

Artificial Intelligence Assistant for Mathematics Education

Antonín Jančařík¹, Jarmila Novotná² and Jakub Michal¹

¹Charles University, Faculty of Education, Prague, Czech Republic

²Charles University, Faculty of Education, Prague, Czech Republic, and CeDS, Université Bordeaux, France

Antonin.jancarik@pedf.cuni.cz

Jarmila.novotna@pedf.cuni.cz

Jakub.michal@pedf.cuni.cz

Abstract: The paper presents the partial results of a research study conducted within the project AI Assistant for Pupils and Teachers. The university, non-profit sector and organization established by the Ministry of Education are cooperating on this project. The aim of the project is to prepare an AI assistant for communication with teachers and pupils. The output of the project should be a system that communicates with pupils and teachers. AI assistant will offer them appropriate teaching materials based on their needs. The system will use not only pre-prepared materials (which is the case presented in this paper), but will be able to independently search and evaluate materials in open databases. We primarily focus on supporting the teaching and learning of mathematics and Czech language. In this paper, we focus on one of the partial researches. The aim of this research was to prepare and experimentally test the possibility of using a series of pre-prepared math problems of an increasing difficulty for individual (partly pupil-managed) practice of algebraic expressions. The topic of algebraic expressions was chosen because it is relatively well-structured and is therefore suitable for this method of processing. At the same time, and this is very important, the topics include the so-called critical topics, i.e. topics that cause problems for pupils and where pupils very often seek help. The topic of algebraic expressions is divided into several subchapters, each of which contains about ten steps, consisting of three tasks, one of basic, one of standard and one of higher difficulty, and supporting materials for mastering them. The pupil can decide what difficulty of the task they want to solve and what supporting materials they want to use. The developed application is available to pupils online in the web environment as well as in the form of an app for the mobile phone. The application has already been published and is in a test regime.

Keywords: chatbot, private tutoring, AI chatbot, algebraic expressions, AI in education

1. Introduction

Tutoring is an important part of the education process. Education, which takes place in close interaction between the educator and the pupil, is very effective. It allows adaptation of the educational content to the particular pupil's needs. In the Czech Republic, the vast majority of pupils have experience with some form of tutoring. However, this form of education is very expensive and results in deepening socio-economic inequalities in education. The AI Assistant Project for Pupils and Teachers, in whose solution the authors of this paper are involved, aims at partial automatization of the tutoring process using modern technologies. Thus, it should make tutoring more accessible to a larger group of pupils.

In this paper, we present one of the developed applications – a chatbot designed for tutoring in the area of algebraic expressions in an online environment. There are several reasons why it is this topic that has been selected for testing the functionality of the chatbot environment. The first reason is that it is a topic that was identified as one of the critical areas of mathematics (Rendl et al, 2013), a topic in which pupils have considerable problems. The second reason is that it is a very well-structured topic. And last but not least, implementation of algebraic expressions into the text mode in which the chat takes place is not as complicated as, for example, implementation of topics from synthetic geometry. The application we present in this article combines AI elements in the form of a chatbot with classic programmed learning tools. The application is currently in test regime and can be accessed both on a web interface and through the Telegram chat application.

2. AI in Education (AIEd)

The issue of the potential use of AI in education has been researched and discussed for more than 30 years. Zawacki-Richter et al (2019) present an overview of this research. They identify four major directions of current research in the area of AI in education. These are:

- 1. Profiling and prediction,
- 2. assessment and evaluation,

- 3. adaptive systems and personalisation,
- 4. intelligent tutoring systems.

Intelligent tutoring systems (ITS), which include the AI assistant we develop, are systems in which one-to-one personal tutoring takes place, where the role of the teacher is fully or partially represented by a computer system. Thanks to the use of artificial intelligence, education is becoming more accessible and is becoming a solution even in situations in which traditional online teaching is necessary but unavailable for time, economic or other reasons. However, it is important to realize that there still are and will be differences between the support provided by the teacher and the one provided by AI. Early research shows that using an AI assistant may make communication easier for some pupils (Kim et al, 2020). A.E. Attard (2021) in his bachelor thesis conducts a research focusing on explaining the knowledge from mathematics, according to which 73% of the users enjoyed making use of the chatbot, and the same percentage of respondents also expressed a desire to use the chatbot again in the future.

3. Algebraic expressions

As Stacey, Chick and Kendal (2004, Preface) state “For mass education, algebra teaching highlights questions of equity and relevance. For progression to higher mathematics, students need algebra but its abstraction makes it hard to learn and hard for beginners to see a reason for learning.” They speak about school algebra in general, but of course, it is valid also for algebraic expressions we are dealing with in this paper. Algebraic thoughts are seen there as consisting of three components: natural language, symbolic language and compound representations. The analysis of these components suggests that their mastering is not straight. In (Stacey, Chick and Kendal, 2004, 9.3), language aspects that may affect individuals’ reading symbolic writings are discussed from the perspective of attributes, which form obstacles for achieving algebraic fluency. An algebraic activity involves operating on the unknown, stating generalization about patters of operations, and making statements about equivalent combinations off operations. Algebraic activity involves operating on the unknown, stating generalization about patters of operations, and making statements about equivalent combinations of operations. Linchevski and Livneh (1999) propose that for successfully use the conventional rules of symbol manipulations. it is necessary for pupils to possess the so-called structural sense. On the one hand, symbolic writings in algebra are compact and powerful, but at the same time, they build obstacles for learners (Stayce, Chick, Kendal, 2004).

MacGregor and Price (1999) observed that pupils with good language skills did not do well when manipulating with algebraic items based on “familiar school algebra tasks”. They hypothesized that these pupils “were not sufficiently aware that the algebraic sign system has its own grammatical rules and conventions that are not intuitively obvious and have to be leaned” (p. 462) (see Stacey, Chick, and Kendal, 2004).

In school mathematics traditionally, algebra has been considered as generalisation of arithmetic. In the present understanding, algebra is considered in a much broader perspective. For example, it is an efficient tool when modelling real situations.

In the following text we focus on algebraic expressions as an important part of school algebra. An algebraic expression in mathematics is an expression which is made up of constants, variables and algebraic operations (addition, subtraction, multiplication, division and exponentiation). School mathematics cannot do without the symbolic language of algebraic expressions already on the level of lower secondary school. Without them, the formulations would be often very long and limited. It would make both written as well as spoken communication too complicated. Algebraic expressions offer the way for describing mathematical concepts and relationships among them. But on the other hand, in the reality of teaching mathematics in school, they are often taught in an instructive, formal way without understanding.

Algebraic expressions (expressions with variables), their properties and manipulations with them are one of the domains of school mathematics mostly declared in the interviews with teachers as difficult for pupils, see e.g. (Rendl et al., 2013). There are two main reasons for it presented by teachers: Pupils have difficulties with grasping rules for algebraic expression manipulations and in the era of the use of didactical technology (DT), it can be done by DT. Numerous attempts to withdraw algebraic expressions from the compulsory curricula have been noted in several countries.

At present, in several professions economical thinking and expressing is required. Many professions are based on algorithmic procedures. It supports the importance of dealing with algebraic expressions in the contemporary school mathematics. But it is necessary to motivate pupils for using them and avoid formalism when manipulating with them. Many mathematics teachers are aware of the obstacles pupils encounter when manipulating with algebraic expression (example for one interview with teachers: "What about leaving out operating with fractional algebraic expressions. Anyway, it is like an alchemy for many pupils." Kubínová, Barešová, Hanušová, 1999).

3.1 Distribution of topics

For the purposes of tutoring, the topic of algebraic expressions was divided into 25 subchapters (see Table 1), which build on each other logically and in terms of growing difficulty. A series of 5 tasks was created for each subchapter, where two were easy, one standard and two more difficult. Only one easier and one more difficult task were finally selected for the test regime. A suitable video explaining the phenomenon/phenomena needed to work with the algebraic expressions were added to each subchapter. The videos were usually selected from publicly available sources such as the KhanAcademy or YouTube. As some subchapters were too narrowly focused (for example, the chapter: Multiplying an expression with subtraction in parenthesis by a positive number), it was not always possible to find a suitable video. This as well as the need for some uniformity in the video environment led us to the idea of supplementing the chatbot with our own videos in the future.

Table 1: The topics of algebraic expressions

1	Introduction (welcome message and explanation)	14	Distributive property (multiplication of expressions in the form $(a+b)(a+b)=a^2+2ab+b^2$)
2	Distributive property (multiplying by positive number, addition in the brackets)	15	Product of two polynomials (using algebraic identity $(a+b)(a-b)=a^2-b^2$)
3	Distributive property (multiplying by positive number, subtraction in the brackets)	16	Product of two polynomials (using algebraic identity $(a\pm b)=a^2\pm 2ab+b^2$)
4	Distributive property (multiplying by negative number)	17	Factoring out (a number)
5	Distributive property (combined)	18	Factoring out (variable)
6	Distributive property (with powers)	19	Factoring out (different variables)
7	Distributive property (with powers 2)	20	Factoring out (brackets)
8	Distributive property (multiplying by variable)	21	Factoring out (factorization of polynomial)
9	Distributive property (multiplying by variable of higher power)	22	Determining number of terms of polynomial
10	Distributive property (multiplying by product of several variables)	23	Polynomic addition and subtraction
11	Distributive property (several brackets with one variable multiplication)	24	Application of algebraic identities for factorization
12	Distributive property (several brackets with several variables multiplication)	25	Vieta's formulas
13	Distributive property (multiplication of expressions in the form $(a+b)(a-b)=a^2-b^2$)	26	Discriminant, search for roots of polynomial

4. Chatbot

The chatbot environment works like any other simple online chat. The conversation can be started online, but it can also be started in the Telegram mobile app. The Telegram application is available free of charge and the chatbot responds faster. The user communicates using simple commands that they select from pre-prepared options. Once started, the pupil has the opportunity to choose from several topics. If the pupil finds the unit easy and has already mastered it, they have the opportunity to skip it and continue with further units. If not, they can play an instructional video or start solving the tasks. After starting the section, the pupil has a choice

of two difficulty levels – easy and standard. Having completed them, they proceed in difficulty. If they do not wish to do so, they do not have to solve the difficult task. If the pupil does not know how to solve the task, in difficult tasks that are offered the opportunity to look at the sample solving procedure. In case of easy tasks, they are offered help and in standard tasks the pupil can choose whether to watch the instructional video or try the easier task. The options that are offered to the pupil at any time of the chat are shown in more detail in the diagram in Figure 1.

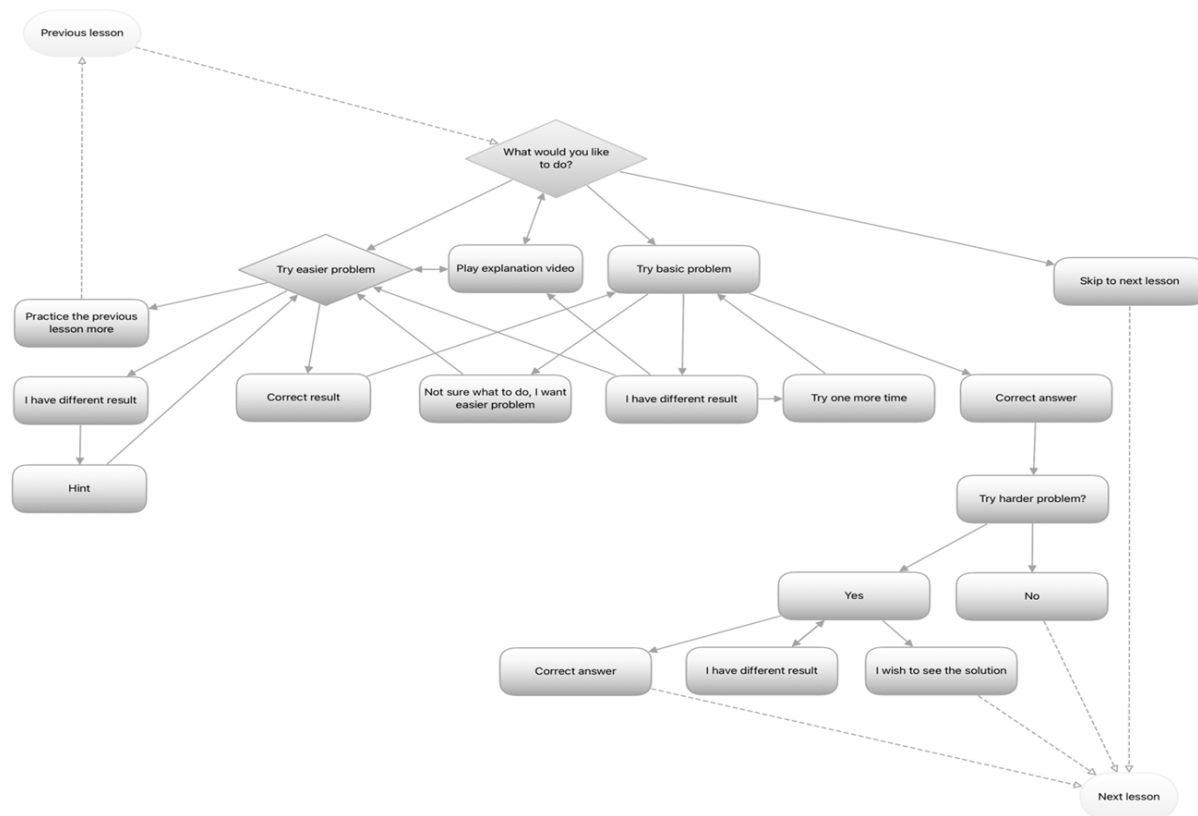


Figure 2: Individual topics of algebraic expressions

4.1 Selecting the answer

We did not choose the classic multiple choice offer for interaction with the pupil, but based it on the older principle of H. Kayen from the University of Sheffield. The pupil answers on his own, writes down the solution and then compares it with or identifies it in the offered answer. What is important in the decision-making processes in our application are the offered options “another answer” and “I don’t know”, which means the pupil is not obliged to choose one particular answer (Kulič, 1971). The absence of distractors puts the pupil in a situation where they see what answer they should expect, and so they can better direct their steps or make corrections to numerical mistakes, for example. We expect thus to approach to lower the level of pupil frustration at times when they are not be able to cope with the task. The non-traditional environment also aims at making a difference between tutoring, for which the application is designed, and the school approach to assessment. We realize that using only one correct answer can, in some cases, tempt pupils to just confirm the correct answer without having to solve their own tasks. That is why we closely monitor the time that has elapsed between entering a question and answer. Then we are able to detect skipping the solution phase on the basis of very short time intervals between entering a question and an answer.

4.2 Communication with chatbot

The impression of communication with a real person is enhanced by the presence of additional texts where the chatbot encourages, applauds but also communicates with them using a variety of funny pictures with popular film characters (Figure 2). Inclusion of these is intended primarily to motivate pupils to continue and finish the unit.

In order to increase pupils' motivation, a function has been integrated into the system, by means of which the chatbot can, at least partially, respond to comments and remarks that are not directly related to the topic. This part was not created within the project. Conversation modules in English were used. The system thus translates the pupil's sentences into English, looking for suitable reactions to them, which again translates back into Czech. Thanks to high-quality tools for machine translations, the need to create a conversation module in Czech was circumvented, which would be very difficult due to the structure of Czech language.

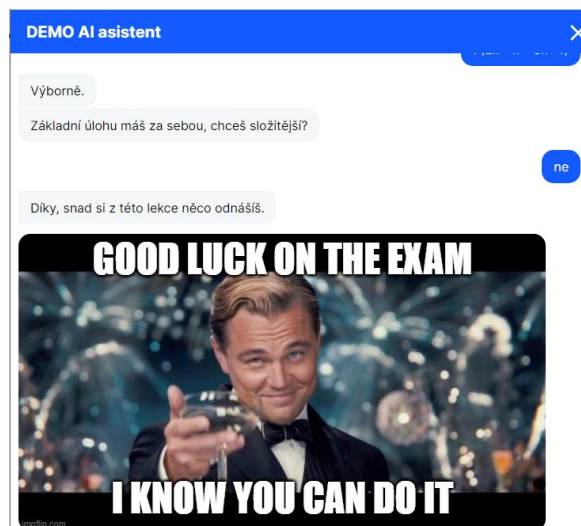


Figure 2: Illustration from the environment of the AI assistant

4.3 Web interface

The application in the web environment is activated using a code. Having logged on, the user gets an option thanks to which they do not have to start the course from the beginning but can directly access the topic that is interesting for them (Figure 3).

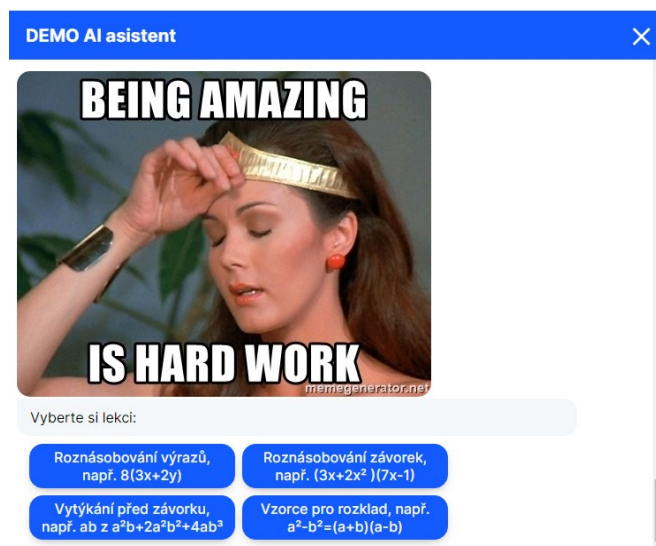


Figure 3: AI assistant – selecting a unit

Having selected the unit, the user continues following the procedure described in Chapter 3. Instead of the web environment, the user can use the application Telegram.

4.4 Telegram app

The application Telegram (Figure 4) is a freely available chat programme that has been repeatedly used in education, especially in teaching languages (Citrawati et al, 2021, Alakrash et al, 2020, Sari, 2017). The advantage of this environment is that it has been developed for mobiles. Thus, pupils can use it without any further obstacles. It comes out of the world of social networks that pupils use on everyday basis.

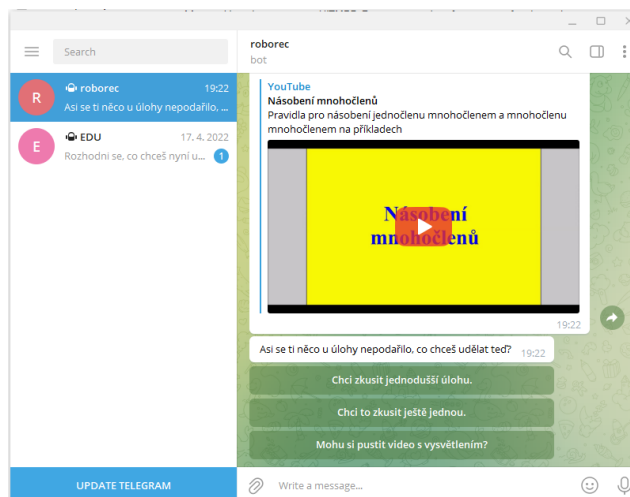


Figure 4: AI assistant – selecting a unit

5. Conclusion

The use of AI in education is a trend that aims to improve and make education accessible. Offering a suitable, inexpensive alternative to commercial tutoring is one of the ways of reducing the impact of socio-economic factors in education. The application, which we are developing as part of the research and which we presented in the article, tries to make tutoring accessible to all pupils.

The presented research is at its beginning. Among the most important issues that the research will focus on is the evaluation of the chosen strategy of not using distractors in solving tasks and the issue of further individualization of educational materials based on information about the learning progress of individual learners.

Acknowledgements

This paper was supported by the project TAČR N. TL05000236 – AI assistant for pupils and teachers.

References

- Alakrash, H., Razak, N. and Bustan, E. (2020) The Effectiveness Of Employing Telegram Application In Teaching Vocabulary: A Quasai Experimental Study. *Multicultural Education*, Vol 6, No. 1.
- Attard, A. E. (2021) *AI assisted pedagogical chatbot* (Bachelor's thesis, University of Malta).
- Citrawati, N. K., Suwastini, N. K. A., Jayantini, I. G. A. S. R., Artini, N. N. and Dantes, G. R. (2021) Telegram as Social Networking Service (SNS) for enhancing students' English: A systematic review. *Journal of English Language Teaching and Linguistics*, Vol 6, No. 2, pp 239-260.
- Kim, J., Merrill, K., Xu, K. and Sellnow, D. D. (2020) My teacher is a machine: Understanding students' perceptions of AI teaching assistants in online education. *International Journal of Human-Computer Interaction*, Vol 36, No. 20, pp 1902-1911.
- Kubínová, M., Barešová, M. and Hanušová, J. (1999) How teachers' beliefs influence mathematical lessons? In A. Afzal, W. Honor, Kraemer, J.M. (Eds.), *Proceedings of CIEAEM 51*. Chichester: CIEAEM.
- Kulič, V. (1971) *Chyba a učení*. Praha: SPN.
- Linchevski, L. and Livneh, D. (1999). Structure sense: The relationship between algebraic and numerical contexts. *Educational Studies in Mathematics*, Vol 40, pp 173-196.
- MacGregor, M. and Price, E. (1999) An exploration of aspects of language proficiency and algebraic learning. *Journal for Research in Mathematics Education*, Vol 30, No. 4, pp 449-467.
- Rendl, M., Vondrová, N. et al. (2013). *Kritická místa matematiky na základní škole očima učitelů matematiky* (Critical Points in Mathematics at Elementary School through the Eyes of Teachers). Prague: Charles University, Faculty of Education.
- Sari, F. M. (2017, November). Maximizing telegram application for teaching reading. In *UAD TEFL International Conference*, Vol. 1, pp. 228-233.
- Stacey, K., Chick, H. and Kendal, M. (Eds.) (2004) The future of the teaching and learning of Algebra. *The 12th ICMI Study*. Boston / Dordrecht / New York / London: Kluwer Academic Publishers
- Zawacki-Richter, O., Marín, V. I., Bond, M. and Gouverneur, F. (2019) Systematic review of research on artificial intelligence applications in higher education—where are the educators? *International Journal of Educational Technology in Higher Education*, Vol 16, No. 1, pp 1-27.