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Klomp, M.; Araffa, K.; Saunders-Smits, G. N.

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MIRTE: an affordable, open, mobile robot education platform

M. Klomp
Cognitive Robotics, Mechanical Engineering, Delft University of Technology
Delft, The Netherlands
0009-0000-3126-762X

K. Araffa
Cognitive Robotics, Mechanical Engineering, Delft University of Technology
Delft, The Netherlands
0000-0001-7804-2217

G.N. Saunders-Smits[1]
Cognitive Robotics, Mechanical Engineering, Delft University of Technology
Delft, The Netherlands
0000-0002-2905-864X

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ABSTRACT

With robots becoming an increasingly constant feature in daily life, we must prepare and educate current and future generations. Although robotics outreach and robotics education are not new in engineering education, many educators and outreach providers face the same hurdles when using educational robots: Educational robots are expensive to buy, can become obsolete quickly and are time-consuming to maintain. In addition, many people feel unequipped to select the right robot for their purpose. This paper describes the development and implementation of a family of modular, affordable, open educational resource, mobile robots called MIRTE, that can be implemented across the entire educational spectrum and how continuity of the robots is ensured by following the principles of Open Education and Open Science. In the paper, current educational implementations are highlighted and plans for future developments and future research are discussed.

[1]*G.N. Saunders-Smits*
G.N.Saunders@tudelft.nl

1 INTRODUCTION

Robots are becoming a common occurrence in our society, with the use of robots no longer limited to industrial and medical applications but also as everyday appliances ranging from self-driving cars to robot vacuum cleaners. This will affect how we live and work in the not-so-distant future. Therefore, we must prepare and educate current and future generations for a life in which interacting with robots is commonplace. Using robots in education is not new. These days, courses in robotics at various levels of complexity, are common practice in most bachelor programmes in engineering. There is also an increasing trend towards dedicated bachelor, master and PhD programmes in robotics worldwide (Tilbury and Xiao 2023). In addition, many secondary schools have been using educational robots as a focal point for years as part of their science and technology curriculum (Evripidrou et al. 2020) as do many STEM outreach programmes aimed at the K-12 audience, such as First Lego League and RoboCup Junior (Eguchi 2016). All these programmes and initiatives face the same hurdles when using robots in their education and outreach: buying and maintaining robots in education is expensive and time-consuming and teachers often feel unequipped to select the right robot for their purpose.

In this paper, we will present an innovative, open-source, open-hardware, open-education mobile robot platform family for implementation in all levels of education which also can serve as an innovation and research platform for industry and research institutes.

1.1 Challenges of current robots used in education

Typically, three types of robots can be identified: fixed-base manipulators, as often seen in medical and industrial applications and two types of mobile robots: the legged robots, such as Boston Dynamics Spot and the rolling mobile robots, such as a robot vacuum cleaner, using tracks or wheels to move around with various levels of autonomy and self-learning capabilities. For education purposes, rolling mobile robots are used most frequently. Generally, educators across the entire education spectrum face several challenges when using robots in education:

1. Educational robots are not cheap, ranging from €100 - €600 per unit, with typically one robot needed per 2 – 8 students for meaningful engagement.
2. Robots become obsolete quickly, either because the manufacturer ceases to exist or because they cease support for the robot or its operating system. The latter is the case with the LEGO Mindstorms robots.
3. Robots are often only used a few hours per week during a few weeks per year, making robots an expensive investment for education (Arvin et al. 2019).
4. Many robot platforms are only aimed at one education level, for instance, only primary education. Few platforms offer flexibility across the educational spectrum and making the step to a more complex robot is an (unsurmountable) big step.
5. The educational focus of many robots is only on programming the robot. The robot itself comes as a finished product with LEGO Mindstorms and mBot being the most well-known exceptions.
6. Many robots are incompatible with standard components or other platforms, limiting possibilities and leading to educators being locked into one supplier (See Table 1).

It is therefore not surprising that many schools have outdated robots or are less keen to invest in yet another new robot, aside from the sustainability issues of schools having to keep purchasing new equipment.

Table 1. Comparison of a selection of low-cost mobile robot platforms for education (HW =Hardware, SW = Software, ★ = Supports ROS 1 and 2)

Robot	Cost (€)	Open Source (HW/SW)	Last OEM update	Easily available	Intended for use in			3rd party compatible (HW/ SW)	Visual Program.	ROS compatible
					Primary Education	Second.& Higher Educ.	Research			
Edison	660	✗	2023	✗	✓	✗	✗	✗	✓	✗
Europa II	120	HW/SW	2020	✓	✗	✓	✓	✓	✗	✓
mBot	79	SW	2023	✓	✓	✗	✗	✓	✓	✗
Thymio	195	SW	2023	✗	✓	✗	✗	✗	✓	✓
MARRtino	220	HW/SW	2022	✓	✗	✓	✓	✓	✗	✓
JetBot	250	HW/SW	2023	✓	✗	✓	✓	✓	✗	★
JetRacer AI Kit	234	SW	2023	✓	✗	✓	✓	✓	✗	★
PHeeno	27	HW/SW	2020	✗	✗	✓	✓	✓	✗	★
Duckiebot	370	HW/SW	2022	✓	✗	✓	✓	✓	✗	✓
Robobo	400	SW	2022	✓	✓	✓	✗	✗	✓	✓
LEGO EV3	500	SW	2023	✗	✓	✓	✗	✗	✓	✗
Koala 2.5	526	✗	2016	✗	✗	✓	✗	✗	✗	✗
Turtlebot 3 (burger)	650	HW/SW	2021	✗	✗	✓	✓	✓	✗	✓
Linorobot (2WD)	100	HW/SW	2018	✓	✗	✓	✓	✓	✗	✓
Mona	120	HW/SW	2019	✗	✗	✓	✗	✗	✗	✗
MIRTE Pioneer	**100**	**HW/SW**	**2024**	✓	✓	✓	✓	✓	✓	★

1.2 Introducing MIRTE

Frustrated with these challenges, in 2019, the first author, a lecturer in Mechanical Engineering at TU Delft set out to develop an affordable mobile robot platform, inspired by the One-Laptop-Per-Child initiative (Ames 2019) so that all children should have access to a robot, that like them, evolves in its capabilities as children become older. The aim of creating such a robot was to enable all levels of students to practice robotics making optimal use of the principles of Open Science to reduce cost and avoid the threat of obsoletion. This resulted in the development of MIRTE, which stands for: "*MIRTE, an Inspiring Robot for Technology Education".* In the remainder of this paper, we will present MIRTE, its features and capabilities and share our experiences in using MIRTE in education and its non-anticipated use for research and development purposes.

2 DESIGN PRINCIPLES BEHIND MIRTE

The first author's primary goal was to create an affordable robot that would last during the entire time any child anywhere spends in their formal education and that the robot itself would always be able to work, developing on par with the developments in the field of robotics and not be hindered by proprietary limitations. This gave rise to two main frameworks guiding the design:

Educational Framework: the robot must fit within the existing educational frameworks. Hence, in line with TU Delft's vision of education, the framework of Biesta (2021) was chosen which is based on the principles of *qualification* (foundational STEM knowledge at the appropriate level), *socialisation* (being able to think critically across cultural and societal contexts by working together in diverse classrooms) and *subjectification* (teaching students to take responsibility for their choices). The Biesta framework is designed for primary, secondary, and higher education and allows for continuous challenging of learners at their level.

Open Science Framework: To keep the cost of the robot to a minimum and to ensure the robot and its operating software would never become obsolete or that users run into limitations due to proprietary issues an Open Source approach was chosen. All software used in the robot is open source and will be made available through GitHub allowing others to contribute and continue development even if the initial creators are no longer involved. In line with that, all educational resources developed for the robot should be free and shared as much as possible as Open Educational Resources (OER). An Open Hardware approach must be used for hardware: no proprietary hardware was to be used and as few custom parts as possible. All components should be generic off-the-shelf components and any custom parts should be producible locally by a user. Using these principles, the cost can be kept at an absolute minimum and the robot will be as accessible, modular, and as inclusive as possible.

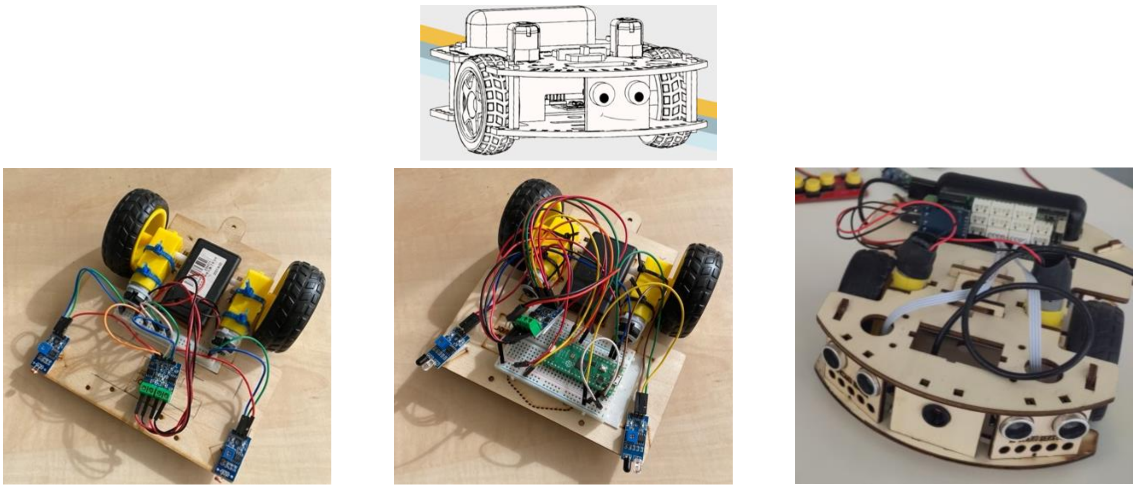
3 MIRTE ROBOT FAMILY

Following these principles, a family of affordable robots was created using an onion analogy, which allows the consumer of the onion to peel away a layer at a time (Fig.1). With each layer being removed, the next, more complex layer of technology is revealed underneath, allowing the learner to be challenged in deepening levels of education, delving deeper into the robot with increasing levels of hardware, the operating software and its complexity. This has resulted in an initial MIRTE family of three. In increasing order of hardware complexity and educational and software challenges, they are the MIRTE Light (Fig. 2a), the MIRTE Basic (Fig. 2b), and the MIRTE Pioneer (Fig. 2c).

Fig. 1. MIRTE's Onion Approach (blue = software, red = electronics, yellow = mechanical/design)

3.1 Design Features

All MIRTEs (https://www.mirte.org) share a common hardware basis consisting of a (wooden) chassis, wheels, motors, battery pack, and light sensor which allows users to add more hardware depending on their needs (modularity) and are powered by a standard 5V power bank. The base is not an off-the-shelf product, instead, we provide the DXF, STL, and FreeCAD files for people to make their own. Alternatively, they can use an existing or custom base. For the MIRTE Pioneer, we developed a dedicated PCB as an alternative to the Open Hardware solution of a breadboard combined with an MB102 Micro USB Interface Breadboard Power Supply Module and a splitter cable. More details on MIRTE's hardware options can be found in the MIRTE Docs (https://docs.mirte.org). In addition, a variety of sensors can be added to the robot, depending on needs and budget. The MIRTE chassis is partially compatible with LEGO Technics to allow for more modularity. In terms of software, the core of the onion is based on the open-source Robot Operating System (ROS: www.ros.org). All source code can be found in our GitHub repository (https://github.com/mirte-robot).



No software | Blockly python | Blockly python ROS

Fig. 2a. MIRTE Light (€15)Primary Education

Fig. 2b. MIRTE Basic (€25)Primary and lower Secondary Education

Fig. 2c. MIRTE Pioneer (€100 – kit: €150) Secondary and Higher Education

(prizes shown based on sourcing components and self-assembly)

From an educational viewpoint, ROS is suitable for use in Higher Education but likely too complex for primary and secondary education, hence two layers of software to reduce complexity have been added. A Python shell was added, for use in secondary education allowing students to code their robot. As this may still be too complex for most primary school students, an additional layer was created using Blockly. By varying the complexity of the hardware on the MIRTE Basic and MIRTE Pioneer and whether or not students are given a built robot or are assembling the robot themselves, students can also be introduced to different levels of complexity in electronics. You can use an off-the-shelf PCB or allow students to delve deeper into the electronics of the robot by using the breadboard alternative instead. You can also vary the types of sensors and actuators to enable students to learn more about signals and sensors.

Within the development process, the MIRTE Pioneer was developed first and is currently furthest in its development and implementation. At the core of this onion is a small, but complex, versatile, mobile, semi-autonomous robot, the MIRTE Pioneer, (Fig. 2c) primarily intended for use in secondary and higher education. The MIRTE Pioneer is fully programmable using ROS, with the ability to use many different sensors varying in complexity including a LIDAR which allows the robot to have simultaneous location and mapping (SLAM) to aid its navigational capabilities. MIRTE Basic and MIRTE Pioneer are currently being developed further, with emphasis on creating additional educational resources and teacher training modules as teachers in primary and secondary education need more support in teaching robotics and computer science.

3.2 Under Development

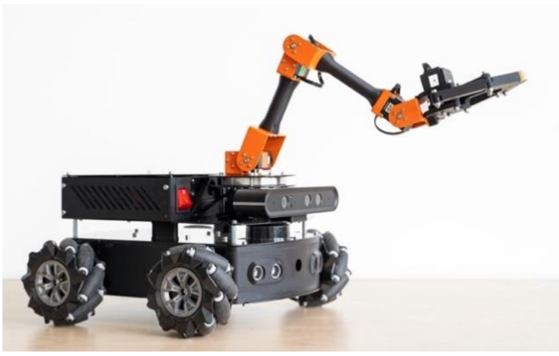
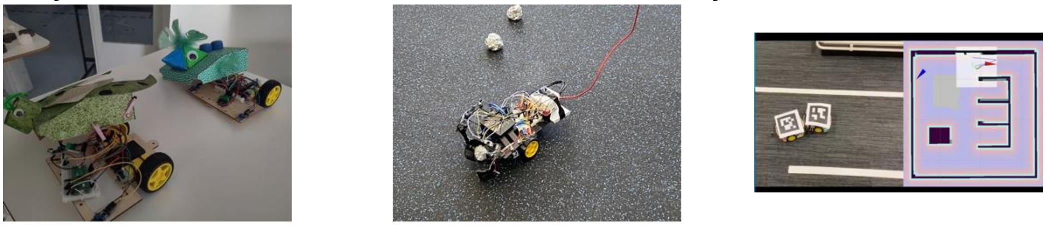


Fig. 3. MIRTE Master (€560)

The MIRTE family is growing. The current MIRTE family can more than cover the domains of primary, secondary, and bachelor education. Recently, a larger, more powerful MIRTE, the MIRTE Master, was developed, (see Fig. 3) with a mobile robot arm, a LIDAR, a depth camera, omnidirectional wheels and a dedicated PCB. It was developed based on a design by 4 BSc students in Mechanical Engineering, showcasing the software modularity of MIRTE. The MIRTE Master is intended for use in BSc final year projects and MSc education as well as research and development projects that require a heavier base and the use of a robot arm. Whilst working under the same principles using the same software, all hardware components of the MIRTE Master have been upgraded and extended compared to the MIRTE Pioneer. It is currently being tested in a BSc final project and an MSc course at our university. Design iterations are being made to further modularity. As soon as the testing phase is finished we will make its open resources available. As

ROS2 is rapidly becoming mainstream, we are also in the final testing stages of the ROS2 support for the MIRTEs which will be used in our education from next academic year and will be added to our GitHub later this year.



a) MIRTE Basic *b) Trash Sorting BSc ME* *c) Cow Herding MSc ME*

Fig. 4 MIRTE robots in use in education & outreach

4 MIRTE DEPLOYMENT

Since their creation MIRTEs have been used across the educational spectrum.

4.1 Primary and Secondary Education and Outreach

MIRTE is currently being used regularly at four local primary schools to introduce young students to the foundational concepts of robotics, and computational thinking. In addition, through outreach programmes, many primary schools source workshops on Robotics using MIRTE (Fig. 4a). MIRTE fits seamlessly into our national STEM curricula, providing a hands-on approach to learning that complements theoretical studies in STEM fields. Currently, MIRTEs are used as an integrated part of the STEM curriculum in three local secondary schools. In addition, students and staff regularly give 2-hour workshops at secondary schools.

Due to their affordability and diversity MIRTEs are an excellent tool to promote STEM with young people. Through workshops, facilitated by dedicated educators and robotics enthusiasts, young people are provided with hands-on experiences that not only teach the fundamentals of robotics but also encourage creative problem-solving and collaborative learning. These workshops take place both on campus and on location on an almost weekly basis. Within this initiative, there is also a strong emphasis on instructor training to equip more educators and STEM volunteers with the knowledge and tools needed.

There is a clear need for resources and support for primary and secondary teachers and workshop facilitators. We are therefore developing dedicated (open) education resources. For primary schools, we are in the process of creating open resources based on our workshops. For secondary education, we have developed open educational resources (https://workshops.mirte.org/nl/) in workshop format. We also provide workshops for primary and secondary school teachers to gain first-hand experience with MIRTE. We are currently in the process of developing a full MIRTE-based robotics learning line for the subject Nature, Life, and Technology, which is an elective in Dutch upper secondary schools.

4.2 Higher Education

MIRTEs are already used intensively in the BSc and MSc Mechanical Engineering (ME) and the BSc of Computer Science and Engineering (CSE) at TU Delft:

1. In the second year BSc Robotics project (6 EC) at ME students are taught about robotics, electronics and sensors. 600 Students build their own MIRTE pioneer in pairs and design and manufacture parts of their base and a small robot arm to perform a specific task, such as trash sorting (Fig. 4b).
2. MIRTE pioneers are also used in the 20 EC, interdisciplinary robotics honours programme for excellent BSc students.
3. In the Introduction to ROS course (2 EC) of the interdisciplinary minor Robotics (30 EC) in the 3rd year of the BSc.
4. MIRTE pioneers have also been used in our MSc Robotics - Fig. 4c (Saunders-Smits et al. 2023, van der Niet et al. 2023) having been replaced by MIRTE Masters this year (Fig. 3).
5. Within the 2nd year BSc course Embedded Software some 100 CSE students make different use of the MIRTE Pioneer, programming the microcontroller but do not change the design of the base.

The affordability of MIRTE allows students to not have to settle for programming simulations, they can test their programmes on a real robot. MIRTE allows lecturers flexibility to select which feature of MIRTE can aid them in achieving the desired learning objectives.

4.3 Commercial and Research and Development Use

An unexpected, but much-valued, user area of MIRTEs also emerged from this project. Due to their affordability combined with their versatility and ROS capabilities, startups and the R&D departments of companies such as Lely and Alliander have started to use MIRTE as a research and development platform which led to demand for us to produce MIRTES for others. However, in line with the non-profit status of our university and our Open Hardware philosophy of build-you-own, we decided not to produce and sell MIRTEs commercially ourselves. To meet this demand and to make it easier for 'non-makers' to get started with MIRTE, the "I am MIRTE Foundation" (https://iammirte.org) was created which produces and sells MIRTE kits to aid those unable or unwilling to source MIRTE materials with all proceeds being used to fund MIRTE workshops in underprivileged areas.

5 REFLECTION AND FUTURE DEVELOPMENTS

With MIRTE approaching its 5th birthday, most of the initial objectives of the first author to make an affordable, open mobile platform have been reached. Although the exact number of robots produced is hard to estimate, as MIRTE is open hardware, more than 1600 MIRTEs have been produced for use within TU Delft and our outreach workshops. To our knowledge, MIRTEs are currently owned and used by 8 schools and universities, with many more schools choosing not to own robots but buy in MIRTE workshops. Starting this summer, we are increasing our promotion activities, for instance through workshops at the RoboCup Junior Symposium in Eindhoven, and presenting this paper at this year's SEFI conference. Using this snowballing approach, we hope to add more users and developers to the MIRTE community, which can be found at: https://www.mirte.org/.

MIRTE Pioneer has matured well, but we foresee the following future developments:

1. Make the MIRTE Basic and MIRTE Light more accessible for primary schools and STEM outreach for that age range by developing open educational resources to aid primary school teachers and STEM volunteers.
2. Facilitate and expedite the use of MIRTE Pioneers in secondary education by developing educational frameworks and modules together with the Science Education and Teacher Training Specialists of both TU Delft and TU Eindhoven to fit within government-set STEM learning outcomes.
3. Expand the use of MIRTE to more universities: a project with the Mechatronics programme of The Hague University of Applied Sciences is awaiting a funding decision and further (inter)national collaboration is high on our wish list.
4. Continue development of the MIRTE Master and its outdoor sibling to add them to the Open Family of MIRTEs.
5. Continue to Grow an Open Science Community of MIRTE users and developers beyond the doors of our university and its immediate surroundings.
6. Scientifically evaluate MIRTE's educational and outreach contributions and carry out long-term studies on its impact, allowing evidence-based improvements to the educational qualities and potential of our MIRTEs across all levels of education
7. Arrange more funding to realise our ambitions

We believe these developments are needed to allow MIRTE to become the affordable (and hence more inclusive) open platform of choice in robotics.

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