STEM EDUCATION WITH EDUCATIONAL ROBOTICS TO TACKLE FAILURE IN MATHEMATICS

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ABSTRACT: The integration of cognitive subjects leads to a different perception of mathematics and science education: STEM education. The use of educational robotics in STEM education favors interdisciplinary activities, which, supported by constructivism learning theory, encourage the learner to master his learning, to develop creative thinking and to co-operate in problem solving. It has been found that the theoretical approach in mathematics education has the greatest share of responsibility in creating and maintaining the conditions leading to mathematics failure. The aim of this paper is to investigate whether the robotic activities designed and carried out at our school, within the framework of the European Erasmus+ KA2 program DREAM, can cope with mathematics failure. The research tools used are questionnaires before and after activities for students and teachers. The results include descriptive statistical analysis, interpretation and conclusions.

KEYWORDS: education, educational robotics, mathematics, DREAM, constructivism learning theory.

1. INTRODUCTION

Mathematics suffers deeply from a “bad reputation” among students: too difficult, useless, etc. Students think that mathematics is too theoretical to be useful for anything in their life, resulting in poor attention and performance. They really don’t consider that mathematics is one of the most important subjects they need to study for their future career, as it will increase their job choices.

The traditional theoretical didactic approach applied for the subject of mathematics in schools (i.e. passive transmission-acceptance of knowledge from teacher to students), having as primary source of information the teacher, as well as the textbook, has proven incomprehensible for a large number of students and insufficient for both cognitive concepts and other critical skills, like team work, problem solving, analytic-synthetic-critical thinking, creativity and communication.

The PISA results (2012) show that 22.1%, i.e. more than one out of five students in Europe, had low performance in mathematics, meaning that they were not equipped with the basic skill necessary for numerous valuable jobs in our current economy. The Commission has the objective to lower this number to 15% in 2020 but, so far, in many countries compared to the previous PISA tests the progression is very weak. These numbers are not only results of the PISA tests but they also arise on a daily basis in math teachers’ experience in classroom. Our students can’t use almost anything of what they’ve learned at school in their daily life. The problem is not just a lack of abilities among European students but also a lack of interest in mathematics. The EU has published in 2011 a very important document, “Mathematics Education in Europe: Common Challenges and National Policies” from the Eurydice network ([MEE18]), which points out the importance of the learner’s motivation and engagement.

While several pilot initiatives are actually taking place in order to increase the interest and performance of the young students towards Mathematics, it is important to point out that there is still a lack of a systematic approach to the issue, especially in the southern part of Europe.

Relatively recently, a discussion has started to strengthen the role of technology in school education, so that students explore meaning in natural sciences and mathematics within a technological context ([RS08, Lew06]). The incorporation of cognitive objects leads to a different perception of science and mathematics education: STEM education, term - acronym of Science, Technology, Engineering and Mathematics ([Eng16, HPS14, MS14]). The tendency to integrate the scientific fields of science, technology, engineering and mathematics is related to the need for technological literacy of all citizens ([ITE00]). Researchers believe that STEM training is emerging as a "good practice" in the learning process ([San12]) that will help students to gain knowledge more effectively, understand better the world around them, increase their engagement with science, mathematics and technology, helping them to inspire and innovate, while at the same time feeling the satisfaction and enthusiasm of the educational process ([BRW14]).

Modern research shows that STEM using educational robotics can provide educational experiences that promote students' creative thinking, cooperativity and problem solving ability ([Ali13]). In addition, research into STEM using educational robotics, involving students of low social and economic level, has yielded positive conclusions about the innovation literacy, i.e. the development of cognitive and social skills ([ECC13]). For all these reasons, our school, 1st General Lyceum of Aigio participates in the European project "Discover Real Everywhere Application of Mathematics" (DREAM) in the context of the European Program Erasmus+, which started in November 2017 and will last for 2 years. One of the aims of the program is to develop, implement and evaluate STEM learning activities using educational robotics.

2. THE EUROPEAN ERASMUS+ PROGRAM DREAM

2.1 The role of partners

The European Erasmus+ project DREAM is a partnership of educational organizations for supporting schools in addressing failure in mathematics using innovative learning methods, such as the use of educational robotics. The partnership involves four partners from three European countries: the schools a) "Constantin Diaconovici Loga" National College of Timişoara, Romania (*coordinator*), b) the "Agrupamento de Escolas Soares Basto", Portugal and c) our school, 1st General Lyceum of Aigio, Greece and the "University of Tibiscus", Timisoara from Romania. The relative percentages of mathematics failure in our countries are really disappointing, Romania 40,8%, Greece 35,69% and Portugal 24,91%. The partnership intends to develop applications and learning methodologies that will help reduce mathematics failure and at the same time methodological tools to measure and evaluate the results to be collected.

Typically, educational robotics is introduced to schools to support individual cognitive subjects such as science or technology, or in some cases to be used by students with special talents in construction, science or mathematics [AK09]. Within the DREAM program, educational robotics is introduced as a learning tool to involve students in problems that are meaningful to themselves and whose negotiation requires the use of concepts from mathematics and maybe other fields as well. The aim is to provide students with an attractive learning environment without fear of failure to gain self-confidence, social skills and interest in STEM, in order to reduce school failure first in mathematics and second in science. In the applications we develop, we use the robotic package LEGO MINDSTORMS Education EV3.

2.2 Research methodology

In order to answer the research question of the program, i.e. "if the use of robotics in STEM activities has reduced failure in mathematics", research tools have been developed by our school concerning both students and teachers. In particular, the participating students complete a questionnaire before and after the activities using a Likert five-step scale. Questions in the second questionnaire, although similar to those of the former, are formulated in a different way and aim to elicit answers about whether robotic activities improve their learning abilities and in which fields.

With regard to teachers, they are asked to complete four different research tools. Firstly, a questionnaire that detects the students' profile of their school performance, absences, difficulties encountered in learning, as well as the specific needs they may have. Secondly, a pre-post and post-activity questionnaire with the aim of collecting information on student behavior in learning, problem-solving skills, learning incentives and observed problems using the Likert five-digit scale of 1 (never) to 5 (always) about the frequency of behavior. Thirdly, a questionnaire at the end of each activity by teachers teaching the robotic activities using a Likert five-level scale of 0 (this behavior cannot be observed) to 4 (does more than expected) to evaluate learning behavior, motivation and problem-solving strategies. The statistical results presented below derive from this questionnaire and concern the participating students of our school. Finally, an open-ended questionnaire for the teachers who teach the activities at the end of each academic year, in which they freely express their thoughts on the whole process, the robotic activities and their application, the strengths and weaknesses in the design and implementation.

Our school participated in the first year of the DREAM project with five educational activities. The application period was 8 weeks (from 1/3/2016 to 29/4/2016). Ten teachers without or with little experience in robotics were trained in school (17-28 February 2016) to implement the activities. The methodology for selecting students was based on the definition of criteria, the expression of interest and finally thirty-two volunteer students in the 11th grade (2015-16) from the fields of Science and Humanitarian were selected (Table 1). Their average rating varies from 9.5 to 16. Additionally, most students had a large number of unjustified hourly absences (21-87) over a five-month period.

Table 1. Students and Teachers of 1st General Lyceum of Aigio at DREAM

Orientation	Students	Teachers
Science	20	7
Humanitarian	12	3

3. ROBOTICS ACTIVITIES IN DREAM

3.1 Learning process using educational robotics

Educational robotics can help students design, construct, plan, control and experiment with their own construction. Through this process, students can guide and control a physical entity through a user-friendly programming environment and they are able to construct their own meanings by observing the natural response of the robot. Lego Mindstorms robotic packages utilize a "black and white box" technology that enables students to implement and expand their ideas using ready-made components ([Kyn08]). One of the aspects of the learning process that is recognized as important is constructivism that can be defined as the learning by making process ([HP91]). From this point of view, the learning process and content are unified, since the concepts are integrated into the technological tool. Thus, it is possible to awaken the interest of students with significant learning outcomes ([D+12]).

3.2 Activities

The activities were designed by our school, they were carried out during the first year of the DREAM program and they were based on the Lego MINDSTORMS EV3 EDUCATION training platform. Each designed activity was based on two main pillars: (a) no prior knowledge in robotics is required; and (b) activities are practical.

3.2.1 Move forward 50 cm

The first activity requires students to calculate how many wheel rotation degrees are necessary to make the robot move forward 50 cm, then to make the robot move this distance and finally to calculate the speed of the robot during the motion.

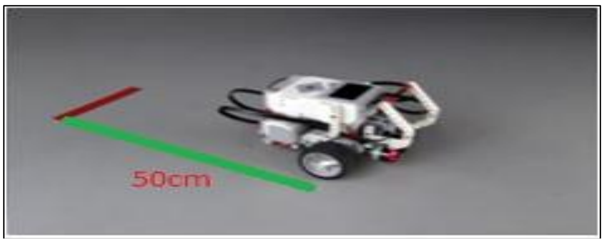

Figure 1. Activity “Move forward 50cm”

Upon completion of the activity, students are able to build a simple wheel robot and plan this basic move, using the mathematical formulae of circle-wheel circumference. They have to think that each time a robot wheel turns one rotation, the entire circumference of the wheel rolls along the ground. The diameter of the EV3 (Education version) rubber tire is about 5.6 cm so the circumference is 5.6 cm * π = 5.6 cm * 3.14 = 17.6 cm. To find the number of rotations necessary to move the robot forward 50 cm, they must divide 50 cm by the distance moved in each rotation of the wheel, which is equal to the circumference of the wheel, i.e. 17.6 cm. Having found the needed number of rotations, they can convert the number of rotations into the corresponding number of degrees by multiplying by 360. To calculate the speed of robot during the motion, students use the mathematical formulae of velocity = distance / time.

3.2.2 Complete on-spot rotation

In the second activity the robot has to make a full on-spot rotation, as show in Figure 2 below.

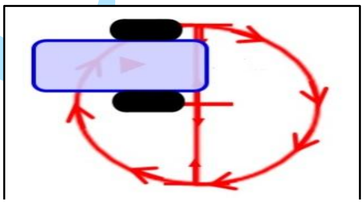

Figure 2. Activity “Complete on-spot rotation”

Upon completion of the activity, students are able to plan this basic move, using the mathematical formulae of circle-wheel circumference. They have to think that the robot should use only the left engine while the right engine will remain still. They must make a circle whose radius is the distance between the wheels. Based on the logic of the previous activity (move forward 50 cm) they can find how many degrees the left engine has to rotate to make a full circle.

3.2.3 Move along the hypotenuse of an orthogonal triangle

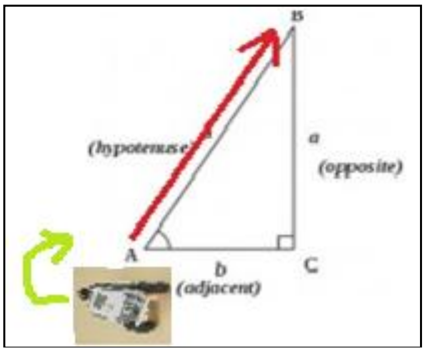

Figure 3. Activity “Move along the hypotenuse of an orthogonal triangle”

In this activity, the robot is assumed to have already moved along two perpendicular arms of an orthogonal triangle, each with length 25 cm. It is now to begin tracing the hypotenuse but it is not pointing in the right direction.
Students have to think that the robot should now turn slowly on the spot until the gyro sensor detects that the robot has turned 135°, which is the supplementary angle 180° – 45° and then the motors should be turned off. Then the robot should calculate the length of the hypotenuse using the Pythagorean Theorem. The calculation will be Hypotenuse length = adjacent arm length / cos(turn angle).
Then the robot should calculate the corresponding number of wheel rotations needed, given that the circumference of the standard Lego wheel is 17.6 cm. Finally, the robot will move in the correct direction and for the correct distance in order to trace out the hypotenuse of the triangle.
Upon completion of the activity, students are able to use gyroscope sensor to experiment with turns and plan precise turn movements. They must use the mathematical formulae of circle-wheel circumference, the Pythagorean Theorem and the concept of supplementary angle.

3.2.4 Draw Geometric Figures

In this activity, students must program the robot to trace:

1. an equilateral triangle
2. a square
3. a regular pentagon
4. a regular 100 - agon.

In any shape students must sign the vertices of shape, select the internal angles and the supplementary angles and determine their measures. They must read the value from gyro sensor and use it to compute the angle of robot's rotation.
Upon completion of the activity, students are able to use gyroscope sensor to experiment with turns and plan precise turn movements. In order to find the measure of angles, they should generalize the formula for the sum of angles in the regular n-gon. They can start with a pentagon and draw diagonals in it.

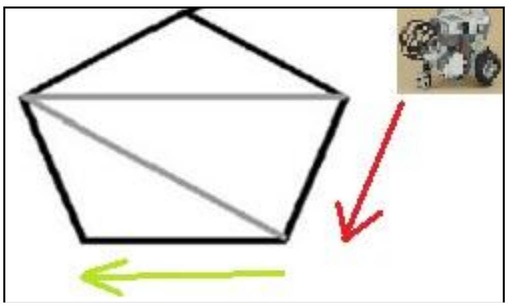

Figure 4. Activity "Draw a pentagon"

They can easily determine the sum of angles in a pentagon, because three triangles are regularly formed (180° · 3 = 540°). Then they can count the measure of one angle $\left(\frac{540}{5} = 108°\right)$ and the measure of supplementary angle to it (180° – 108° = 72°). In this way, they may observe that the measure of supplementary angle in arbitrary regular n-gons is $180 - \frac{180\cdot(n-2)}{n}$.
So, they will learn the method of generalizing known properties, i.e. how to determine the formula for the sum of angles in the regular n-agon. In this way, they will be able to program the robot to trace any regular polygon, like the 100-angle polygon asked in the activity.
As an extension of this activity, we may also offer students the option to understand and observe the concept of the limit. We may compute with our students the value of limit of the supplementary angle sequence $a_n = 180 - \frac{180\cdot(n-2)}{n}$. This way, students can understand that a regular polygon with an increasing number of sides approximates a circle.

3.2.5 Acceleration due to Gravity

Using the LEGO Mindstorms EV3 kit, an experimental apparatus is constructed that is used by students to measure the time it takes a free falling body to travel a specified distance (Figure 5). Students use a touch sensor or a light sensor, one motor and one LEGO Mindstorms EV3 brick, to measure the time of flight for the falling object, at different release heights. A robotic gripper holds the object and releases it upon receiving the operator command. When the object reaches the end-point of its travel, the touch or light sensor is triggered and the time of object's descent from release to impact at the touch or light sensor is recorded and displayed on the LEGO Mindstorms EV3 screen. Moreover, using several different release points, students calculate the corresponding average velocity of the falling object. Next, they plot a graph of average velocity versus time and apply a best fit line to this graph. Finally, students determine the slope of the best fit line, which is equal to (1/2)*g and compare it to the standard value of g (see Figure 5).
This lab activity reinforces for science: the concept of gravitational acceleration and an experimental method to determine this constant, compare it with the theoretical g and prove experimentally that objects with different weights will have the same acceleration in free fall. Students can realize that the g couldn't be measured accurately and reliably using clocks, because times less than 1 sec are difficult to measure with a clock and the synchronization of process "leave ball and count time" is also difficult.
This lab activity reinforces for mathematics: the

concept of the equation of the best fit line (y = mx + b) for the v / t relation and how to use Excel to draw this line, as well as the concept of line slope which coincides with the coefficient (m) of line equation and it is used for calculating g.

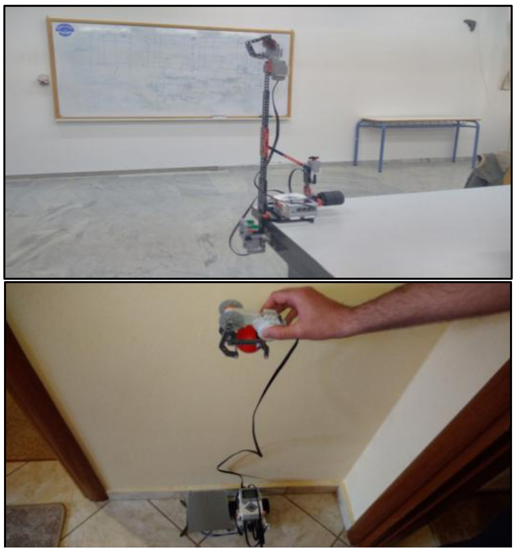

Figure 5. Activity "Acceleration due to gravity"

4. RESULTS OF DREAM

As the program is in progress, we have no final conclusions. However, for the first year of application, data from all the participating schools was collected and statistically processed. In this paper, we present some results for the first year of the program regarding the 32 students of our school. Results were collected through a structured questionnaire using a Likert 5-level scale from 0 (this behavior cannot be observed) to 4 (doing more than expected). This method provides a tool for detecting the progress of each student in specific areas, such as the ability to co-operate in small groups, to address problems and difficulties in the learning process, etc.

The following graphs, which came from teachers' answers to the above questionnaire, present data specific to three criteria than those surveyed: participation in groups, problem solving and adaptation to behavioral rules. The vertical axis of the graphs depicts the frequency of behavior while the horizontal axis depicts the correspondent behavior of the five robotic activities. Thus, in Figure 6, we see a high level of collaboration among team members in all five activities. In particular, in the "*Acceleration due to Gravity"* activity, the students showed even greater engagement and collaboration within the group. It is worth mentioning that the teams were formed at random and in some cases the members of the team had never worked in the past.

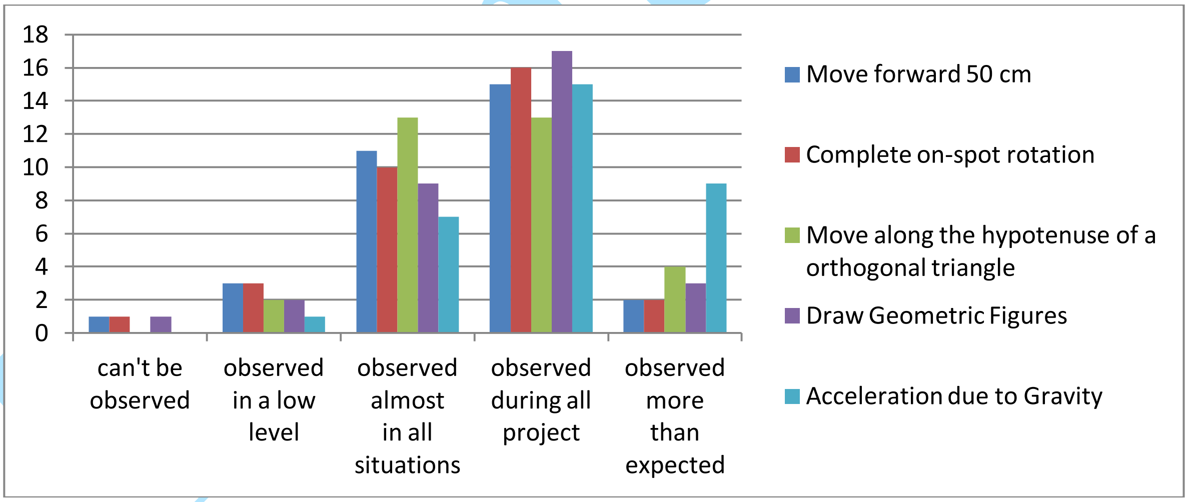

Figure 6. Group membership

An important area of investigation is also the students' interest in problem solving. The results show that in all activities there was increased interest in dealing with and solving problems (Figure 7). It is estimated that this is due to the design of activities that encourage students to solve basic mathematical problems based on practical applications. As a result, the students showed an improvement in their self-esteem and self-confidence, which prompted them to invest time and effort in problem solving procedures.

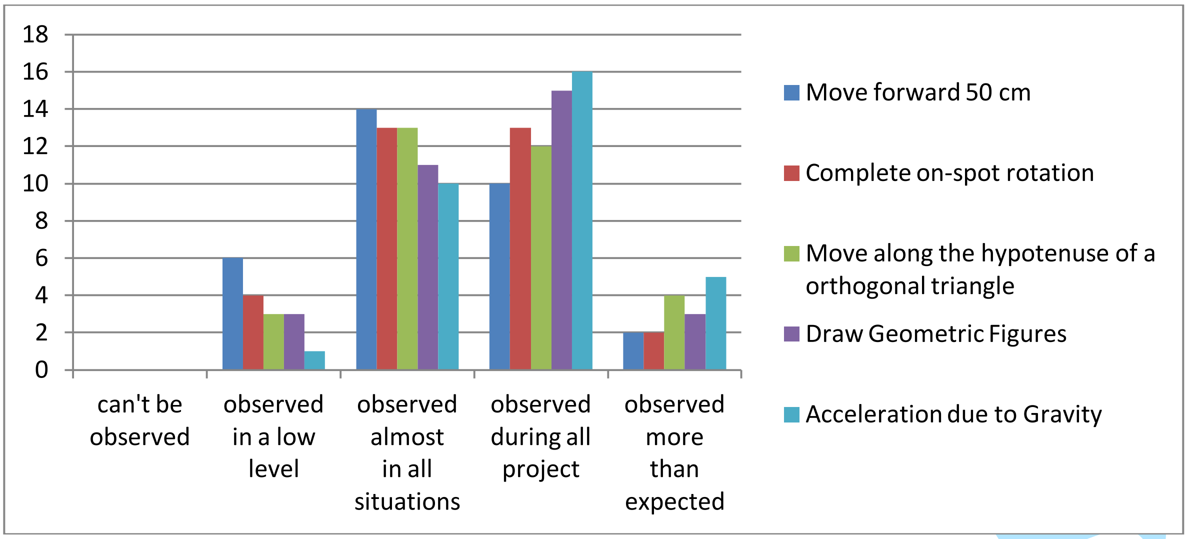

Figure 7. Problem solving

In addition, behavioral problems were investigated considering that students experiencing cognitive learning difficulties may also experience behavioral problems in the traditional class. In Figure 8, we see the results of adjusting students to class rules. In all cases, students showed positive behavior and followed the teacher's instructions and rules. This may have happened because the students were able to overcome their cognitive difficulties and successfully complete the activities.

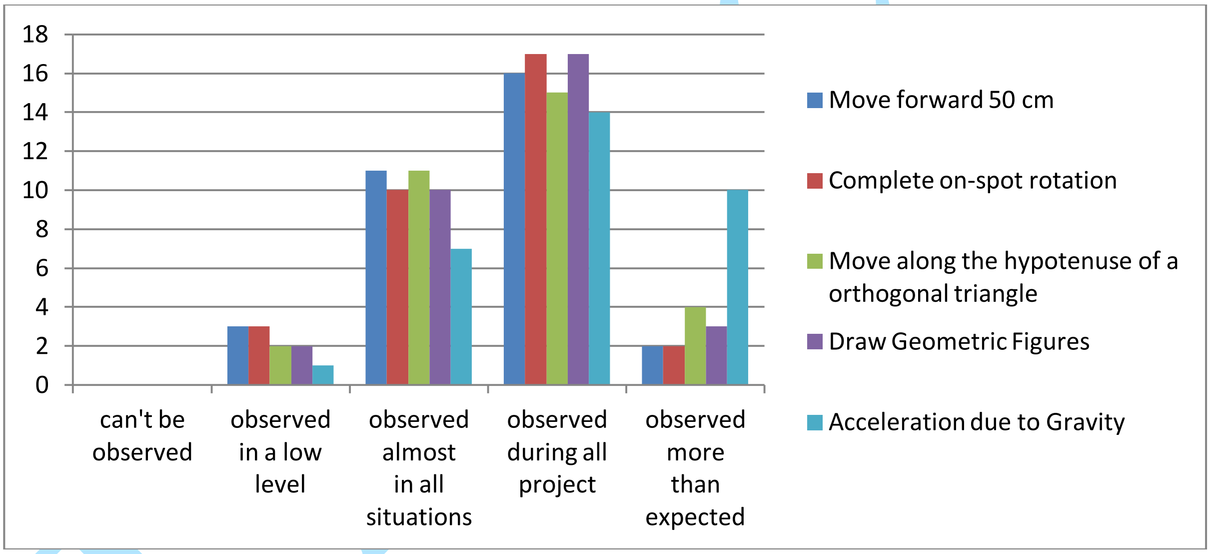

Figure 8. Adaptation to behavioral rules

5. DISCUSSION

STEM education using educational robotics through a constructional view of learning helps to change the orientation of the mathematics learning process in relation to the traditional classroom. Thus, the learning process becomes more interesting for students and with fewer cognitive difficulties. After eight weeks of engaging students in the DREAM program, we can conclude that they showed enthusiasm, high participation, willingness to work together, positive behavior and negotiation skills of the problems to be solved. Also, the positive feedback of the program is very important, according to teachers' responses. For the continuation of the program, focus will be on building new activities and scenarios in the context of a constructivism approach. In conclusion, the first year of the program was very positive and we hope that the second year will be constructive as well.

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