DEVELOPING THE PROBLEM-SOLVING ABILITY – RESULTS OF AN ONLINE COMPETITION III.

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Abstract. In our increasingly changing world, there is a great need for education to keep pace with the progression. That is why it would be important to improve the curriculum in a way where acquisition of knowledge, realistic processing, and the problem-solving activities play a greater role, instead of merely transferring the knowledge.

In this article, I'm focusing on the development of problem-solving skills. I present and analyze an experiment I carried out with volunteer IT students and compare the results with those of a previous research. Based on the evaluation, it can be concluded that the problem-solving skills of the students can be greatly improved.

All these findings suggest placing greater emphasis on exercises with primary purpose to develop problem-solving skills with IT tools, both in higher education as well as public education too.

Keywords: problem-solving, IT education, modeling, challenge, creativity, Excel task, programming task

1. Preceding research

During my previous research [2,3] I was focusing on how much the student's problem-solving ability is developing during the current high school education. The research consisted of two parts. First (in 2008), I was studying how 10-15-year-old students solve thought-provoking tasks during an online competition, which need not primarily lexical knowledge but creativity. As a continuation, in 2017, I repeated the same tasks with university students of similar age at the time of first study, so I could compare the results of the students of the same grade before and after high school studies. Based on the evaluation, the problem-solving skills of students during the high school years did not increase substantially.

When analyzing the research, another question popped up in my mind: – How can be improved the problem-solving way of thinking? That is, if students meet certain type of a problem, can they apply (or transform) the idea of solving that particular problem taken from another topic? This question came to my mind because in the 2017 experiment, two different exercises could be solved by almost the same principle, but the students did not discover any relationship between the two exercises.

2. The tasks of research

Participants of the survey were volunteering computer science students. As a first step, they participated in a lab lesson where we discussed the two exercises of the 2017 experiment. The two exercises were as follows.

"Beetle on the edges of a cube"
A beetle walks on the edges of a cube. Our goal is to reach from a corner to the opposite one. It does not know the edges, so on each corner, it can choose any of the three directions with equal probability. Once the beetle starts off on an edge, it will reach the end.

- What is the probability of the beetle reaching the goal after 10 steps?
- How many steps are needed the beetle to reach the goal with 90% probability?
- If we place a "stationary" spider (that is waiting for the beetle) into the starting corner after the beetle starts off, then what are the probabilities of (i) the beetle reaching the opposite vertex (the goal) or (ii) being eaten by the spider?

"Betting"
Joe wants to visit a museum with an admission price of 10 euros, but he has only 2 euros. He asks for a loan from Georg who likes to play, so he offers to win this money with one of the following games. Which one of the games is worth choosing for Joe and how big is his chance to win the 10 euros? On average, how many games are played until the final result is reached?

- „Double or nothing" game with one of the following rules:
  - The player is always all in, except when he has 8 euros, when he risks 2 euros only.
  - The player always plays with all his money.
  - The bet is the minimum of the existing money and the missing amount.
- Coin toss: One of the players is betting on the HHH, the other one on the HTH combination and the winner is who first tosses his own combination. Is the choice of combination important? Why?

The first exercise was analyzed in detail and was first jointly solved by using a spreadsheet and then I presented a program. Regarding the second exercise, I only showed the outline of the solution. I was referring to lack of time, but in fact I wanted to give the least but still enough help to succeed in solving a similar exercise. However, I made the solution of both exercises available for the interested students.

After the joint session, students had to solve the following exercises individually.

“Reproduction of rabbits"

A farmer has a rabbit couple. This is what we know about the reproduction of this species:

- The female occasionally gives birth to 8 puppies on average
- A mother is giving birth in about every month and a half.
- Young animals are mature from 3 months of age.
- The average lifespan of the rabbits is 3-5 years, and they are not very fiery in their last 1-2 years

Questions:

- Based on the above, how many rabbits will be there in the yard a year later?
- How will our population change?
- How can death be incorporated into our model?

Help: For simplicity, let's consider the following trivia.

- Do not consider individuals, but couples instead. This conceptual constraint is not very significant but helps to focus on births.
- Assume the birth cycle fixed: every mother (couple) gives birth to 8 offspring (4 couples) every 1.5 months.
- Exactly 3 months (2 birth cycles) are needed for maturation: so, 3 cycles after their birth, the young animals themselves can also give birth.
- Based on the above, we distinguish four types of animals: Newborn, Kid, Young, Parent.

3. Solving the Problem

We can illustrate the change of our population over a cycle (1.5 months) with the following state diagram:

Figure 1. State diagram of population’s change

Based on the state diagram, a matrix can be filled in, where the (*i*, *j*) element is indicating the probability of the rabbit turning from age *i* to age *j*. Based on the above analysis, the attached matrix is obtained.

	1	2	3	4
1	0	1	0	0
2	0	0	1	0
3	0	0	0	1
4	4	0	0	1

Figure 2. Matrix of population’s change

The exercise contains 1 adult rabbit couple initially, so the starting state can be described by the vector (0, 0, 0, 1). The next step is obtained by running the start state on the state diagram to get to the state (4, 0, 0, 1). Note that this can be obtained by multiplying the start state with the matrix describing the state diagram. If we add up the number of rabbits of different ages, we get the number of our population.

The answer to our first question is after the 8th cycle, that is, a year later we will have 386 individuals.

The second question is much more complicated: when shall we stop our simulation in order to have a figure on the change of the rabbit population? Since the number of rabbits constitutes a monotonous, incessant, endless convergent series, we consider the change in the total number of rabbits as the exit criteria, that is the ratio of the total population of the current and the previous cycles. This value will converge to 1.7484 after the initial large fluctuation, which will show our population's growth in 1.5 months.

The simplest idea to incorporate mortality in the model is to supplement the states with 17 "parent" states and 12 "old" states, which mean they are still alive, but not reproducing anymore. After the last "old" state, our rabbits die, so they are subtracted from the total number of the population. Perhaps it may be astonishing that the death does not substantially reduce the rate of the population growth.

If we do not want to create so many new states, let's agree that it is enough to add only one "old" state to the diagram, with the meaning it no longer generates any offspring. Thus, during a cycle, 1/18 part of the parents will become old and only 17/18 part will remain parent. Similarly, 11/12 part of the old rabbits will stay old and 1/12 part will die. By working with this diagram, we finally get the result, which is that our rabbit population grows 72.45% in a cycle.

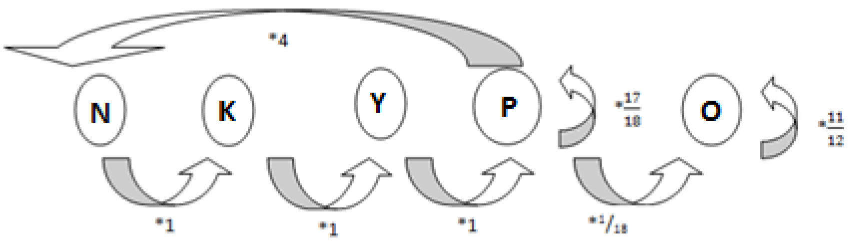

Figure 3. State diagram of population's change with death

4. The evaluation of the research

4.1. Based on the students' solutions

I got 12 solutions from the students, of which were 11 evaluable. The12th student had a deduction on paper, but he only dealt with the first exercise, and the solution was wrong anyway. There were 10 students who have selected program writing as the exercise solution tool, and only 1 student solved it (correctly) using the spreadsheet.

There were 11 students who started out on a correct set of thoughts, and 7 of them (nearly 64%) gave a correct answer to the first exercise.

There were 8 students dealing with the second exercise, and 6 of them (75%) solved it correctly.

There were only 3 students considering the deaths in this exercise, and one of them (33%) solved it correctly. This was the student who did not write a program, but used a spreadsheet instead, and was not working with five states only, but with 36 states instead.

Compared with the previous research, the students produced a much better solution than their mates the previous year, where there was no correct solution at all, and the ratio of almost good solutions was 36% (beetle) and 42% (betting).

4.2. Based on the questionnaire

After completing the assignment, I made them fill out a questionnaire, and I compared the results with those of my previous research questionnaire.

The first surprising result was the exercises that the "Beetle on the edges of a cube" and "Betting" exercises were rated differently by the students: in the 2017 questionnaire it was 65% of the students rating the "Beetle" problem to be the more difficult one. In contrast, in this year's questionnaire it was 75% of the students rating the "Betting" exercise as the more difficult one, because of the complexity of the problem.

In both questionnaires, it was the "Beetle" exercise the more appealing for the students, though with different ratios. In the previous questionnaire, both tasks were liked by 52%, so it was the ratio of indifference (22%, 26%) and dislike (26%, 22%) the decisive. The difference was more emphasized in this year's questionnaire: while it was (50%, 50%, 0%) the ratio of the "liked", "indifferent", and "disliked" answers for the "Beetle" problem respectively, the same figures of the "Betting" problem were (37.5%, 25%, 37.5%), respectively.

Another very interesting result of the comparison of the two questionnaires was that 69.2% of students in the 2017 questionnaire had met similar problems to the "Betting" exercise, while only 25% of the students completing it this year answered the same. The same trend can be found with the "Beetle" problem, but the two ratios are much closer (38.5% or 25%). I think this is because the students in the later questionnaire have already seen the solution, but the idea of the solution was not known for them.

It was also instructive to compare the time spent on exercises. Based on this we can conclude, the students spent more time on the "Rabbits" task, which is reflected in the quality of their solution too.

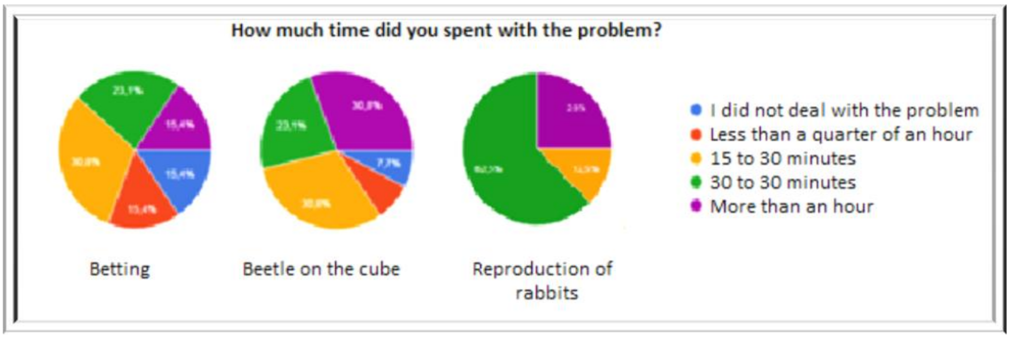

Figure 4. Comparison of the time spent on the exercises

5. Place and role of exercises in the education

Although the research was not representative, but still it can be stated, that there is a place for the problem-solving tasks in the education. The students were able to apply the acquired mindset, but one hour was not enough for everyone to fully master it. Based on the questionnaire, the students found the exercises interesting enough to deal with them.

Based on all of this, I believe that there is a place for problem-solving tasks both in public as well as tertiary education.

There is a high drop-out rate at the computer science studies. One of the reasons of this could be that the programming skills of many students from secondary schools are insufficient [1]. To address this problem, a possible idea is to create a special course in the first year that helps students to catch up. The exercises mentioned in this article could fit into the curriculum of such a course, since both the programming skills as well as the problem-solving skills of the student are also improving. The principle that all students need some level of computational thinking is becoming increasingly important in the non-specialized higher education courses too. The subject of these courses is very diverse nowadays, but I think it is perfectly suitable for dealing with the exercises of the article, primarily with a spreadsheet solution.

It makes sense to consider similar exercises in high school computer science study groups.

6. Other similar tasks and solutions

In this chapter, I will deal with some of the simple "price-moving" exercises that can be solved both in high school and in higher education.

(1) The price of a product is increased twice, and then reduced once with the same percentage, so that the price will be the same with the original price. How much was the percentage of change?

(2) The price of a product was increased by x%. What percentage to lower the raised price to get the original price again?

(3) In one factory, for a product, the following two price increase models can be chosen by the staff of the trade: 6% per annum or on first year nothing, then 3% per semester. Which one to choose? May the answer still depend on something else?

I will deal with the solution of exercise 1 in detail only, because exercise 2 is a simpler, preparatory or guiding exercise, and I propose the exercise 3 to undertake and deepen exercise 2. Depending on the time allocated to the exercises and the age of the students, one of the exercises 2 and 3 can be omitted.

Although it is simple to calculate tasks with a mathematical equation, do not follow this direction! It is much more interesting to start with a guess instead of an immediate solution, then create an idea after a number of attempts, and finally, find a solution to the problem. By doing so, we not only convince the students into thinking, but we also develop their heuristic skills.

Note that finding solutions to exercises 1 and 2 can be done by binary search. (Sometimes it is called logarithmic search.) (Figure 6)

The exercise can be solved by using an Excel spreadsheet (Figure 5) but is also suitable as a programming exercise (Figure 6). Input parameters are the price of the product and the threshold limit for the downtime, that is, the accuracy. Based on this, we calculate the searched value by interval bisecting strategy.

I propose to illustrate both solutions.

The price of the product:		10 000 Ft											
The accuracy:		1											
							Solution:						
Lower limit:	0%	50,00%	50,00%	50,00%	56,25%	59,38%	60,94%	61,72%	61,72%	61,72%	61,72%	61,77%	61,79%
Upper limit:	100%	100,00%	75,00%	62,50%	62,50%	62,50%	62,50%	62,50%	62,11%	61,91%	61,82%	61,82%	61,82%
Average value:	50,0%	75,00%	62,50%	56,25%	59,38%	60,94%	61,72%	62,11%	61,91%	61,82%	61,77%	61,79%	61,80%
first lift:	15 000 Ft	17 500 Ft	16 250 Ft	15 625 Ft	15 938 Ft	16 094 Ft	16 172 Ft	16 211 Ft	16 191 Ft	16 182 Ft	16 177 Ft	16 179 Ft	16 180 Ft
second lift:	22 500 Ft	30 625 Ft	26 406 Ft	24 414 Ft	25 400 Ft	25 901 Ft	26 153 Ft	26 279 Ft	26 216 Ft	26 185 Ft	26 169 Ft	26 177 Ft	26 181 Ft
reduction:	11 250 Ft	7 656 Ft	9 902 Ft	10 681 Ft	10 319 Ft	10 118 Ft	10 012 Ft	9 957 Ft	9 985 Ft	9 998 Ft	10 005 Ft	10 002 Ft	10 000 Ft
difference:	1 250 Ft	2 344 Ft	98 Ft	681 Ft	319 Ft	118 Ft	12 Ft	43 Ft	15 Ft	2 Ft	5 Ft	2 Ft	0 Ft
stop:												OK	

Figure 5. Solving the first exercise using a spreadsheet

```
fn BINARY_SEARCH (price, accuracy)

al, ul, l := 0, 1, false
do while not l
        av := (al + fl) div 2
        fl := price * (1+av)
        sl := fl * (1+av)
        r := sl * (1-av)
        if |price-r| ≤ accuracy
          then l := true
          else if price–r < 0
```

then *al* := *av*
else *ul* := *av*
return *av*

Figure 6. Exercise 1, solution algorithm

7. Summary

The results of my current and previous [2,3] surveys show that students' problem-solving skills do not show significant progress during their high school years, even though it is very easy to improve. It draws attention to the shortages of public education, but above all to the outdated orientation of the concept. We need to take advantage of the opportunity for rectification and change of direction as soon as possible. I have outlined several possible ways, depending on the age and interest of the students.

One of the directions of my future research will be to expand the scope of the exercises presented in this article.

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