the system. The activities of the students when working with the system are logged, and the log-data from the use of the system may give rise to very interesting learning analytics. Figure 1 shows the interface of one the Syllog versions.

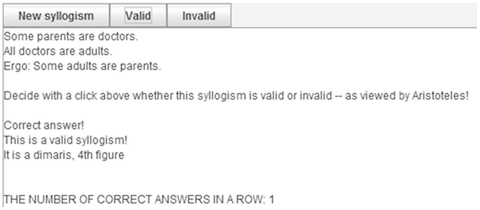

Fig. 1. Gamified quizzing with syllog.

A student's ability to do syllogistic reasoning can be analysed in terms of the score calculated on the basis of log-data from the use of Syllog. This score is calculated as: Score = correct answers/answer count.

The score measures how well the user is doing in evaluating the validity of syllogistic arguments. Logic teaching is at least in part aimed at raising this score. The statistical analyses of the scoring data were performed using standard methods from descriptive statistics and statistical testing. An interesting question concerns the students' competence to evaluate the validity of syllogisms before receiving formal training on this subject [6–8]. In the previous studies we have provided evidence to the effect that the students' ability to distinguish between valid and invalid syllogisms before the teaching starts is significantly higher than the level of guessing. The value of this early score appears to be

[4] Using this deductive approach to the syllogisms, it is possible to show a number of interesting results concerning the invalidity of certain syllogistic arguments. For instance, by going through the five rules of inference it is evident that if both premises are existential, then nothing new follows regarding the relation between subject and predicate. The same holds if both premises are negative i.e. o-propositions or e-propositions. The use of the inference rule (EX) has sometimes been seen as controversial, and the 9 syllogisms which depend on this rule have consequently been seen as "questioned". Clearly (EX) has to be rejected, if we hold that the statement "all S are P" is true given that S is the empty set. Therefore, if this is accepted it should obviously not be permitted to deduce "some" from "all". If the EX rule is excluded, the number of valid syllogisms is reduced from 24 to 15.

rather stable from year to year during the period 2012–2015. The studies suggest 0.608 as the value of this early score.

This kind of information is clearly valuable for teachers who want to design a course in basic logic. However, it is certainly also interesting to measure the average score after some logic teaching. The study based on data from the 2012 version of the course showed that there is no or very limited improvement in the score if it is measured after a traditional course in basic logic (with traditional work with exercises on paper during Period 3). No significant improvement of the average score was detected in this case (see [6]).

In the user interface shown in Fig. 1 it should be noted that "The number of correct answers in a row" is displayed. Using this facility it is in fact possible to establish a competition between the groups and this rather simple gamification element actually turns out to work as a motivation in the practical setting. This effect of simple gamified quizzing was studied based on the data from the course in 2013 and further studies in 2015. This study showed that the use of gamification elements can have some positive effects on the motivation to learn, and in combination with a traditional course on syllogistics it can lead to a an increased understanding of logical validity in the sense that the student's ability to evaluate the validity of an arbitrary syllogism becomes better (see [7,9]).

During Period 3 of the 2014 version of the course the students could do exercises in small groups using a version of Syllog including the deduction rules presented in Sect. 2. The rules were presented on the screen in terms of the CGIF formalism after a general introduction to the formalism (a lecture). The gamification facility mentioned above was also included in the interface. The study showed that only a small fraction of students could benefit from the use of this system. No significant improvement of the average score was detected [8].

During Period 3 of the 2015 course the students could work in small groups with a proof facility based on the five deduction rules mentioned in Sect. 2, presented in terms of controlled natural language. The user interface is shown in Fig. 2. The user can click on New to get a new syllogism presented on the screen. Then the user may apply some of the inference rules ('Trans', 'Subst', 'Contra', 'Mut', 'Ex') to see what follows from the two premises and from other propositions that have been proved so far. This is done by clicking on the button corresponding to the inference rule that the student wants to apply. Whenever ready the user may decide whether he or she believes the syllogism to be valid or invalid. This is done by clicking on the relevant button. In this way the user may perform experiments with the syllogisms in question. Hopefully, this leads to a deeper understanding of syllogistic validity.

As is indicated in Fig. 2, the system automatically translated the premises of the argument into a controlled fragment of natural language. E.g. the premise "No parents are doctors" is immediately translated into "All parents are non-doctors", etc. In this way it becomes easier for the user to see which of the rules (if any) may be applied.

The average score was measured at the beginning Period 3 when the work with the deduction module starts (and after some work with "gamified

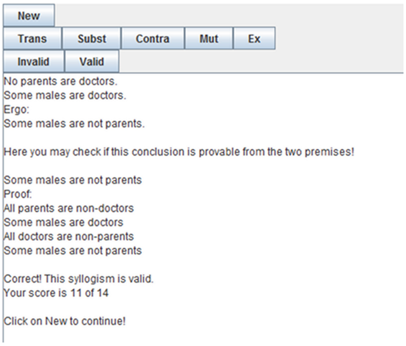

Fig. 2. The interface of the syllog system used in 2015.

Table 1. The 2×2 table summarizing counts from the 2015 course of how often students replied correctly to the syllogisms in the beginning of Period 3 and immediately after this period. These values may be compared with the value (from earlier studies) of the score before the teaching starts, i.e. 0.61.

	Correct reply?		
	Yes	No	Score
The beginning of Period 3 (n = 133)	1145	615	0.651
After Period 3	1112	462	0.706

quizzing"). After Period 3 the average score was measured again. The aggregated results and the scores are shown in Table 1. The results support strong statistical evidence against the presumption that student will handle the syllogisms equally well before and after Period 3 (p-value < 0.001 by the χ^2 test).

4 Conclusions

The present study as well as the previous studies provides strong evidence for the usability of the log-functionality of PROLOG+CG in order to establish relevant analytics regarding the teaching and learning of logic.

Based on the study of the Syllog data from the courses in 2013 and 2014 we have seen that we may benefit from the use of interactive e-learning tools during a logic course, whereas no significant improvement of the ability to do syllogistic reasoning could be detected after the traditional course offered in 2012. Our study provides evidence that students during a course using such a system improve their ability to evaluate logical validity significantly. In particular, the student could benefit from having access to Syllog with deduction rules in terms of natural language, whereas a similar system in terms of CGIF (as in the 2014 course) was of almost useless in most cases. Table 2 shows the result from the four versions of the course.

Table 2. A comparison of the results based on log-data from the four versions of a course in basic logic. Only the content of Period 3 of the course has been changed from year to year.

Year	Period 3	Results
2012	Traditional work with logic exercises (no use of e-learning tools)	No significant improvement of the ability to do syllogistic reasoning was detected after the course [6]
2013	Traditional work with logic exercises + gamified quizzing with Syllog	A small but significant effect of the teaching was detected [7]
2014	Traditional work with logic exercises + gamified quizzing with Syllog + work with a deduction module in terms of CGIF	Mixed result. Only some of the students could benefit from the work with the CGIF module. No significant improvement of the average ability to do syllogistic reasoning was detected [8]
2015	Traditional work with logic exercises + gamified quizzing with Syllog + work with a deduction module in terms of natural language	A significant improvement of the ability to do syllogistic reasoning was detected. The highest value of the average score (0.706) was measured in this case

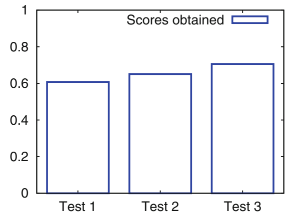

Fig. 3. Scores obtained in Test 1 (2012, without the use of e-learning tools), Test 2 (2013, repeated in 2015, with a gamified quizzing tool) and Test 3 (2015, with a gamified quizzing tool and a tool to the investigation of the deductive structures of syllogisms).

Observations of the students during their work with the tools suggest that the work with the tools in 2013 and in 2015 stimulated their motivation and interest in the topic. Figure 3 is an attempt to put the results in perspective:

The 2014 study [8] shows that most of the communication students were unable to benefit from a Syllog tool using CGIFs in order to investigate the deductive structure of the syllogisms. It is likely that this will be the case for any tool that makes use of a complex formalism or symbolic language. However, the present study shows they can in fact benefit from the use of the deductive module presented in terms of controlled natural language. Still, an average score of 0.706 in the 2015 test is not very impressive. Obviously, the challenge is to develop better e-learning tools and teaching strategies in order to improve the students' ability to do syllogistic reasoning even more. For this purpose, it might be useful to know more about the kind of difficulties that the students are facing when they are working with syllogisms. Further studies of the log-data may provide such information, and we may thereby obtain useful information on how to develop more effective e-learning tools and teaching strategies.

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