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The Use of E-learning Tools and Log Data in a Course on Basic Logic

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Abstract. This paper is a study of the use of e-learning tools and log data in evaluating and further developing a course on basic logic. It is a continuation of earlier studies involving practical experiments with students of communication from Aalborg University. Two tools are involved: *Syllog* for training syllogistic reasoning and *Proplog* for training basic propositional logic. The data are logged anonymously during the course, as well as during the individual exam. Using the log data, we have obtained important insights into the effects of the lectures and exercises. We argue that the log data from using the two tools can be transformed into useful learning analytics. Careful studies based on log data can provide useful information on how the quality of the course. On this basis, it can be suggested how the course can be improved using the learning analytics based on the log data. This is evident from studies carried out over seven to eight years using log data from the use of *Syllog* and recent studies based on log data from the use of *Proplog,* also show how insight based on the log data may lead us to improvements of the course. During the present study we have developed a method by which we can determine whether the students will handle one kind of symbolic logic test better than another.

Keywords: Syllogistics, Propositional Logic, Validity of Arguments, Learning Analytics, e-Learning Tools, Logic Teaching.

1 Introduction

For more than 20 years, a course on basic logic and argumentation has been offered to students in the area of 'communication and digital media' at Aalborg University. One of the authors of this paper (Peter Øhrstrøm) has been involved as a teacher throughout this whole period, whereas two of the other authors (Thomas Ploug and David Jakobsen) have been involved for some of the years. The topics covered in the course have varied a bit from year to year, but Aristotelian syllogistics and basic propositional logic have been on the agenda throughout the whole period. A joint textbook [1] is used for the course, along with two learning tools, *Syllog* and *Proplog*, which have been developed specifically for this course.

The focus in the present study is on the use of log data that emerged from using the tools to develop and improve the parts of the course on basic logic dealing with Aristotelian syllogistics and basic propositional logic. The students using these tools to further their learning, and the teachers and course developers can improve the quality of the course using insight based on the log data.

In 2010, the *Syllog* tool was designed (cf. [3], [4], [5], [10]), and slightly improved versions of it have been used in the course since then. The tool has been employed during logic exercises to make the learning experience game-like and joyful. Furthermore, all the interactions with the tools are logged in a database. Of course, the students have been informed that this is done, but none of them have seen it as problematic because the logging is done anonymously.

Studies of the log data have led to several improvements in the course when it comes to teaching syllogistics (cf. [6], [7]). Since 2018, the ambition has been to do something similar based on the analysis of log data from the use of *Proplog*. In the current paper, we discuss the use of *Syllog* and *Proplog* as teaching tools and as tools for providing valuable learning analytics.

2 Syllog and Proplog

The interface of the present version of the *Syllog* tool is shown in Fig. 1. The user can click on 'New syllogism' to get a new syllogism presented on the screen. Then, the user will have to decide whether the syllogism presented is valid or invalid, that is, whether the conclusion follows necessarily from the premises (in any possible/thinkable scenario). The systems allow for some kind of gamification, since a sound will play when the group obtains 10 right answers in a row. This has worked as a kind of competition (see [7] and [10]). During the exercises, the students were asked to work with *Syllog* in small groups of two to three people each for about 15 minutes.

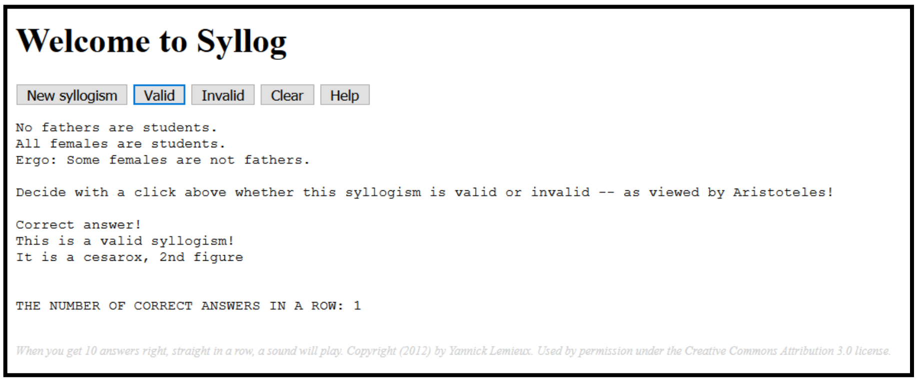

Fig. 1. Interface of the *Syllog* tool. Note that in case of a valid syllogism, the system will give the medieval name of the argument. The student may compare these names with the Aristotelian theory presented during the lectures of the course.

A student's ability to do logic reasoning can be analysed in terms of a score calculated based on the log data from the use of *Syllog*. This score is calculated as follows:

$$Score = correctanswers \,/\, answercount \quad (1)$$

The statistical analyses of the scoring data were performed using standard methods from descriptive statistics and statistical testing. Student t-tests and Cohen's d effect size were applied to measure the difference between the responses in two independent samples. The following Cohen's conventions were applied: 0.2=small effect, 0.5=medium effect and 0.8=large effect [10, p. 267]. The quantitative data were analysed with MS Excel (Windows). Data from the groups that answered less than five questions were excluded from the measurements; thus, the value N of each test does not include sessions with very few answers. Furthermore, some student groups apparently took long pauses during their sessions, and groups with an average time of more than two minutes per exercise were not taken into account in the computation of the time statistics in the tables. The aggregated scores and use of time are shown in Tables 1–4.

It is well-known that there are 256 possible syllogistic arguments. According to Aristotelian theory, 24 of them are valid, whereas 232 are invalid (cf. [1] and [8]). In *Syllog*, valid and invalid arguments occur with the same frequency. This means that a student who is giving answers at random should end up with a score of about 50%. One interesting result is that the score is significantly higher than 50% even before they have been taught any logic. At this early stage, the score is typically 60–70%, mainly depending on an individual's abilities (cf. [6], [7], [11]).

> A very important learning goal is to make the student able to decide on the question of validity/invalidity in a qualified manner. The student should not only be able to raise his or her ability to identify a valid argument (and an invalid argument), but he or she should also be able to understand and explain why a particular argument is valid (or invalid).

The strategy in case of the use of *Proplog* is basically the same as in the *Syllog* case. The user interface of *Proplog* is shown in Fig. 2.

All the propositions in *Proplog* have to do with 'Adam' and 'Eve' being at home or not being at home. Furthermore, the system uses negation, implication, conjunction and disjunction. The tool uses the below set of simple propositional arguments, where p stands for 'Adam is at home' and q stands for 'Eve is at home'.

For the construction of *Proplog*, we have considered two kinds of basic propositional reasoning:

1. Implicative: $A \rightarrow B, C \models D$
2. Disjunctive: $\sim(A \wedge B), C \models D$ and $(A \vee B), C \models D$

Here, each of the pairs, (A,B) and (C,D), includes both p and q in any order and with each of the two propositions being negated or unnegated. Clearly, this gives us 64 possible arguments for each of the above structures. However, many of these arguments seem rather similar and uninteresting. Furthermore, it will be good to bring the number of arguments down to obtain reliable statistics when calculating scores on the basis of the log data. For this reason, we have chosen to concentrate on the following set of 32 arguments, 16 valid and 16 invalid, which we find representative for basic implicative and disjunctive reasoning (cf. the classical forms mentioned above).

1. $p \rightarrow q, p \models q$
2. $q \rightarrow p, q \models p$
3. $\sim p \rightarrow q, \sim p \models q$
4. $\sim q \rightarrow p, \sim q \models p$
5. $p \rightarrow \sim q, p \models \sim q$
6. $q \rightarrow \sim p, q \models \sim p$
7. $p \rightarrow q, \sim q \models \sim p$
8. $q \rightarrow p, \sim p \models \sim q$
9. $\sim p \rightarrow q, \sim p \models q$
10. $\sim q \rightarrow p, \sim p \models q$
11. $p \rightarrow \sim q, q \models \sim p$
12. $q \rightarrow \sim p, p \models \sim q$
13. $\sim(p \wedge q), p \models \sim q$
14. $\sim(q \wedge p), q \models \sim p$
15. $(p \vee q), \sim q \models p$
16. $(q \vee p), \sim p \models q$
17. $p \rightarrow q, q \models p$
18. $q \rightarrow p, p \models q$
19. $\sim p \rightarrow q, q \models \sim p$
20. $\sim q \rightarrow p, p \models \sim q$
21. $p \rightarrow \sim q, \sim q \models p$
22. $q \rightarrow \sim p, \sim p \models q$
23. $p \rightarrow q, \sim p \models \sim q$
24. $q \rightarrow p, \sim q \models \sim p$
25. $p \rightarrow \sim q, \sim p \models q$
26. $q \rightarrow \sim p, \sim q \models p$
27. $q \rightarrow \sim p, \sim q \models p$
28. $p \rightarrow \sim q, \sim p \models q$
29. $\sim(p \wedge q), \sim q \models p$
30. $\sim(q \wedge p), \sim p \models q$
31. $(p \vee q), p \models \sim q$
32. $(q \vee p), q \models \sim p$

It would, of course, have been possible to base the *Proplog* tool on another selection of propositional arguments. However, some selection of this kind will be needed to build the *Proplog* tool because we need a procedure for picking the new arguments, that is, a scope to the arguments that can occur in the system. The above set has been composed in a rather systematic manner. In the first place, it consists of arguments in which one premise is an implication between *p* and *q* (perhaps with one of them negated), and the antecedent and the consequent (or their negations) in any order serve as another premise and as a conclusion, respectively. In addition, a few arguments from disjunctive reasoning (and their invalid counterparts) have been included in the set. It is evident that the set is closed under permutations of *p* and *q*.

*Proplo*g is—like *Syllog*—using the same frequency of valid and invalid arguments. Again, the score before any logic teaching will be significantly higher than 50%. As in the *Syllog* case, we have reasons to believe that the score will be 60–70% properly, mainly depending on an individual's abilities (cf. [11]).

The results of a recent study (cf. [11]) indicate that our current lectures and exercises help the student be able to perform significantly better when it comes to *Syllog*. In fact, the score rises from 67% at the pretest (before the teaching) to 80% at the post-test (after the teaching). It should also be mentioned that the students on average take more time for the post-test (70 sec.) compared with the pretest (47.5 sec.). This seems to indicate that based on the teaching, they knew how to handle the problem and that they—given a little extra time to ponder—could come up with more precise answers. However, in the same study, something similar did not happen in the *Proplog* case. On average, the students took more time for the post-test (90 sec.) than the pretest (37.7 sec.). Nevertheless, the *Proplog* score remained the same (65%).

The difference between the *Syllog* and *Prolog* cases is rather surprising because we have tried to show the students through the lectures and exercises how the questions of validity/invalidity should be handled. It was definitely not the intention that the *Prolog* teaching should be sloppier than the *Syllog* teaching. In the following section, we have tried to explore this surprising difference again using new data and another group of students.

3 A new experiment

The surprising observation mentioned above has recently been studied empirically using data from new students. Whereas the earlier study (cf. [11]) was based on data from the course offered in the spring of 2019, the current study is based on data from the course offered to second-year students in 'communication and digital media' at Aalborg University in Aalborg and Copenhagen during the spring of 2020. All the lectures on the two topics in question were given before the COVID-19 lockdown in Denmark on March 11, 2020. The same holds true for most of the exercises. We use data from the training sessions (exercises) after the lectures in question and before the COVID-19 lockdown. The results are shown in Table 1.

Table 1. Summarising counts from the 2020 course of how well student groups scored on the training period after the lectures. The training sessions are carried out in groups of two to three people, and the students are encouraged to discuss the question carefully before they agree on an answer.

	Score Mean (*SD*)	**Time Mean (*SD*), [sec]**
Syllog training (*N*=103 groups)	0.73 (0.20)	36.8 (28.8)
Proplog training (*N*=138 groups)	0.65 (0.17)	35.9 (24.3)
P-value (Effect size)	0.0009 (0.43)	-

Based on the study of an experiment from 2019 (cf. [11]), it seems likely that many students found the *Proplog* case more difficult to handle than the *Syllog* case. If so, the *Proplog* score should be significantly lower than the *Syllog* score if both scores are measured during the training period. The above results confirm this expectation (*p*-value=0.0009 and effect size=0.43).

Given that many students find propositional logic more difficult than syllogistics and that most students have been unable to improve their *Proplog* score based on lectures, the challenge is to update the lectures to support the students' learning in a more effective manner. For this reason, it would be helpful to know which aspects of propositional logic the students need help with. Actually, the new experiment has also provided information on the *Proplog* scores of each of the arguments—1–32—during the training session. However, it is evident that the differences between the evaluations of the members of the symmetric pairs (1/2, 3/4, 5/6, etc.) are very small. It seems reasonable to ignore these differences as variations within statistically acceptable limits. As a consequence, we may consider the pairs as units in the further discussion (i.e., each pair basically represents the same argument). The results are shown in Table 2.

Table 2. The scores of the arguments based in log data from the use of *Proplog* during the training period after the lectures in propositional logic. The training sessions are carried out in groups of two to three people, and the students are encouraged to discuss the question carefully before they agree on an answer.

Task number	Total number of responses	Score
½	216	0.97
¾	233	0.93
5/6	191	0.93
7/8	198	0.44
9/10	216	0.36
11/12	206	0.54
13/14	226	0.75
15/16	216	0.87
17/18	210	0.49
19/20	202	0.48
21/22	208	0.53
23/24	224	0.62
25/26	204	0.63
27/28	235	0.70
29/30	197	0.58
31/32	225	0.65

The number of responses for each task varies between 191 and 235, as generated by a random number generator in the programme. By the Kolmogorov-Smirnov Uniform Test, the distribution of the numbers of responses is not significantly different from a uniform distribution (p-value=0.98). Obviously, calculating scores based on just 200 responses may be uncertain. On the other hand, the results are sufficiently clear to show some important tendencies.

The highest score—97%—is obtained for arguments 1 and 2:

If Adam is at home, then Eve is at home.
Adam is at home.
Therefore, Eve is at home.

This is clearly an instance of Modus Ponens, and almost all students found this argument valid. In general, the scores of the Modus Ponens argument are very high.

The lowest *Proplog* score in the experiment—36%—is obtained for the arguments 9/10:

If Eve is not at home, then Adam is at home.
Adam is not at home.
Therefore, Eve is at home.

This is like arguments 7–12 an instance of Modus Tollens, which is known to be significantly more difficult to handle than Modus Ponens. However, 36% is a very low score for somebody who has attended a course dealing with basic propositional logic. It should also be mentioned that the responses are given by groups of two to three students after some discussion.

It should also be mentioned that the *Proplog* score of argument 19/20 is as low as 47%:
If Eve is not at home, then Adam is at home.
Adam is at home.
Therefore, Eve is not at home.
Furthermore, the score of argument 29/30 is just 58%:
Adam and Eve are both not at home.
Eve is not at home.
Therefore, Adam is at home.

In both cases, the score is at the level of random answers. These results suggest that the students' understanding of the properties of implicative and disjunctive reasoning is unsatisfactory.

All this is a very strong indication of the need for rethinking the introduction to propositional logic in the course on basic logic. Apparently, the students need to understand the use of truth values better, and the course should focus more on making the students able to evaluate simple propositional arguments using truth values and techniques based on semantical trees.

We should note one further insight into the students' understanding of basic logic. This has to do with the asymmetry between the evaluation of valid and invalid arguments. The mean value of the scores of the 16 valid arguments in the set is 72%, whereas the mean value of the scores of the 16 valid arguments in the set is 59%. This indicates that it is significantly easier to identify a valid propositional argument than to identify an invalid propositional argument.

4 The use of *Syllog* and *Proplog* at the Exam

Syllog and *Proplog* have both been used during individual exams at the end of the logic course. For the exam, the students were asked to find 10 syllogistic arguments using *Syllog* and five propositional arguments using *Proplog*. They were supposed to include the arguments found by the tools in their assignments in the form of screenshots from the systems. Their task was to explain carefully why the arguments have the validities suggested by the system. This means that the students should be able to demonstrate that the valid arguments actually are valid and that the invalid arguments actually are invalid. This kind of assignment is quite relevant because the answer given by the student clearly indicates to what extent he or she has understood the validity of the syllogistic and propositional logic. In both cases, it turns out that understanding the notion of validity is rather weak. In particular, it should be noted that although many students have a rather clear understanding of what it takes to demonstrate that a syllogistic argument is valid, the students have a very weak understanding of how it should be shown that a syllogistic argument is invalid. In the analysis of the syllogistic arguments in their assignments for the exam, most of the students failed to explain or demonstrate the invalidity of one or more arguments offered by *Syllog*. Given this weakness in the assignments, it would be a good idea in the lectures to put more emphasis on the use of Venn diagrams to show the invalidity of a syllogistic argument. It might even be possible to create a new tool for analysing invalid syllogistic arguments.

A lot of log data from the use of *Syllog* and *Proplog* have been stored during the exam period. The context of these data is clearly very different from the context of the log data collected during the training sessions. First, the use of the tools during the exam period is not motivated by obtaining a high score or 10 right answers in a row. In this period, the tools are just used to find the number of arguments that the student wants to write about in his or her assignment for the exam. This means that the student is using less time to consider his or her responses. Furthermore, the student is working alone during the exam period (four days), whereas the training sessions are carried out in groups of two to three people, and the students are encouraged to discuss the question carefully before they agree on an answer. All this means that it should be expected that the *Syllog* score is less during the exam period, mainly because of using less time for each response and not being able to discuss the response with a group. The results are shown in Table 3.

Table 3. Summarising the counts from the 2020 course of how well the students in groups and individually scored using *Syllog* in the training period and in the exam period after the lectures.

Syllog	***Score Mean (SD)***	***Time Mean (SD)*, [sec]**
Training (*N*=103 groups)	0.73 (0.20)	36.8 (28.8)
Exam (*N*=288 individual sessions)	0.62 (0.19)	17.8 (23.8)
P-value (Effect size)	$<10^{-6}$ (0.56)	-

These results show that the students tended to speed up their interaction with *Syllog* when left alone with the system. The results also show that the *Syllog* score is significantly higher when more time is used to consider the responses and when the responses can be discussed with a group. The individual sessions displayed a strongly significant negative effect of medium size (effect size=0.56). However, when restricting the mean response time per exercise for the exam sample to be more than 10 seconds, the score raised to 0.72 (*SD*=0.20). Apparently, several students used the program quite hastily and with mistakes.

When it comes to *Proplog*, the situation is different. The results in Table 4 show that the students do not speed up their interaction with *Proplog* when left alone with the system. The results also show that the *Proplog* score is not very diverse compared with the responses that coming from a group. The individual sessions show a significant negative effect of small size (effect size=0.28).

This indicates a difference in familiarity with the two systems. The students probably felt that they knew *Syllog* better and could use it much easier than *Proplog*. For this reason, they were ready to move faster on the *Syllog* tests when left alone during the individual exam period. Because propositional logic and the *Proplog* tool remained rather unfamiliar to the students, something similar did not happen in this case. This is at least a possible explanation of the difference between the results in Tables 3 and 4.

Table 4. Summarising counts from the 2020 course of how well the students in groups and individually scored using *Proplog* in the training period and in the exam period after the lectures.

Proplog	***Score Mean* (*SD*)**	***Time Mean* (*SD*), [sec]**
Training (N = 155 groups)	0.65 (0.17)	35.9 (24.3)
Exam (N = 195 individual sessions)	0.60 (0.19)	34.9 (29.1)
P-value (Effect size)	0.015 (0.28)	-

In the analysis of the propositional arguments, many students have apparently not obtained a clear understanding of how propositional validity and invalidity can be demonstrated. It seems that there is a need for an even stronger emphasis on the analysis of arguments in terms of truth values and semantical trees.

5 Conclusion

It is evident that the two e-learning tools *Syllog* and *Proplog* can be useful for the students during their course in basic logic. The use of the tools can make logic learning much more joyful, and the game-like properties of the systems can stimulate their exploration of the logical structures significantly. Furthermore, the use of *Syllog* and *Proplog* can support teamwork and groupwork in logic learning because they can stimulate cooperation and discussion in the joint exploration of logical structures and problems. It may, in fact, be possible to develop the material further to establish a proper online course in logic and argumentation. For this purpose, we may consider further developments of the tools. One obvious option could be an automatic and online calculation of the score during a session.

It is very welcome that *Syllog* and *Proplog* offer quantitative feedback on the effect of their teaching in terms of the log data. As we have seen, these data can be very helpful when we want to improve our logic course. In fact, an interesting learning analytics can be based on log data. It seems that we in this way can obtain a very detailed account of how much formal logic the students have actually learned during the course. This makes it rather obvious how we can improve our course in basic logic. In the present case, there is no doubt that there should be a stronger emphasis on propositional logic in the next version of the course. In particular, the course should include a better and more precise introduction to the evaluation of propositional arguments with respect to validity.

The results of the present study show that the students handle the *Syllog* test significantly better than the *Proplog* test. It is tempting to conclude that students´ performance in logic tests depends on the type of formalism. Maybe the majority of students will simply handle syllogistic logic better than propositional logic. However, it is important to be careful here. In principle, the relation between the *Syllog* and *Proplog* performances may alternatively depend on order in which the topics have been presented during the course. For this reason, it should be investigated whether a new organisation of the topics in the course would provide different learning conditions for the students. Right now, the two topics within basic symbolic logic—syllogistics and propositional logic—are presented at the beginning of the course. Syllogistics is presented first mainly for historical reasons, given that syllogistics goes back to Aristotle, whereas the first propositional logic was formulated by the generation of logicians succeeding Aristotle. For systematic reasons, however, the opposite order might be more natural. In addition, it might be attractive to have more informal material presented between the introductions of the two formal topics. It might be attractive to design and run a new experiment in order to investigate whether another organisation and order to the topics in itself could enable the students to handle the two kinds of symbolic logic in a better manner.

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