

ROB-E – Swarm Robotics for Education in Circular Economy

Melanie Schranz

Lakeside Labs, Lakeside B04b, Klagenfurt, Austria, (mschranz@lakeside-labs.com) ORCID
[0000-0002-0714-6569](https://orcid.org/0000-0002-0714-6569)

Paul Amann

smart lab CARINTHIA der Fachhochschule Kärnten, Lakeside B12b, Klagenfurt, Austria,
(mp.amann@fh-kaernten.at)

Raphaela Egger

plasticpreneur® by doing circular gmbh, Viktor Kaplan-Straße 2, Wiener Neustadt, Austria,
(raphaela@plasticpreneur.com)


Sabrina Schifrer


Wunderwelten, Kranzmayerstraße 61c, Klagenfurt, Austria,
(wow.wunderwelten@gmail.com)

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Abstract

These days, climate change, robotics and artificial intelligence are discussed on the same level of interest. Our mission is bringing these topics into education: The paper presents the project ROB-E, which aims to pass social and technical skills to pupils of different age groups and school levels (primary and secondary school) in the research fields bionic, robotics, and swarm intelligence encompassing the application of circular economy and environmental protection. This leads to a workshop series that build on one another: After getting into circular-economy-related topics (incl. resource-friendly production, re-use and recycling), pupils design their own robots based on the circular design approach and bionic. They 3D print them with recycled PLA, assemble the individual (electronic) parts and program their robots as a swarm of cleaning robots to collect and sort garbage. Thus, they start an exciting journey with current cutting-edge topics applied on everyday life-situations of pupils.

1. Introduction

Inspired by the animated movie „WALL-E“ we created the project ROB-E: the movie tells the story from the robot called WALL-E that is left alone on a future, completely polluted Earth where no life can exist ([WALL•E | Trailer | Official Disney Pixar UK 2008](#)). Humans left the Earth while the job of the robot is to tidy up human’s garbage, piece by piece. Exactly this story brought an interdisciplinary team from multiple domains together: intelligent systems, robotics, bionics, smart production and circular economy are highly important fields that need to find their interrelation in the current situation of environmental pollution and climate change.

The team was created by the University of Applied Sciences Carinthia operating the Smart Lab1 that works with people in the fields of robotics, design and 3D printing. Lakeside Labs GmbH2 is a non-university research organization specialized in self-organizing networked systems. The company plasticpreneur by doing circular gmbh3 designs and produces small-scale machines for plastics recycling for daily use, and deals with awareness-raising projects related to circular economy. Additionally, the association Wunderwelten4 contributes with its knowledge in the field of cooperation, sustainability and social responsibility. The project is accompanied by „BIKO macht MINT5” that offers extracurricular infrastructure and pedagogical concepts for pupils in science and technology, and the “Mädchenzentrum6” that provides gender competences. Another connection among all project partners is the local cooperation in the Educational Lab7 of the Lakeside Science & Technology Park in Klagenfurt, Austria, that offers a research lab to investigate, develop and test new formats of education and training.

This paper gives insights to a workshop series developed by the partners to address the synergy among the cutting-edge interdisciplinary fields of future solutions for the challenges we face these days. Starting with the challenge of circular economy and the current expertise of the company partners, we design a workshop series together with research organizations to investigate and develop future approaches with pupils from primary and secondary school. For each workshop, we design and apply a specific framework with customized methods for the different school types.

This paper is organized as follows: After an overall overview of the ROB-E project and the participating organizations in Section 1, Section 2 provides more detailed information on the motivation for the entire workshop series, as well as the innovations behind the actual work. Section 3 presents the core of the paper and describes the individual workshops of the workshop series as well as additional instruments applied. Finally, Section 4 concludes the paper.

2. Motivation and Innovation

Generally, robotic systems show an increased trend in daily use (e.g., vacuum cleaning robots at home, robot arms in industrial production), or in education (e.g., Lego Mindstorms, Spiderino (Jdeed, Schranz und Elmenreich 2021)), nowadays. Nevertheless, understanding, designing, or even programming a robotic system still presents a general boundary for most of today’s society including digital natives8. This is also an upcoming issue in the continuous demand on STEM9-educated and enthusiastic employees. It is well known that the challenge to motivate students for technical studies needs to be taken already during compulsory

¹ smart lab Carinthia, <https://www.fh-kaernten.at/studium/villach/smart-lab-carinthia>

² Lakeside Labs GmbH, <https://www.lakeside-labs.com/>

³ Plasticpreneurs, <https://plasticpreneur.com/>

⁴ Wunderwelten, <http://www.wunderwelten.jetzt/>

⁵ BIKO macht MINT, <https://www.lakeside-scitec.com/educational-lab/module/biko-mach-mint/>

⁶ Mädchenzentrum Klagenfurt, <https://www.maedchenzentrum.at/>

⁷ Educational Lab, <https://www.lakeside-scitec.com/educational-lab/educational-lab/>

⁸ People especially youngsters who grew up in the digital world.

⁹ STEM (Science, Technology, Engineering, and Mathematics)

schooling (Jdeed, Schranz und Elmenreich 2021) where we additionally need to pay attention to gender-sensitive and diversity-aware access.

Self-efficacy and responsibility, for ourselves, others and the environment making this understandable to the participants is very important to us. At a time like this, people are needed who have the courage to initiate something, to start, to turn ideas into reality in order to have positive social and ecological effects worldwide. People who dare to rethink the economy and break new ground by using their talents and skills in new professional fields that aim to protect our world and work together on a more climate-friendly future. The ones that will need to better understand the interplay between cutting-edge technologies and environmental needs are future, curious young researchers. Thus, our mission is to awake the spirit of discovery and find first points of contact with pupils from the local region in primary and secondary schools.

One innovation of the presented workshop series is the inclusion of complex topics like swarm intelligence and thus, complex systems theory, that starts to be part of our daily lives (Schranz, et al. 2021). To mention a specific example, at the moment there is only one textbook available, called “Schwarmintelligenz” in German by Hamann (Hamann 2019) who adapted the knowledge of swarm intelligence for university students.

A second innovation is the interrelation of multiple disciplines that find their common means on the example of a swarm of robots that have the task to clean up our Earth. In a time where climate change is extremely important, the playful exploration and combination with cutting-edge technologies and innovative economic models enables the participants to immerse themselves and empathize with potential concepts for the world of the future. Because of the strong brain-hand connection, the rapid prototyping approach is practical and not just recorded theoretically. Due to the wide range of topics that come together in this project, long-term awareness can be created and skills such as self-efficacy and systemic thinking can be strengthened.

Additionally, the way in which the material of these complex topics is prepared for this workshop series in an applicable way for pupils from primary and secondary school brings a benefit for pedagogues. This material contains beside theoretical inputs also hands-on activities by means of toolkits. The toolkits show an extra innovation as it is produced from recyclable materials. It is developed in a way to let the pupils interact with it also after the workshop series. The files for 3D printing will be provided open-source.

3. Workshop Series

The program has following goals related to the pupils in the primary and secondary schools:

1. Sharing of social and technical knowledge and application-related abilities in the fields of bionic, robotics, 3D printing and swarm intelligence within the scope of circular economy and environmental protection.
2. Strengthen creativity: pupils will design their own robots, which are printed with recycled materials. Finally, the robots will cooperate in a swarm behavior of choice.
3. Participation of min. 150 pupils in the project (with a minimum of 50% girls), whereby a considerable proportion comes with an immigration background.
4. Performance of the workshop series at min. 5 schools in two cycles.
5. Getting familiar with the living environment of researchers via interviews and radio broadcasts in 17 podcasts.
6. Integration of parents to the project via information and dissemination events.
7. Involving testimonials from technical companies.

8. At least one excursion to partner companies during the project.
9. Preparation of the topics with image clips.

Project goals related to the pedagogues include:

1. Technical-scientific and gender-sensitive diversity-aware inputs and sharing of method concepts for pedagogues, to use and integrate these topics in the classes.
2. Dissemination of learning materials and toolkits for pupils in primary and secondary schools with the title “ROB-E – We clean up the Earth”.

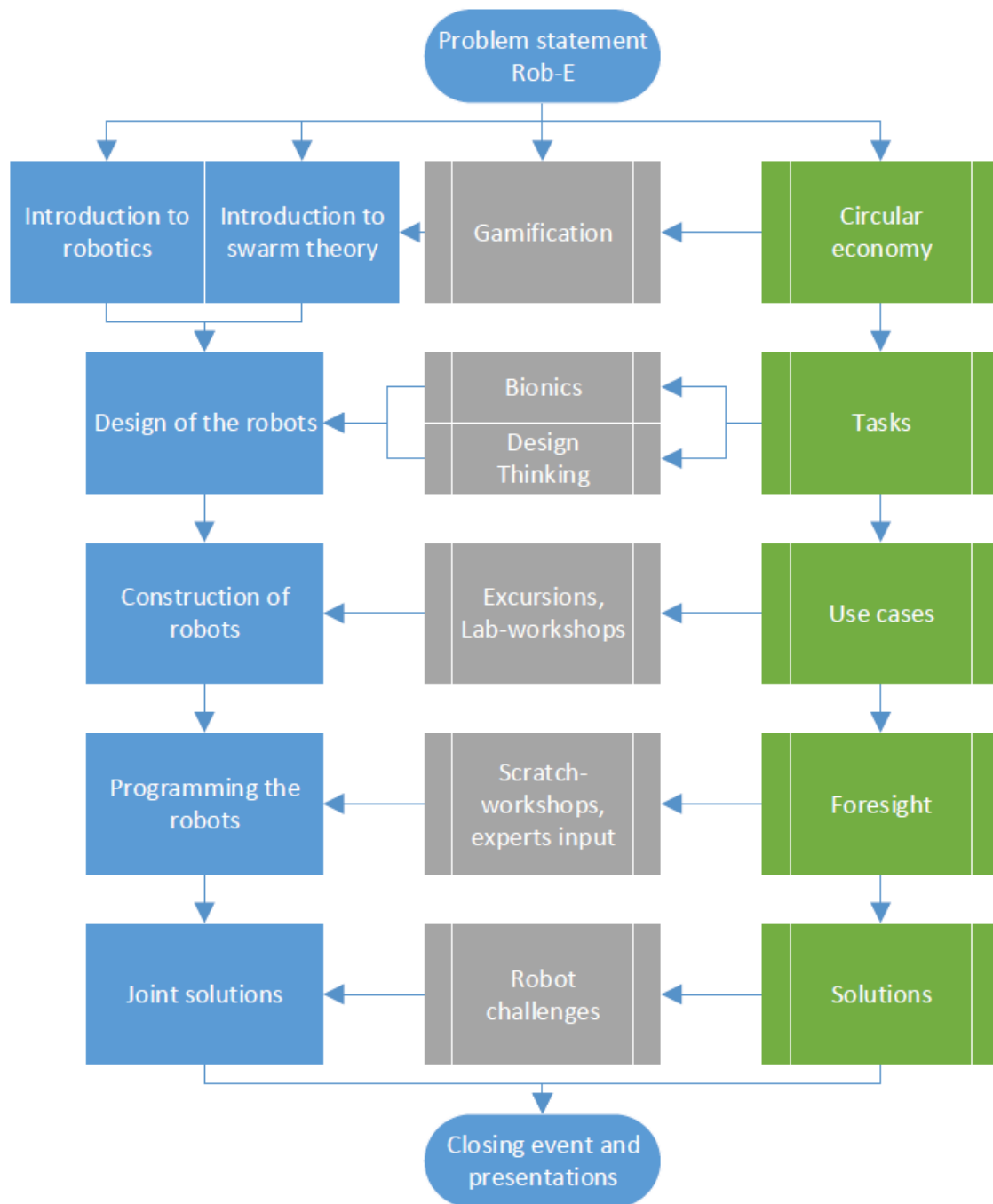


Figure 1: The key topics and the related methods to be used for the workshop series.

3.1. Project Setup

The workshop series is partitioned in six key topics and a set of methods to reach the goals in the topics. A general overview is provided in the form of a block diagram in [Figure 1](#).

The key topics include:

1. Capture the problems
2. Introduction to robotics and swarm intelligence
3. Designing the robots
4. Developing the robots
5. Programming the robots
6. Cross-linking the robots during a school event

These topics are built up by different pedagogical elements, such as gamification. Especially for pupils playful learning with educational games is of central interest. The reason is that a game creates enjoyment of activity and thus, ease in the learning experience. Furthermore, we foster problem-solving-oriented learning: Starting with the current environmental challenges, pupils learn how to solve problems and using new approaches to find solutions. Especially creativity is of high importance. Additionally, they learn from experts. The workshops will be given by experts in the field of swarm intelligence, bionic, robotics and circular economy. They prepare the contents for the workshops in a way that pupils in primary and secondary school can easily catch it. Experts will accompany the preparation process from education (BIKO). Moreover, they perform hands-on learning. The robots are designed and built by the pupils themselves. Finally, experimental learning plays an important role: The workshops are aligned and enriched with experiments.

For each workshop, we scheduled four school lessons each 45 minutes, 180 minutes in total. Regarding the timetable, Workshops started in January 2021 and will finish the workshop series at the end of the school year in 2022 (see [Figure 2](#)). Although schools need to implement several COVID measures (incl. people not belonging to the schools are not allowed to enter the buildings), we were already able to implement workshops remote as online session.

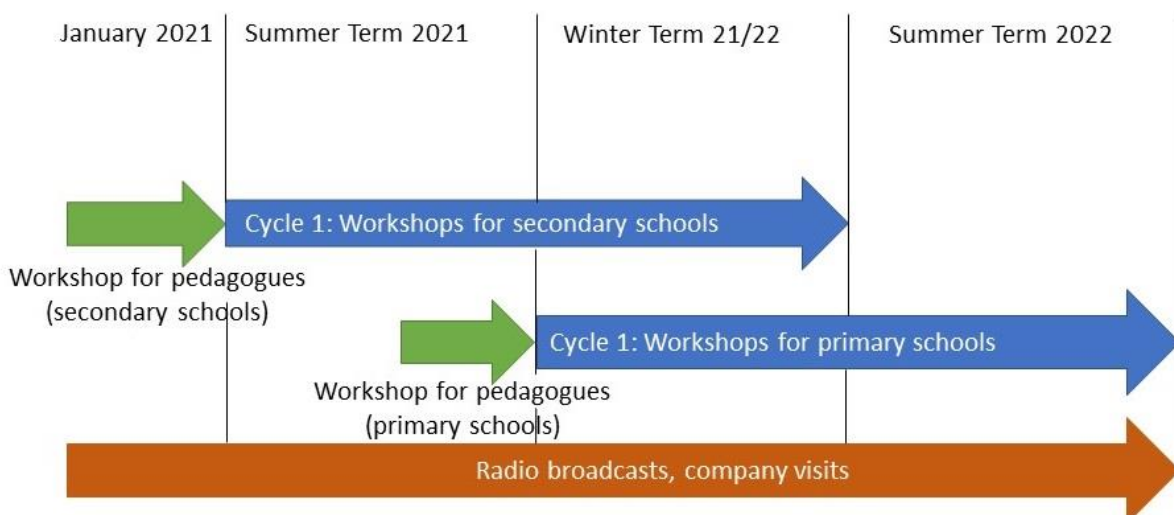


Figure 2: Diagramme of the timetable of the workshop series planned.

The pupils will be actively integrated in all phases of the workshop series. This especially includes their ideas for the design, development and programming of the robots. Individual needs can be considered any time, as well as linguistic and social boundaries that need to be

overcame, e.g.: due to migrant background. This is guaranteed due to two additional involved people for the workshop series beside the regular teacher.

3.1.1. Workshop for Pedagogues

Before the workshop series starts with the pupils, the teachers and pedagogues get an introductory workshop on the content and on pedagogical elements using so-called train the trainer elements. One main aspect is the question on how to demonstrate content from natural science in a gender-sensible and diversity-aware manner. This is done with hands-on experiments, creating understanding for the complexity of interrelation, co-learning and support also during the workshop-phase.

The pedagogues will also be present during the workshop series in class, get additional material to strengthen and deepen the discussed topics as follow-up or preparation material.

3.1.2. WS1: Presentation of the Problem

The aim of the first workshop is to dive into the topic and understand the challenge. Together with the participants, a journey into the story of Wall-E – the little hero who tries to put the world back to order – is undertaken. At the same time, empathy is promoted and awareness of the similarity between the film and our current situation is created.

The topics of climate, economy and the use of our planet's resources are explored interactively, gamified in co-creation, and related to one another. We look beyond national borders into other countries, their waste management systems and countries without functioning waste management (Figure 3 will be used as inspiration). Prejudices are thrown overboard and critical and solution-oriented thinking (and acting) are trained and encouraged.

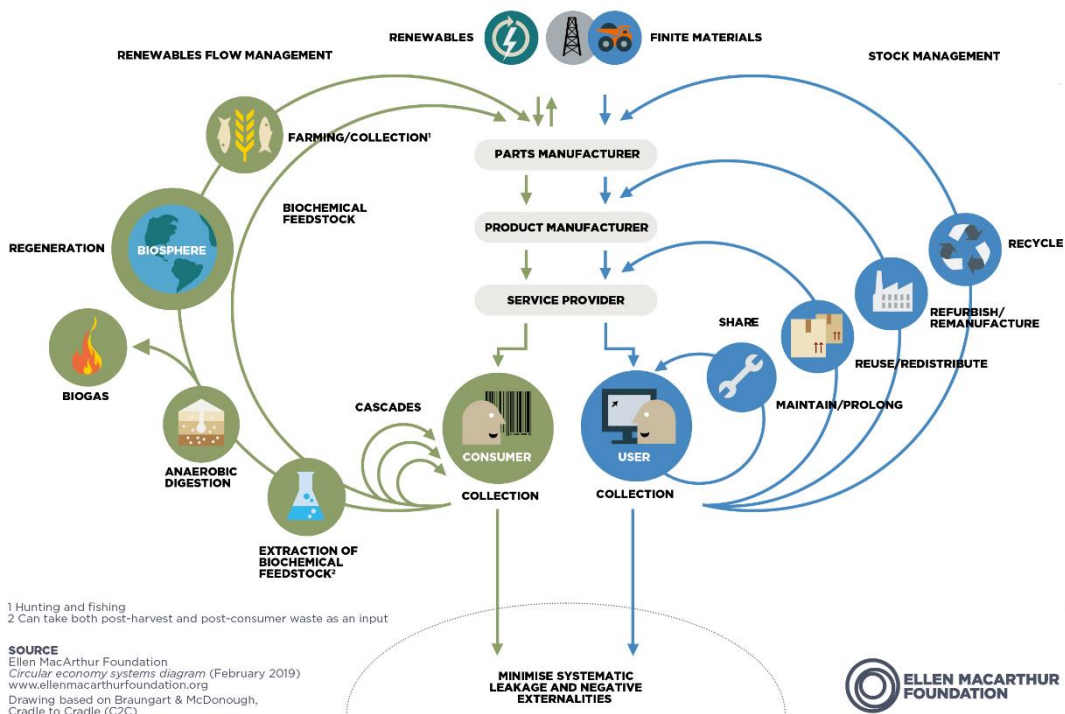


Figure 3: Circular economy systems diagram by Ellen Mac Arthur Foundation. <https://ellenmacarthurfoundation.org/circular-economy-diagram>

Circular economy as a solution approach for the economy of today and tomorrow is an essential part of the first workshop and serves with its components (including reuse, remanufacture, refurbishment, recycling) as the basis for the further workshops.

3.1.3. WS2: Introduction to Robotics and Swarm Theory

This workshop consists of three parts, one rather theoretical and two practical ones: In the first part we talk about swarm intelligence, the main characteristics and current projects we are working on. Furthermore, we encourage young researchers to work in a robotics and research environment, where the employment opportunities are very diverse. The topics comprise programming, robotics, computer science, physics, mathematics, self-organization and many more. Nevertheless, in such a team, the core competence is teamwork, as everybody can be a real specialist in only one topic, but not in all of them. With the example of Lakeside Labs, we additionally show the gender diversity and especially motivate young women for an employment as “real” researchers, project leaders or CEOs.

After the presentation, we start with two hands-on parts:

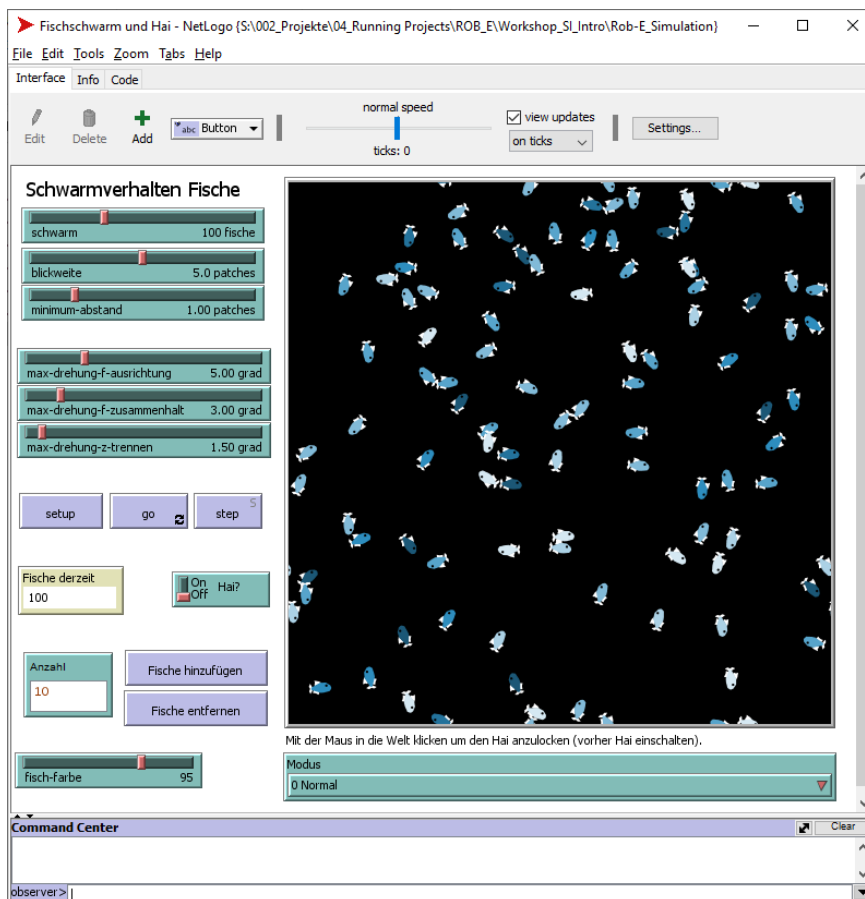


Figure 4: Simulation environment NetLogo to simulate a swarm of fish.

1. Simulation in NetLogo: Not just listening to a presentation, but hands-on experiments allow to experiencing swarm intelligence and its characteristics. This is done with the agent-based simulation environment NetLogo (Tisue und Wilensky 2004) that simulates a swarm of fish each following three local rules that lead to an emergent, swarm intelligent behavior according to the BOIDs model (Reynolds 1987): alignment, separation, cohesion (see Figure 4, user interface of the model in German). The pupils in the school get task sheets to experiment with the simulation model. This includes answering questions on, e.g., what happens if you

add or delete fish, if you change the intensity of the local rules or if a shark enters the scene and disturbs the swarm behavior.

2. Experiment with LEGO WeDo 2.0: To explore the subject of robotics from a practical point of view "LEGO Education WeDo 2.0" ([LEGO Education WeDo 2.0 Computational Thinking Teacher`s Guide 2017](#)) learning set is used for initial experiments. It consists of a Bluetooth hub, a motor, various sensors and the usual LEGO bricks, with which simple robots can be built. The instructions as well as the programming of the robots are carried out on a tablet. After a guided exercise, the participants are given the task of building an individual car. The workshop concludes with a short competition in which the cars of the participants compete against each other (see [Figure 5](#)).

With these first exercises, the "computational thinking" is promoted, which is required for the following workshops.



Figure 5: Car competition with LEGO WeDo 2.0

3.1.4. WS3: Design of Robots

The robots will be designed in the third workshop. After a brief review of the previous workshops and their results, keynote speeches will be given on the topics of circular design, bionic and design processes – such as “empathize – define – ideate – prototype – test” are used, in order to inspire and support the participants for the next steps.

The essential questions are asked (among others): What garbage should the robots collect? Where is this rubbish? Which adaptations does the basic robot body need to collect the garbage? Which energy source do the robots use? How can you prevent people or animals from being harmed in the process? Etc.

These are important questions that each of the small teams must ask themselves in order to be able to generate ideas and create prototypes. The prototyping takes place in the "rapid prototyping approach" – hands-on with scissors, pen, paper, glue and much more, robot parts

are tinkered – created from a large number of provided materials such as cardboard, clay, cord, wood etc.

3.1.5. WS4: Building the Robots

After dealing with possible designs of the robot in WS3, the robot will be built in this workshop (find all tasks listed in Table 1). The structure of ROB-E is divided into a basic module and individually designed extension modules. The basic module of the robot is 3D printed in advance so that it can be assembled in this workshop. Except for small soldering work on the geared motors, the parts of the robots are only plugged in or screwed on.

After completing the basic module, the students have the task of implementing the design ideas from WS3 into additional modules for the robot. To produce the additional modules, students are introduced to the world of additive manufacturing in a simple way. The first step for 3D printing is to generate 3D models from the individual ideas of the students. Good experiences were made with the program tinkercad (Tinkercad, n. d.), with which schoolchildren can create simple 3D models in a short time. Finally, the extensions are printed out with FDM 3D printers and attached to the basic module.

Table 1: Tasks to build the robots.

Task	Content
1	Explanation of the tasks of the individual components
2	Assembling the basic model
2.1	Solder the cables to the gear motors
2.2	Screw the gear motors to the chassis
2.3	Screw the battery holder, microcontroller, sensor and servo to the body
2.4	Screw the chassis to the body and connect the cables
3	Brief introduction to 3D-printing
4	Introduction to the CAD software tinkercad
5	3D design and 3D printing of the extensions

3.1.6. WS5: Programming of Robots

After the robots were individually designed and built by the pupils, the pupils will start to program them (find all tasks listed in Table 2). The main idea is not to give a profound programming course, but rather on a learning-by-doing principle. This reduces possible boundaries related to unfounded fears related to the complexity in technology and introduces a motivation that shows the pupils what is possible in a short amount of time. We already made positive experience with workshops that we did with the swarm robotic platform Spiderino (see Jdeed et al. (Jdeed, Schranz und Elmenreich 2021) for more details).

The robot uses the microcontroller, an ultrasonic sensor and several proximity sensors. For the programming, a bridge to the Arduino Studio was built: this allows an easy microcontroller access for pupils. Additionally to that, pupils get several pre-defined functions that can be re-used for their purposes. This workshop includes following schedule:

Table 2: Tasks to program the robots.

Task	Content
1	Recap on swarm intelligence and introduction to swarm robotics specifically.
2	The robot should be able to move forward for 2 seconds, stand still and move back for two seconds (repeatedly).
3	The ultrasonic sensor measures the distance from the top of the robot. As soon as the robot is too close to a wall, it is able to return.
4	The shovel uses another motor that needs to be controlled. It can go down when it finds garbage, picks it up and transports it back.
5	With the communication module the robots can exchange messages and inform each other, where the garbage is.

3.1.7. Cooperation Day

The workshop series will be concluded with a final event. At this event, as far as the current COVID measures will allow, the pupils from different schools, their teachers and parents, will jointly celebrate the outcome of the workshop series. The designed and developed robots will be connected and compete against each other in a cooperative cleaning-up task. This will show which school class was able to build the most successful swarm behavior. Beside this, the importance of topics in climate change, circular economy and the importance of getting inspired by nature will be emphasized.

3.2. Additional Instruments

To make the project successful we have additional instruments that help to strengthen the impact. Schools have the possibility to visit partner companies and record radio shows. We further have an evaluation of every workshop that leads to a quality assurance of the whole project. In addition, a local video production company produces complementary videos.

3.2.1. Company Visits

The pupils and their teachers get to know research organizations and research-oriented companies in Carinthia. Beside the workshops, these visits also bridge the path to real-world employment of the topics worked on during the workshop series. These companies are selected to show an initial impression of job profiles and career opportunities.

3.2.2. Radio Broadcast & Video Production

Pupils will make interviews with experts from swarm intelligence, robotics, bionics and design using interview methods to set up a radio show of 45 minutes. This initiative is supported by the local radio station Agora, which brings the shows not only terrestrial, but also in the podcasts “Unsere Wunderwelten”¹⁰ and “Kooperationskultur Kärnten/Koroška”¹¹. On the one hand, this is an extraordinary dissemination instrument to inform the general public about the project. On the other hand, the barrier between pupils and researchers is reduced. In total, we will organize 17 radio broadcasts.

¹⁰ Unsere Wunderwelten, <https://www.agora.at/sendungen-oddaje/detail/which/unsere-wunderwelten/>

¹¹ Kooperationskultur Kärnten /Koroška: <https://www.agora.at/sendungen-oddaje/detail/which/kooperationskultur-kaernten-i-koroka>

During the project time there are four videos produced that help to disseminate the main topics of Bionic, Swarm-Intelligence (already available online¹²) and Circular Economy. In addition, one basic information video about the cooperation will be produced that is used for dissemination purposes.

3.2.3. Evaluation

The entire workshop series is accompanied with a continuous evaluation of the pupils. This is achieved via continuous observation of a second person, an evaluator, on-site during workshop execution, and written consultation of the pupils using evaluation sheets. This feedback is directly included in the next workshop, but especially in the preparation and adaption of the teaching material.

The evaluation sheet for the pupils include the following questions:

- What is the overall impression of the workshop? (choice between really good, good, ok, bad)
- The topic is of interest to me. (marking a bar between “a lot” and “not much”)
- I learned something new. (marking a bar between “a lot” and “not much”)
- How was the video streaming working? (choice between really good, good, ok, bad) – (This question is just for online events).
- What I would like to have different the next time? (open text box)

The evaluation sheet of the evaluator includes these points to be rated (always choice between good, good, satisfactory, sufficient, and not sufficient):

- The technical implementation (video broadcast quality, understandability)
- Structure of the workshop
- Understandability of slides
- Expertise of the presenter
- General quality of the workshop
- Consideration of gender-specific themes
- How to improve the workshop? (question with open text box)

As the ROB-E project is still ongoing, including delays due to the COVID-19 measures that prohibit us to visit the schools from time to time, we will inform the reader with an upcoming publication at the end of the project.

Conclusion

Education in STEM subjects is of high importance and motivated employees are much in demand. Additional challenges, like climate change and sustainability form the requirement on the ability of combining multiple topics and fields of interest. Therefore, we present in this paper ROB-E, a school project where pupils learn with gamification, hands-on learning and experts from the field to combine and work on circular economy, swarm intelligence and robotics. The designed workshop series is and will be carried out by different school types (primary and secondary school), while evaluating the entire program and provide additional dissemination activities (including radio broadcasts).

¹² Was ist Schwarmintelligenz?, Lakeside Labs, <https://www.youtube.com/watch?v=SOs0c9aW44s>

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