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ORIGINAL RESEARCH

Teacher Training in Educational Robotics: The ROBOESL Project Paradigm

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Abstract This paper presents the training curriculum for teachers developed in the context of the ERASMUS+ project, ROBOESL (2015–2017). The paper focuses on the robotics-based learning methodologies inspired by constructivism and project-based learning principles and implemented within the framework of the ROBOESL training and learning activities. The ROBOESL project (www.roboesl.eu) is an innovative one in educational robotics (ER) in the sense that it introduces ER as a learning tool for children at risk of school failure and early school leaving (ESL). The ambition of the project is to engage students at risk of school failure in an attractive learning environment that can rebuild confidence, self-esteem and social skills and eventually offer a pathway to further schooling. Based on the belief that the role of teachers is crucial for the success of this endeavor, we developed a training curriculum that aims in enabling teachers to master the technical and pedagogical skills that are necessary in order to use the robotic technologies in school, enrich their teaching and learning activities in classrooms with robotics and, finally, become able to develop their own robotics activities by using innovative, student-centered and constructivist pedagogical approaches with a focus on preventing school failure and ESL. The paper presents the main innovative characteristics of the training curriculum and concludes with exemplary training activities for teachers in the form of ready to use worksheets.

Keywords Educational robotics · Teacher training · Curriculum · ROBOESL project

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1 Introduction: Aim, Objectives and Target Group

Educational Robotics (ER) is a growing field with the potential to significantly impact the nature of science and technology education at all levels, from kindergarten to university (Alimisis 2013). The continuously growing interest in ER worldwide has enabled the creation of communities of researchers and educators across the E.U. and worldwide, the organisation of special scientific conferences e.g. EDUROBOTICS 2016 conference (http://edurobotics2016.edumotiva.eu/), ROBOESL 2016 and 2017 conferences (http://roboesl.eu/conference/), publications of special issues in scientific journals (Alimisis and Moro 2016), books (Alimisis et al. 2017) and more.

However, ER is often introduced in education from a narrow perspective implying that it is suitable only for science and technology majors or for gifted children (Alimisis 2013). Current societal developments call for a democratisation of opportunities to access learning with robotics and other cutting-edge technologies for every child, for every citizen. Being in line with this societal and educational trend, the ROBOESL project (Robotics-based learning interventions for preventing school failure and early school leaving, 2015–2017, www.roboesl.eu) introduced ER as a learning tool for children at risk of school failure and early school leaving (ESL) (Alimisi 2016; Daniela et al. 2017).

The contribution of the proposed robotics-based projects in the ROBOESL framework (Moro et al. 2018) was the creative and innovative use of robotics aiming in engaging students at risk of school failure/ESL in playful learning, providing an attractive extra-curricular learning environment free of any sense of fear for failure, rebuilding confidence, self-esteem and social skills and, finally, to providing a safe pathway into further schooling. Robotics projects are of unique educational value since they are carried out in the real world, using concrete tools and materials. In this sense, they are more beneficial to learners than schoolwork based on typical learning materials such as textbooks, blackboards and paper-and-pencil exercises. Finally, the ROBOESL project aspires to broaden students' thinking about what learning and schooling is and to motivate an alternative kind of exploratory learning that can support interest for schooling, foster self-confidence and promote a sense of well-being for students at risk of school failure and ESL.

Training teachers in educational robotics is always an important factor for the successful introduction of ER in school education (Alimisis 2009). The aim of teacher training is more than just building and programming robots. It is rather about enabling teachers to build on the educational benefits of robotics for providing a learning landscape that fosters curiosity, critical thinking, problem-solving and creativity for learners. The ROBOESL curriculum targets teachers that are non-experienced in educational robotics, with a focus on those who work with children at risk of school failure and early school leaving. The ROBOESL curriculum aims in enabling teachers to master the necessary technical and pedagogical skills for using the robotic technologies in school, to enrich their teaching and learning activities in the classroom with robotics and to enable them to develop their own robotics activities using innovative, student-centered and constructivist pedagogical approaches with a focus on preventing school failure and ESL.

The aim of the training curriculum is specified in the following main objectives:

- To provide a stepwise approach for a step-by-step acquisition of technical skills in using robotic technologies (hardware and software).
- To enable teachers to implement the robotics-based learning activities in their school, designed within the ROBOESL project's framework.

- To practice and adopt the same pedagogy (constructivism/constructionism) that teachers are encouraged to implement in their school.
- To develop projects and strategies of broader perspective, offer teachers multiple pathways for introducing robotics in schools, in order to engage young people with diverse interests and learning styles.
- To highlight that robotics benefits are appropriate for all children, especially those at risk of school failure or early school leaving.
- To offer a clear performance guide towards the trainees' achievement of expected outcomes helping trainees to understand the training context.
- To promote learning through the interaction of the trainees with the robotics technologies.
- To support self-directed actions allowing trainees to learn independently.
- To support the development of "real" training scenarios encouraging the engagement of the trainees in authentic problem-solving.
- To adjust training to the trainees' needs and interests by offering training tasks with various possibilities of advancing to different levels of difficulty depending on their interests and needs.
- Finally, to provide the methodology and tools for the overall evaluation of the training program.

2 Training Methodology

The methodology of the training curriculum is designed so as to support interdisciplinary robotics projects in schools. Drawing upon the well-known axiom that "*teachers teach as they are taught, not as they are told to teach*", the training curriculum aims in engaging teachers in the ideas underpinning the ROBOESL learning interventions, in the same way that they are expected to implement them in the classroom. The curriculum is based on the constructivist/constructionist pedagogy (Piaget 1974; Papert and Harel 1991) and the project-based learning approach as well as on details on how the deployment in the class can take place.

Project-based learning (PBL) is a teaching and learning methodology that engages learners in sustained, cooperative investigation and includes authentic content, authentic assessment, teacher's facilitation, explicit educational goals, collaborative learning and reflection. PBL is a model for classroom activities that shifts away from the classroom practices of short, isolated, teacher-centered lessons. PBL helps learning become more meaningful and useful to students by establishing connections to the life outside of the classroom, addressing real world problems and developing real world skills. PBL supports learners in developing a variety of skills, including the ability to work well with others, make thoughtful decisions, take initiative, solve problems, boost their self-directed learning skills and motivation for learning.

Thus, established principles of learning, such as motivation, relevance, practice, active and contextual learning, operate significantly in a PBL environment and to a much lesser extent in conventional curricula. In the classroom, PBL offers substantial opportunities for teachers to communicate and establish relationships with their students. Teachers are required to be ready to shift their role, based on modern didactic practices, and to become facilitators, scaffolders and co-learners.

The main principles behind the ROBOESL methodology include iterative and non-linear actions such as:

- Iterative design: learners design their artifacts and/or solutions to the problem at hand, make their own plans of action, check and revise them continuously according to the results they receive.
- Selection of tools: learners have access to the necessary tools for the project at hand and are free to make their own selection of tools to be used, depending on the needs of their projects.
- Making: making includes both building robotics artifacts and programming desired behaviors for robots.
- Playing: learners enjoy playing with robots, are curious to discover new things and are open to surprises and excitement when their projects take unpredictable pathways.
- Sharing: learners share their artifacts, ideas and solutions with peers and the community.

3 The ROBOESL Training Paradigm and Scaffolding Mechanisms

The projects proposed for teachers (and students) within the ROBOESL framework aim in integrating aspects of real, relevant and meaningful learning. The projects provide links to different subject/cognitive fields and to the real world, addressing problems that have personal relevance to the learners. To this end, authentic contexts and real life interdisciplinary scenarios are suggested, to create opportunities for engaging learning experiences. The learners can "engineer" or alter the proposed scenario; they can extend a scenario or design their own scenarios personalizing their robotic learning experiences. This will allow the learners to move towards a more self-directed approach and work on projects that are in line with their interests and needs.

The training curriculum incorporates some innovative scaffolding mechanisms such as:

- "*What if*" experimentations: for instance, when learners are programming their robots, they are encouraged to find out what happens if they change parameters in their program. In this way, learners are challenged to explore alternative solutions and explore in depth the underlying scientific concepts. An example from the "sunflower project" (Alimisi et al. 2017): what is the reaction of the robot if the light source approaches (or moves away from) the robot?
- *Active reflection* upon the task: during the execution of a task the learners are invited to stop execution, ask for feedback and take time for some reflection on their previous action.
- *Half-baked solutions*: the learners can seek more support while working on complex tasks. Supporting resources are available in the form of worksheets, examples of code and videos to guide the learners' engagement in robotic constructions and programming but without revealing solutions; the solutions are not given; only the path to the solution is scaffolded in a discrete way. For instance, in the "Let's play and dance" project [16] learners can see some parts of the solution. However, some values need adjustment and some missing blocks should be reasonably snapped together (Fig. 1).
- *Going beyond trial-and-error strategies*: Usually learners begin their problem-solving efforts using trial-and-error strategies that result in weak solutions and provide poor

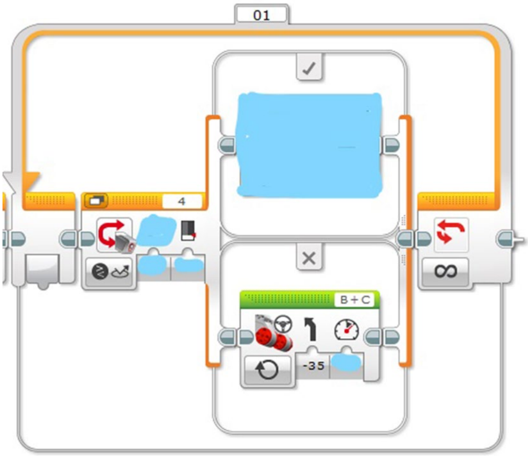


Fig. 1 The "half-baked" solution for making the robot following the black line

learning results. However, these trial-and-error practices might as well be a first necessary step to engage students in useful explorations within their robotics projects and offer good opportunities for teachers to gradually encourage students to progress beyond trial-and-error strategies and try out more rational approaches to problem solving that will be closer to the scientific methods. An example from the "desert scout" project (Alimisi et al. 2017): *Tryout the use of the "Move Steering" command to make the robot turn for the angle that is needed in order to move on the lines of the hexagon. (Later) Based on the results of your experimentations, try to discover with your group a mathematical solution to link the rotation of the motor with the turning angle of the robot.* Another example from the "Roborail" project (Alimisi et al. 2017): *What happens if the distance between the stations changes? Working again with the "trial and error" method takes time! Let's use some maths to make the train travel the distance between stations.* Some tips and figures follow, reminding that when the wheel rotates 360 degrees (1 full rotation) the robot travels $2\pi R$ distance ($R=$radius of the wheel).

- *Embodiment or "play the robot"*: Very often students use intuitively their own bodies to understand how to program a certain behavior for their robotic device. While students are trying a modelling strategy to reason about the problem, they should be encouraged to use either the available technological resources or their own bodies to simulate the desired behaviour of the robot. For instance, a learner's hand movement might be used to simulate the robot's movement; in this case, learners move their hands in the same way they would want to program the robot to move. This embodied activity might serve the learning purpose better than a movement of the robotic device itself and might scaffold the so-called "embodied cognition".
- *Triggering inductive reasoning*: while learners are instructing robots to execute successive tasks that build upon the previous ones, their reasoning and action moves from individual instances and specific observations to general statements, enabling the inference of a general law or principle. An example from the "desert scout" project (Alimisi et al. 2017): *What is the angle to turn each time to draw a triangle? If you get it right, the turtle will draw a closed triangle. Try it with your robot. What is the angle to turn each time to draw a square? Confirm this with your robot. Now what is the angle to turn each time to draw a hexagon?* The tasks may progress until the robot draws a

circle and all this may eventually result in the well-known “Turtle total trip theorem” formulated by S. Papert years ago; the robot/turtle will draw a closed figure with *n* sides when the sum of the angles turned is 360.

4 The Role of the Teacher

Teachers in educational robotics settings change their role to facilitators and enablers. ER projects require that learners themselves are active. This automatically shifts the teachers’ role from leading to supporting and scaffolding the learning process. Teachers are advised to try out the robotic curricula before bringing them in their class. However, their role is not to ensure that students solve problems and run projects in ways anticipated by the teachers, nor just to follow given steps in order to conclude to a predefined result. According to the constructivist theoretical framework, the teacher does not function as an intellectual “authority” that transfers set knowledge to students but rather acts as an organizer, coordinator and facilitator of the learning process itself.

The teacher’s role is to organize the learning environment, raise tasks/problems to be addressed, offer the necessary resources and support to boost students’ engagement in interdisciplinary projects. The teacher discreetly helps where and when necessary, encourages students to try out different ideas and solutions, inspires teamwork and establishes the evaluation of the activity in cooperation with the students. In some cases, students may be more skilled or experienced than the teacher, in a robotic technology; this should not be conceived as a threat for the teacher’s prestige or authority. Teachers can anticipate to feeling surprised and learn from their students; this in turn will encourage students to adopt a similar open and sincere learning ethos. Overall, the teacher ensures a playful, open, non-judgmental and collaborative classroom environment that fosters creativity and collaboration.

5 The Role of Students

Students in ROBOESL projects are seen as active learners, with a high need to explore, discuss and share experiences and ideas. Students fabricate “real things” (such as a robotic vehicle or a sunflower), program behaviors (such as car parking for vehicles or turning to the sunlight for sunflowers). When preparing a work with programmable robotic constructions, students are first encouraged to reflect on the problem that is addressed through the project. Discussions can take place within groups; then the groups supported by their teacher set up an action plan to solve the problem. The students work in groups to materialise the plan, taking into consideration the teacher’s feedback. Students may redefine the action plan following the experience gained during the preliminary work. They are invited to creatively synthesize the parts of the solution and reach conclusions regarding the problem under exploration. The final products and solutions of the groups are presented in the class, discussed and evaluated. Finally, the students are invited to reflect upon their work, express their views and record their experiences in a diary. Students should be allowed to spend some time playing with the robotic devices, walk around and collaborate with their classmates.

Compared to the typical learning results achieved by students within traditional school settings, this is a valuable learning process, allowing the development of teamwork, problem-solving, creativity, critical thinking and more of the so-called 21st century skills. Even if the development of these skills is not identified with the ranked test results and school marks still used in schools, they are important for the learners' personal development, their future in school and beyond school life.

6 Exemplary Training Activities for Teachers

The ROBOESL training activities start with the familiarization of teachers with the educational robotics hardware and software. Teachers and the teachers' trainers can use an engaging robotics project (e.g. follow the line) to give an immediate feeling of the potential inherent in robotic technologies. Then teachers can start familiarising themselves with the robotics kit and the programming environment that will be used in the training course (in the case of ROBOESL project this was Lego Mindstorms EV3 but similar approaches can be followed with other robotic technologies).

6.1 Indicative Training Activity on Learning Methodology: Commenting on Three Different Teaching Practices

A training activity for familiarization with learning methodology is introduced in the beginning of the course, aiming in triggering classroom discussions that will connect the lab activities to the learning theories behind Educational Robotics, with a focus on constructivism and constructionism. For instance, three different teaching practices for introducing first time robotics in class are presented: a teacher-guided approach, a semi-structured approach and an open one. Teachers elaborate on the three approaches and give their comments and preferences. The teachers' trainer takes the opportunity to trigger pedagogical discussions with teachers.

More specifically, teachers work in groups of 3–4 to elaborate the following topics/questions:

After your first experiences with educational robotics please comment on the following cases (10 min):

Three teachers introduce for the first time robotics in their class.

Teacher A starts with a presentation of the Lego Mindstorms kit together with the projection of slides that show in detail the content of the kit and demonstrates in front of the class how to make a first robotic construction.

Teacher B divides the class in groups of 3–4 students, provides a Lego Mindstorms kit to each group and a handbook with step-by-step instructions to build a robotic car.

Teacher C divides the class in groups of 3–4 students, provides a Lego Mindstorms kit to each group and then encourages and helps the students to explore the content of the kit and invites them to try out a first robotic construction of their own choice.

Comment on each of these three cases and identify strong and weak points for each case. Why do you think these are strong or weak points?

Which of the three practices you think would fit better for your students to follow in your class?

A plenary discussion follows where one representative from each group debriefs the answers of the group. The discussion closes with references to behaviorism, constructivism (Piaget), constructionism (Papert) and project-based learning. Relevant resources are suggested for further study.

6.2 Indicative Training Activity on Learning Methodology: Commenting a 5-Stages Methodology

A 5-stages constructivist methodology for doing robotics projects is introduced, intended to trigger discussions between trainer and teachers/trainees. This activity might come after the completion of a first robotics project with the aim to familiarize the trainees with constructivist/constructionist methodologies that can be deployed in their robotics projects and classes later on.

Teachers work in groups of 3–4 to elaborate the following topic/question (10 min):

> *Selecting the proper learning and teaching methodology is crucial for successful robotics activities in school classes. It is not enough to introduce robotics in class, technology alone cannot affect minds; robotics must be integrated in a well-designed learning methodology. Study the TERECoP project methodology that you may find at* www.terecop.eu*. Then discuss and comment on it with your group.*

A plenary discussion follows where one representative from each group debriefs the comments of the group. Relevant resources are suggested for further study.

6.3 Exemplary Robotics-Based Training Activities

Ten robotics projects have been developed in the framework of the ROBOESL project (Moro et al. 2017). Teachers and teachers' trainers can find (Alimisi et al. 2017) a worksheet for each of the ten robotics projects and can use them either during a teachers' training course or for their own self-training before they introduce the curricula in their class. They can also use the worksheets to support their students in executing the same projects in the classroom and are free to make changes and adjustments, if needed. Teachers are encouraged to use these projects and worksheets as an inspiration for creating their own projects, depending on their interests and needs.

In addition to the detailed technical descriptions and guidelines (Moro et al. 2017, 2018), the curriculum of each project provides:

- A real-life scenario: teachers may use this scenario (or come up with similar scenarios of their own) to put the robotics projects in a meaningful and authentic context for their students. The proposed scenarios are open enough to allow learners to imagine and develop their own variants. For instance, in the "desert scout", the project (Alimisi et al. 2017) starts as such: *for several years autonomous robots have been used as scouts instead of humans, in all the cases when the use of a machine was advised because of hard or even dangerous conditions. Write down with your group 3 examples where robots are used in missions dangerous for humans*.

  Other projects just set the context and call learners to formulate their own scenarios. For instance, the project "*To be or not to be*?" suggests: *Write with your group a short* *theatrical scenario where the robot plays an active role as a character of the theatrical play, either as a protagonist, a singer or an interlocutor. Come with your group on stage and play the theatrical scenario, including the role you envision for your robot to play!*

Scenarios promote interdisciplinary projects and touch important problems from the real world. For instance, the "*Wall-e project*" (Alimisi et al. 2017) introduces the following topic: *The modern world -and especially the densely populated areas- are dealing hard with waste management today and will do so even more in the future. Americans produce nearly 400 million tones of solid waste per year but recycle less than one third of it. Landfills are filling up so quickly that the UK may run out of landfill space by 2017! What is the role of consumerism in the human impact on the environment? Statistics indicate waste collection to be one of the most dangerous jobs. How can robots help with waste management? Discuss these questions first in your group and then be prepared to present your opinions in the plenary of the classroom. Can you devise a robot to collect garbage?*

- Pedagogical objectives that are divided into general and specific ones. The general ones refer to objectives usually included in robotics projects while the specific ones refer to objectives that should be achieved by the students upon successful implementation of the activities described in the specific curriculum.
- Suggestions for learning methodologies that exemplify the constructionist methodology and are tailored to the scenario introduced in each curriculum. Suggestions should not be considered by teachers as "cooking recipes" to follow step-by-step in the classroom but rather as ideas and recommendations on how to implement the robotics projects with their students, making their own choices according to their students' learning styles, needs and interests.
- Evaluation tools that provide a rubric for teachers and can be used to evaluate the students' achievements in each specific objective of the project. More evaluation tools used to measure the impact on students can be found in Daniela and Strods (2017).

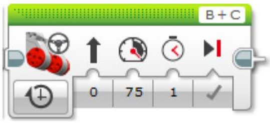
An indicative short worksheet for the "*RoboRail*" project follows, to exemplify the ROBOESL training methodology.

Scenario: Imagine a train travelling in a straight rail. The distance between two successive stations is the same. A train runs over this rail travelling at a constant speed on the track between two stations and stops for some time at each station before leaving again. When it reaches the end of the line, it waits a bit longer and then it comes back in a reverse way, towards the station of departure.

Your project:

1. Draw the rail with a straight line and some stations in the same distance, on a long sheet of paper and put it on the table or on the floor or put (directly on the table or on the floor) some sort pieces of tape in the same distance among them, to stand as stations.

2. Build a robot to emulate the train on the monorail. You will need a robot with 2 motors but no sensors. Each motor will drive one wheel. Add a ball caster at the rear to allow steering



3. Examine how the block Move Steering works

4. Exploration: Set the duration in seconds. How many seconds the train needs to travel from one station to the next?

Write your answer here: ………………………….

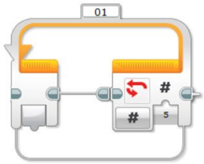
How did you find this answer? ……………………

5. The next step is to make the train wait for some seconds, after it has reached a station. The Wait block helps here.

6. Now make your train travel through the whole line, stopping at each station for a few seconds.

7. Can you think of a command that would help the set up of the previous programming task?

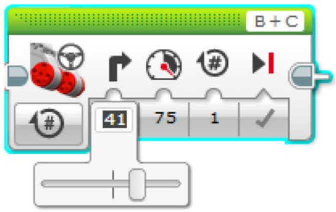
Write your idea here: ……………………



8. Here is the Loop block to repeat the motion as many times as you wish. You can insert your blocks inside one Loop block.

Make your train travel through the whole line, using the Loop block.

9. Now, make your robot reverse its direction towards the final station, experimenting with the steering block.



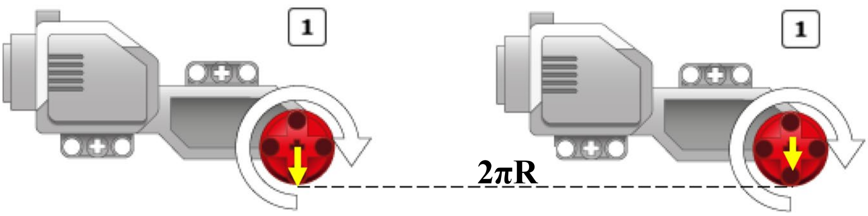
10. Finally, put all these tasks together: make your train travel through the entire rail, stopping at each station for a specific time, reverse direction at the final station and come back to the starting position, stopping again at each station for the same time.

11. What happens if the distance between the stations changes? Working again with the "trial and error" method takes time!

Let's use some maths to make the train travel the distance between stations.

Tip! In the Move Steering block, the 'duration' can also be typed in terms of rotations or degrees of the motor.

Remember! When the wheel rotates 360 degrees (1 full rotation) the robot travels 2πR distance (R=radius of the wheel).



Write here your solution: …………….

Check your solution; does it work?

7 Relevance to ESL and Concluding Remarks

The rationale behind this curriculum is the belief that school failure and ESL are symptoms of the traditional education system's inability to adapt to new educational realities. In line with this belief, our curriculum focuses on the heart of the schooling problem; that is the quality of the education offered to new generations.

According to the EU Council Recommendation (Official Journal of the European Union, C191/1, 2011), ESL prevention should contribute in avoiding the conditions favoring ESL by ensuring that intervention regarding emergency difficulties is early enough so as to prevent them from leading to ESL. Giving guidance to Member-States on how to tackle early school leaving suggests as important the introduction of "extra-curricular activities to raise self-esteem, motivation and resilience of young people at risk of leaving school early" and "better support for teachers".

Early school leaving is a long process of school disengagement closely connected to school failure, very often associated to the subjects of science, technology and mathematics. Taking advantage of the popularity of robotics among the younger generations and their excitement in playing with robotic toys, the ROBOESL curriculum tackles school disengagement in several ways:

First, encourages teachers to implement the suggested learning methodologies in a flexible way, tailored to the students' learning styles, needs and interests.

The projects are always based on real-life scenarios to provide a meaningful, authentic context for learning activities.

Offers opportunities for learners to work on hands-on activities that foster practical skills useful in their life and in demand by the labor market.

Provides learning experiences that promote the childrens' creative thinking, problem-solving skills and inventiveness.

Supports the personal development of students by encouraging teamwork and the enrichment of their communication and social skills.

Overall, the ROBOESL curriculum contributes to the support of teachers in developing encouraging, supportive, relevant and engaging learning environments that focus on the needs of the individual students, motivate their interest in schooling and encourage them in staying at school. Finally, in this project, the innovation we have in mind is to broaden the students' thinking about what learning and schooling is and to motivate an alternative type of exploratory learning that can favor the transformation of learning and schooling into a tool that fosters self-confidence and promotes a sense of well-being.

The full ROBOESL curriculum is freely available in English, Greek, Italian and Latvian (http://roboesl.eu/). Throughout 2017, parts of the curriculum have already been piloted in three pilot courses with 20 teachers in Athens, Riga and Genoa, concurrently with the development of the curriculum. The experiences that derived from the pilot phases helped to refine and adjust the curriculum to the teachers' needs and suggestions. Evaluation results have already been published showing good acceptance and satisfaction of trainees (http://roboesl.eu/). Furthermore, the three pilot training courses were followed by robotics activities in school classes, in all three participating countries where teachers had the opportunity to implement the ROBOESL learning approach with their students (aged 13–17). The evaluation of those learning activities in schools has shown that the ROBOESL paradigm had an important impact on the students' skills and attitudes (Daniela and Strods 2017). In addition to this, it is worth mentioning that some of the teachers -following their training- designed and developed a new robotics project for their students, implementing the ROBOESL paradigm in a flexible way and with different robotic technologies (Karkazis et al. 2018) which is in perfect line with our aspiration to enable teachers to act as designers and creators of their own robotics projects.

Future implementations of the ROBOESL curriculum are planned with further teachers' training courses that will hopefully provide additional feedback for further refinement and development of the curriculum.

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