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Computational Thinking in K-12: Azerbaijan's Experience

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Abstract. Computational thinking is the process of finding numerical patterns and formulating algorithmic solutions. Polyup, a digital math playground, allows students to gain computational thinking skills through an experimental and gamified environment. Azerbaijani schools tested Polyup in their classrooms to see if it improved student attitudes towards math and motivated students to practice their math abilities. In this paper, Polyup is presented, the methods of deployment and usage of Polyup are reviewed, and we summarize the impact that Polyup has had on Azerbaijani students and schools.

Keywords: computational thinking, educational games, math education, Edtech, Azerbaijan.

1. Introduction

Computational thinking, an important theme of computer science for K-12 education, is defined as "the thought process involved in expressing solutions as computational steps or algorithms that can be carried by a computer" (NCSM, 2018). The importance of computational thinking extends beyond computer science and is a fruitful pathway to build the conceptual understanding of problem-solving and algorithmic thinking.

How can we develop an effective learning environment for computational thinking education in K-12? Mathematics educators have long seen the value in utilizing aspects of computer science to support the learning of mathematics, and computer science learning will in turn benefit through such a process. Therefore, computational thinking can be seen as a catalyst in learning mathematical concepts by utilizing the tools of computer science.

Which concepts of computer science can be used as such tools? Mainly algorithmic thinking through computing and approximation, using variables as identifiers and containers, loops and iteration, boolean operators, conditional loops, and recursion. All these tools of computer science can be taught in the language of mathematics rather than a specific coding syntax. We present such a computational thinking "playground" where students can experiment with these building blocks and create expressions and algorithms.

2. Computational Thinking Playground

Computational thinking is a four-stage problem-solving framework consisting of decomposition, pattern recognition, abstraction, and algorithm design, as shown in Fig. 1. We have enriched and connected the stages with a "playground" as an environment for the experimental problem-solving.

We intend to present a digital computational thinking playground that has been used by more than a hundred thousand K-12 teachers and students as a platform for problem-solving. This playground is an easily accessible place where learners can tackle problems through experimentation.

To build this playground, we used a functional programming environment as the medium for problem-solving. A solution to the problems in this environment involves executing executing a sequence of functions. Functional programming treats computation as the evaluation of mathematical functions and avoids changing-state and mutable data, so it is a powerful tool that can be used in a modular form for problem-solving. Such modularity is key, as it specifically empowers learners to utilize what they have built in the past for future solutions.

The proposed computational thinking playground empowers learners in reasoning, problem-solving, and algorithmic thinking in a gamified fashion. Anonymous user data is gathered from every learners' moves, providing a very rich platform for learning design research. Results of the analyzed data can be used to improve the platform and also bring recommendations and feedback to the learners (Tabesh, 2018).

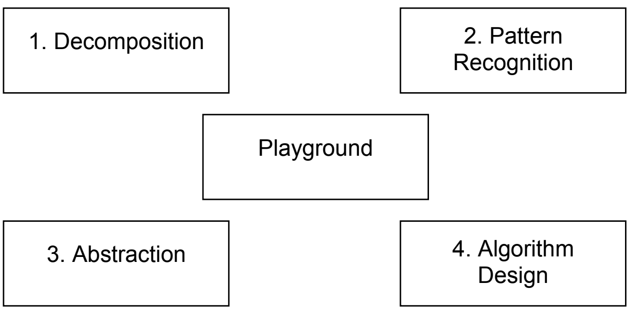

Fig. 1. Four Steps of Computational Thinking.

3. Polyup Platform

We considered the following objectives for the platform:

- Enable creative engagement.
- Develop mathematical skills.
- Support a growth mathematical mindset.
- Be collaborative and social.
- Equity and Accessibility.

The developed computational thinking platform is called Polyup (Polyup, 2019) and is a web application enabling problem solving in a functional programming paradigm. By using the elements of mathematics as the building blocks of the paradigm, students can be on-boarded quickly and spend more time learning how to solve computational problems rather than use the particular platform.

In the platform, the user is equipped with numbers, operations, and basic functions. The user can create a stack of computation in a functional modular form; computation simply goes top to bottom in a postfix style. Users can drag and drop numbers and operations on stacks to build an algorithm that achieves each puzzle's desired output.

The Polyup platform includes numbers, operators, booleans, variables and functions, as shown in Fig. 2.

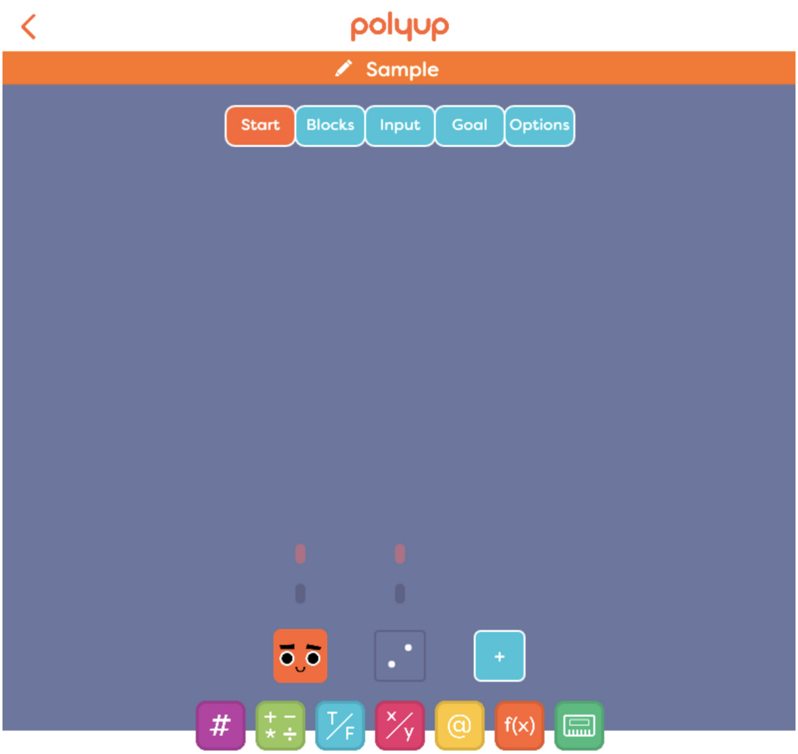

Fig. 2. Polyup Platform blocks.

The following features can be found on the Polyup platform:

- Reverse Polish Notation (RPN).
- Variables as identifiers.
- Iterative processes and loops.
- Boolean functions and conditional loops.
- Recursion.
- Block programming.

To learn more about the Polyup platform, we look at the following toy examples to calculate 3 + 4 in iterative (Fig. 3.a and Fig. 3.b) and recursive (Fig. 4.a and Fig. 4.b) fashions. Of course, we could just write a 3, 4, and a plus sign, but we use these round-about approaches as a window into more advanced algorithms that can be created.

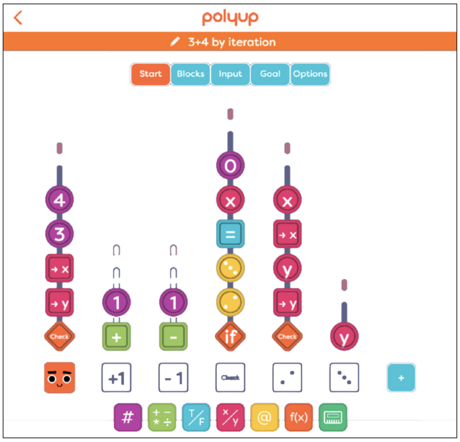

Fig. 3.a: Script of 3+4 by iteration.

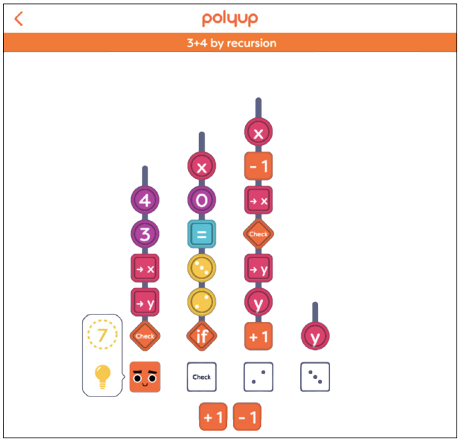

Fig. 3.b: User interface of 3+4 by iteration.

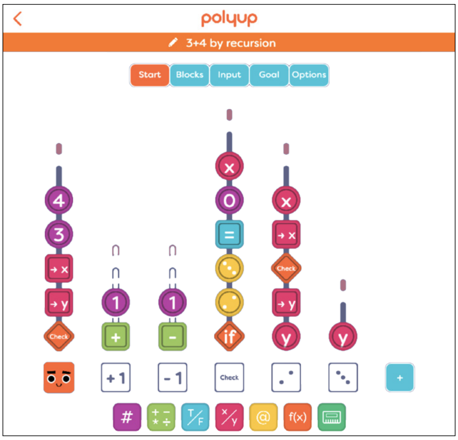

Fig. 4.a. Script of 3+4 by recursion.

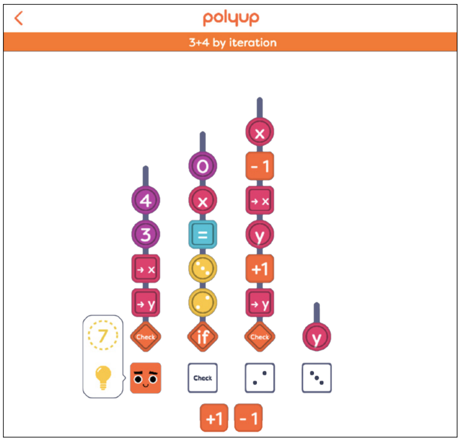

Fig. 4.b. User interface of 3+4 by iteration.

In the iterative approach, we first set our variables, x and y, in the first stack. 3.a shows the puzzle in creation mode -- here, the puzzle's creator gets to define what the player sees at the start of the puzzle, the goal of the puzzle, and the blocks the player gets to use to achieve the goal. The author chose to give most of the structure of the program to start with, but notice that +1 and -1 stacks are modularized and hidden from the player in Fig. 3.b (the stacks have a dashed line around them in 3.a, meaning they are hidden stacks). Fig. 3.b shows the player's solution. When the player runs this program, Poly goes from top to bottom, and the variable "set" blocks take in the block directly above them. As a result, x will be initially set to 3 and y set to 4. Then, we go to the "Check" stack to check if x is equal to 0. If it is, then we return y, which represents the sum so far. Otherwise, we increment y by 1 and decrement x by 1. So, when computing, y will be incremented and x will be decremented x times, leading the final result to be the final value of y, or 4 + 1 + 1 + 1 = 7.

Alternatively, in the recursive approach, we call the "check" stack over and over while decrementing x until it hits 0. As a result, the stack denoted by the two dots will be called x times, and thus after all the calls, we will have a stack of x "+1" blocks, which will in effect increment y by x, and return x plus y.

4. Polyup in Azerbaijani Schools

Polyup was introduced in Azerbaijani schools in October 2018. In order to encourage the use of Polyup's platform in Azerbaijani schools, with the aim of developing students' computational thinking and involving them in the game-based learning environment, the following steps have already been implemented:

1. Recruitment of Master trainers, localization, and development of training programs.
2. Content development aligned with the local math curriculum.
3. Presentation of Polyup at education fair, conferences and teacher workshops.
4. Pilot implementation in selected schools.
5. Involvement of schools, students and teachers to the Azerbaijan Challenges within Polyup.

Brief discussions about each of the above items are as follows:

1. Nine selected local master trainers were trained over video by the Polyup team. These master trainers in turn translated the teacher's guide and adapted training program materials to their local curricula. They provided online support as well as face-to-face training. However, on most occasions face-to-face meetings were held with teachers, as per their request.
2. Master trainers identified topics that were not mentioned in the portal and new machines were created and placed in the portal for 15 projects in 5 topics for grades 1 to 2, 11 projects in 11 topics for grades 3 to 5, 6 to 8, 9 to 12 and 9 projects on agricultural technology and green (alternative) energy. These machines, consisting of 3-7 chips, were highly demanded by teachers and students and were

actively used during the lessons. Additionally, the local Polyup team localized and adapted the “Teacher’s Manual” on how to use the platform and create new machines.

3. The Polyup Platform was presented at the Education Fair organized by the Ministry of Education and at the AgTech and Green Energy Forum, jointly organized by the Ministry of Agriculture and the Ministry of Energy. The benefits and advantages of Polyup platform were presented and discussed during 30 workshops and roundtables, both in Baku and the various regions.
4. In order to promote the platform, the local Polyup team organized school visits and conducted information sessions for school principals and teachers. The interested teachers from more than 14 schools were trained and registered on the platform. Throughout the training, teachers were informed about the principles of working with Poly Machines the creation of new Machines. Moreover, teachers developed their skills to create project-based machines. As a result of training program, teachers and students were engaged and actively participated in the Azerbaijani and international challenges established by Polyup. The methodology for using Polyup online platform during lessons is as shown in Table 1:

   According to the observations, the Polyup online platform is mainly used during lessons in the following forms (see Table 2):
5. During the info sessions and pilot implementation, all teachers were also introduced to Azerbaijan Poly Challenge. They were trained on how to join the Challenge. Starting from March 2019, five Azerbaijan Poly Challenges were held and five winners were awarded with different prizes, such as tablets and notebooks. Moreover, one of the project participants, who joined the international challenge “Youcubed Prize”, has won a chance to participate in online course for math teachers organized by Stanford University. More than 200 teachers and 1000 students from Azerbaijan participated in the Azerbaijan and international challenges.

According to the results of a survey conducted by local Polyup team students, Polyup project raised interest and competitiveness among them, since the platform is focused on game-based learning. Therefore, with the support of the Ministry of Education, more schools, students, and teachers are expected to be involved in the future.

Table 1

The methodology for using Polyup

№	Methodology	Recommendations
1	Practical lessons	Can be used as mathematical calculations in the process of teaching STEM subjects
2	Project-based lessons	Can be used as integration with social sciences in the form of long and short-term projects
3	Problem based lessons	Can be used to connect mathematics with real-life experiences

Table 2

Polyup online platform using during lessons

№	Type of activity	Use form	Used tools	Recommendations for use
1	Class	Teacher assigns a class work. Students fulfill their assignments. Then, the student who quickly finished the assignment performs the solution of task on the machine on the smart board and sees if the sequence is correct	Smart board, computer, projector	The platform can be used during les-sons (topic explanation, classroom assignments) for classroom exercises and after-school activities. All students are involved in the discussions and cooperate through the activities
2	Small groups	Teacher gives an assignment to small groups (consisting of 4-7 students) of students. The groups solve tasks on the computer	Computers, projector	Through this type of activity, students are involved in a competitive environment, which further engages the students
3	Pairs	Teacher gives an assignment to the students. Students solve a task on the computer in pairs	Computers, projector	Through this type of activity, students are involved in a competitive environment, which further engages the students
4	Individual	Teacher gives an assignment to the students. Students individually solve tasks on their computers	Computers, projector	The activity identifies the individual potential of each student, so a teacher can guide them accordingly

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