ROBOT THEATER

Comprehensive guide for professionals

RobotTheater: Comprehensive guide for professionals

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RobotTheater: how can robots become an integral part of theater plays
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Content

1. Robots and Robotics

A robot, according to the definition of the Encyclopedia Britannica, is any automatically controlled machine that replaces human effort. However, it does not have to resemble human beings in appearance or perform functions in the way humans do [1]. Relatedly, robotics is an engineering discipline focused on robot design, construction, and operation [2].

The word robot first appeared in 1920 in the play R.U.R. (Rossum's Universal Robots) by the Czech writer Karel Čapek. The subject was human-like robots made to work on factory assembly lines, rebelling against their human masters. Etymologically, the term comes from the Czech word "robota" and means "forced labor". As such, it remained until modern times, but with an expanded meaning from its original form [3].

With the development and progress of robotics, many large and small companies have reduced production costs and increased their profitability using robots. Therefore, the purpose of robots and robotics was primarily to perform the most difficult, dangerous, and tiring tasks instead of humans.

Figure 1. Spot welding robot [4].

1.1. Elements of Robots

Robots mainly consist of three parts [5]: the controller, mechanical parts (effectors), and sensors. The controller includes a processing unit, memory, and software. It processes data received from sensors, controls mechanical parts, and ensures the execution of tasks. Mechanical parts enable physical interaction of the robot with its environment. They include actuators that move parts of the robot, joints that allow flexibility, end effectors such as grippers or tools specialized for specific tasks, and locomotor systems, such as legs, wheels, or tracks that allow the robot to move in their surroundings. For robots or parts of robots to move, an energy source is needed. There are different energy sources that are adapted to robots needs and the environment in which they operate. These can be batteries, electrical networks, solar energy, hydraulic or pneumatic systems, and fuel cells. The energy source determines the autonomy, mobility, and capacity of the robot to perform tasks. Sensors play a crucial role in allowing the robot to perceive its environment, both internally and externally, by gathering information. Smart robots can learn from this data to determine the size, shape, and direction of objects in their surroundings. For instance, sensors assist the robot in assessing the necessary amount of pressure to grasp an object without causing any damage.

1.1.1. Effectors

Effectors are robot parts that perform some actions and perform tasks - grab objects, turn parts of the robot-like wheels, etc. An effector can be any element that you can attach to a robot and control it, using the robot's computer.

End effectors are the tools at the end of robotic arms, and they directly interact with objects in the world. One such example is the "gripper" at the end of a robot arm, and in addition to them, end effectors can also be lights, hammers, and screwdrivers. Medical robots have their specialized effectors, such as tools for cutting in surgery and suturing incisions.

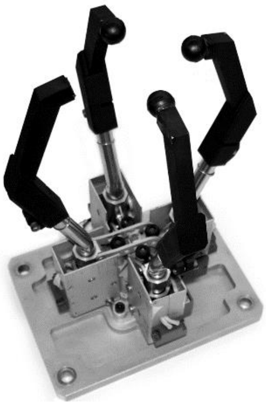


Figure 2. Robot end-effector [6].

Figure 3. Robot end-effector [7].

1.1.2. Actuators

Actuators are components that allow robots to move in space and manipulate different objects. Actuators convert various forms of energy, such as electrical, hydraulic, or pneumatic, into mechanical movement or action. They are key in enabling robots to perform assigned tasks, such as walking, grasping, rotating, or pressing. There are different types of actuators: motors, cylinders and artificial muscles, and each type has its specific applications depending on the needs of the robot and the tasks to be performed.

Motors can be used for many moving parts of robots, from joints on robot limbs to wheels on robot vehicles. Pneumatics (operated by air or gas under pressure) and hydraulics (operated by liquid pressure, like water or oil) are other ways of moving robot parts, especially where the robot needs a lot of power to perform a certain task.

Speakers enable robots to produce sounds and facilitate communication between smart robots and humans. Speech, in essence, is a form of behavior intended to influence the environment by conveying information to those around us.

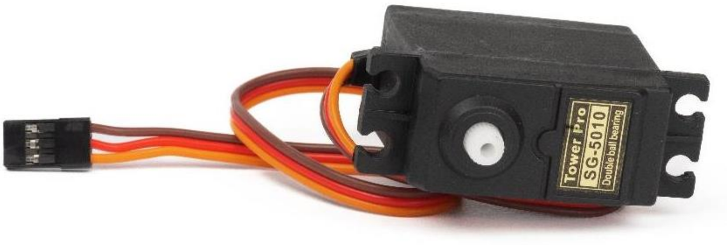


Figure 4. Servomotor.

1.1.3. Sensors

Just as humans perceive their environment with the help of senses through which they obtain information about the environment (eyes for sight, nose for smell, ears for hearing...), robots also collect information about their environment with the help of sensors that determine their behavior robot. Numerous types of sensors give the robot various possibilities.

Some of the sensors that can be installed on robots are cameras, microphones, ultrasonic sensors (SONAR), accelerometers, magnetometers, temperature, and pressure sensors, etc.

Cameras allow the robot to construct a visual representation of its environment, that is, to estimate features of the environment that can only be defined by sight, such as the shape and color and the size and distance of objects.

Microphones allow robots to detect sounds, while with the help of an ultrasonic sensor, the robot can determine how far it is from a solid object, such as a wall, and thus correct its movement through space. Some robots come equipped with thermometers and barometers to measure temperature and pressure.

Robots equipped with light detection and ranging (LIDAR) sensors use lasers to create three-dimensional maps of their surroundings as they move through space. One example of robots that use such sensors is autonomous vehicles. Some robots use accelerometers and magnetometers that allow the robot to sense its movement concerning the Earth's gravity and magnetic field.

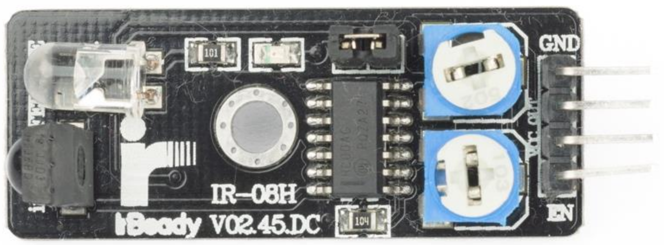


Figure 5. Infrared sensor for detecting obstacles or black line.

Figure 6. Color and ultrasonic sensor for Lego Spike Prime robots.

Figure 7. Mobile robots are equipped with a LIDAR sensor, allowing it to map the surrounding area and avoid obstacles [8].

Sensors transform physical inputs into electrical outputs, while actuators perform the opposite function. Actuators receive electrical signals from control modules and convert them into physical outputs. They are capable of various functions, including rotating rotors and controlling valves. Figure 8 illustrates the loop from sensors to actuators, representing a model of a robot's perception of the environment.

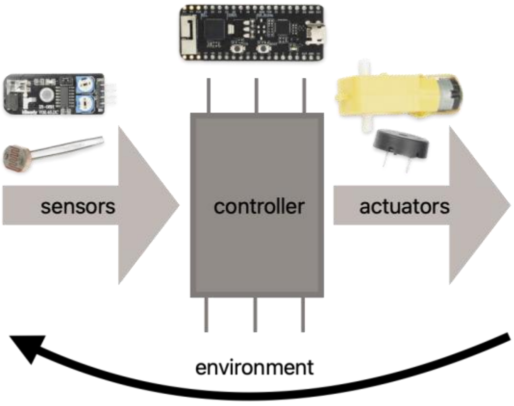


Figure 8. Sensors to actuator loop.

1.1.4. Controllers

The controller serves as the component responsible for governing the behavior of the robot. Controllers can be pre-programmed, enabling the robot to repeat specific operations repetitively. Such robots may either be unaffected by changes in their environment or possess limited capabilities to detect information from specific portions of the environment. Consequently, these robots will function optimally only if the environment aligns with their pre-programmed actions.

There are many different types of control systems used in robots, and we will mention two so-called robotic architectures.

The top-down architecture requires that we first train the controller (brain) of the robot that will receive input data from sensors and act accordingly. We do this by writing an artificial intelligence (AI) computer program.

Bottom-up architecture involves connecting the sensor directly to the effector and then ranking the sensor-effector pairs in order of priority to determine which one "wins" and controls the robot if more than one pair is activated. We call this architecture a "hierarchy" where the right hierarchy can produce incredibly "intelligent" behavior. Robots that use this kind of architecture are called "behavior-based" robots.

Today, the most used controllers are:

- Arduino Uno – probably the most famous microcontroller, especially popular among hobbyists, educators, and artists due to its simplicity, open community and abundance of available resources,
- Arduino Mega – like the Arduino Uno, but with more I/O (Input/Output operations) and more memory, useful for more complex projects,
- Raspberry Pi Board – although technically more microcomputers than microcontrollers, Raspberry Pi boards are extremely popular in robotics and DIY projects due to their powerful processing power and connectivity capabilities,
- ESP8266 – extremely popular due to its WiFi functionality and low cost, it is used in various IoT applications,
- ESP32 – successor of ESP8266, with additional features like Bluetooth, better performance, and more I/O (Input/Output) options,
- ATmega Series – a family of microcontrollers often used in Arduino boards, the ATmega series is well known and respected for its efficiency and performance.

These microcontrollers are popular due to their availability, community support, wealth of libraries and resources, and are often the first choice for educational purposes, hobbyists, and many professional applications. Choosing the right microcontroller depends on the specific requirements of the project, including the required processing power, I/O capabilities, communication protocols, power consumption, and cost.

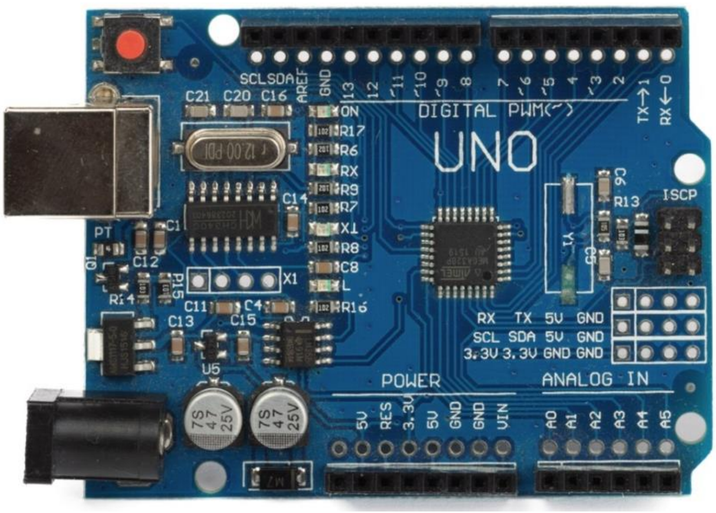


Figure 9. Arduino UNO microcontroller.

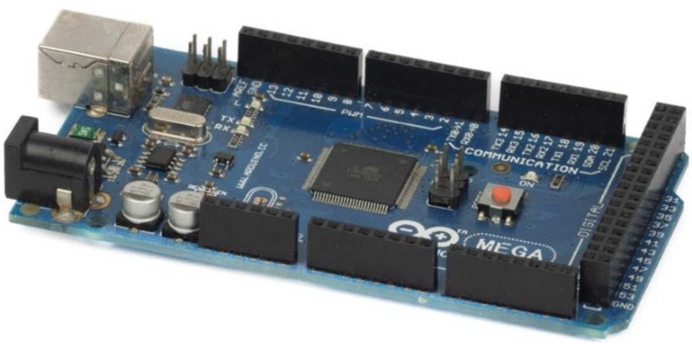


Figure 10. Arduino Mega microcontroller.

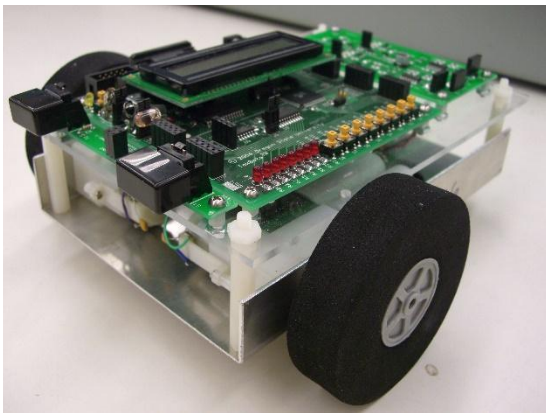


Figure 11. TekBot is equipped with the ATmega 128.2 microcontroller board [9].

1.2. History of robotics

The history of robots and robotics [3] traces back to **automata**. As early as 350 BC, the Greek mathematician Archytas created a steam-powered mechanical bird. Leading up to the industrial revolution, people conceptualized, described, and constructed various automatons used for entertainment, religious ceremonies, and to simplify everyday arduous tasks.

The advent of electricity marked the beginning of the development of modern robots as we know them today. In the mid-20th century, George C. Devol patented the **Unimate robotic arm**. Ten years later, with the assistance of Joseph Engelberger, it was further refined and transformed into an industrial robot. This robot was employed on the General Motors assembly line at the Inland Fisher Guide plant in New Jersey, where it facilitated the transfer and welding of die castings onto car bodies, mitigating the risk of worker exposure to harmful fumes or potential injuries.

Some significant robots throughout history are:

- **ELSIE** (Electro-Light-Sensitive Internal-External), developed in the 1950s, was the first mobile robot in history. Although its technical capabilities were limited, it possessed light sensitivity and electromechanical components for internal and external stability.
- **Shakey**, from the 1960s, was a robot equipped with tactile sensors and a vision camera. It could move on the ground and was controlled by two computers, one onboard and one remote, connected via radio.
- **MARS-ROVER**, developed in the 1970s, was a platform equipped with a mechanical arm, proximity sensors, a laser telemetry device, and stereo cameras. Created by NASA, it was designed for exploring hostile or unknown terrains.
- **SRI's CART**, from the 1980s, was a platform that employed Cartesian coordinates to model obstacles through its vertices.

These robots played significant roles in advancing robotics technology throughout history.

1.3. Types of robots

Today's robots can generally be grouped into six categories [10][11]:

1. **Autonomous Mobile Robots (AMR)** – robots that move independently, use sensors and cameras, and process and analyze the collected data based on which they make a real-time decision (e.g., about their movement around the factory).

2. **Automated Guided Vehicles (AGV)** – robots that rely on pre-defined paths and are typically used to deliver materials and move objects in controlled environments such as warehouses and factories.
3. **Articulated robots (robot arms)** – robots that imitate the functions of the human hand, where more rotary joints allow them a greater degree of movement, so they are excellent in handling material or in welding.
4. **Humanoids** – robots that perform human-oriented functions and often assume a human-like form, gather information from the environment, and perform tasks such as providing instructions at airports.
5. **Cobots (Collaborative Robots)** – robots designed to work together with people with whom they share space and help perform some dangerous or difficult tasks.
6. **Hybrids** – a combination of different types of robots capable of performing more complex tasks. For example, an AMR with a robotic arm is an ideal robot for handling packages inside a warehouse.

Autonomous robots [12] can gather information about their environment using various sensors and can move and perform tasks independently without human assistance. They possess the ability to perceive their surroundings, enabling them to avoid potentially dangerous or harmful situations for humans, property, or themselves. The software utilized by these robots, in conjunction with the sensors, plays a crucial role in real-time object localization and classification, enhancing the capabilities of smart robots.

One notable example of an early smart robot is **Shakey**, created in 1958 by a research team led by Charles Rosen at the Center for Artificial Intelligence of the Stanford Research Institute in the USA. Shakey could analyze commands and break them down into basic components. It navigated through unknown environments using cameras to perceive its surroundings. The robot acquired its name due to its wobbly and shaky movements, characteristic of its early design.

Figure 12. Robot *Shakey*, Carlo Nardone from Roma, Italy, CC BY-SA 2.0 [13].

After 2010, numerous smart robots applicable in the household appeared, such as **robotic vacuum cleaners** and **lawnmowers** that make our daily tasks easier, and there are also smart robots that **cook** delicious meals according to preloaded recipes.

Three smart robots have also inhabited the International Space Station (ISS) and since 2019 have been helping astronauts with routine tasks so that astronauts can devote themselves more to research. These are cube-shaped autonomous flying robots called **Astrobees or Star Bees** - Honey, Queen, and Bumble.

Figure 13. NASA's astronaut and an Astrobee robot (NASA) [14].

One of the most advanced smart humanoid robots now is **Sophia**, the first robot citizen in the world and the first representative of robotic innovation for the United Nations development program.

Robotic soccer players are used to promoting robotics and artificial intelligence research, and they are brought together by the international scientific initiative RoboCup, which aims to advance the development of smart robots. Their mission is to develop a team of fully autonomous humanoid robot soccer players by the middle of the 21st century who will defeat the winner of the last World Cup in a soccer match, by the official rules of FIFA.

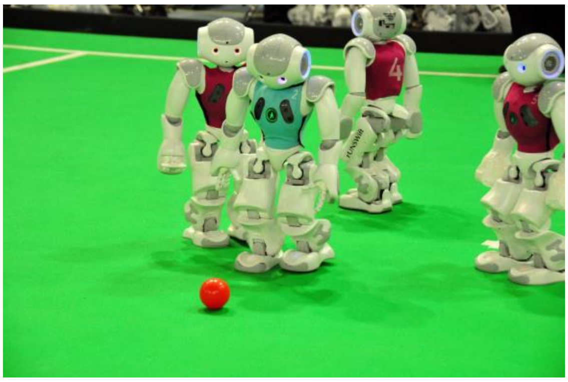


Figure 14. Robots are playing football at RoboCup league [15].

The Institute of Electrical and Electronics Engineers (IEEE) classified robots as follows [16]:

- **aerospace robots** – a broad category that includes all sorts of flying robots, but also robots that can operate in space,
- **consumer robots** – robots you can buy and use just for fun or to help you with tasks and chores,
- **disaster response robots** – perform dangerous jobs like searching for survivors in the aftermath of an emergency,
- **drones** – also called unmanned aerial vehicles, drones come in different sizes and have different levels of autonomy,
- **education robots** – broad category is aimed at the next generation of roboticists, for use at home or in classrooms,

- **entertainment robots** – designed to evoke an emotional response and make us laugh or feel surprised or in awe,
- **exoskeletons** – robotic exoskeletons can be used for physical rehabilitation and for enabling a paralyzed patient to walk again,
- **humanoids** – robots designed to look like people,
- **industrial robots** – consists of a manipulator arm designed to perform repetitive tasks,
- **medical robots** – medical and health-care robots,
- **military and security robots** – designed specially to be used in military and security issues,
- **research robots** – primarily intended to help researchers do research,
- **self-driving cars** – robots that can drive themselves around,
- **telepresence robots** – allow you to be present at a place without going there,
- **underwater robots** – robots that can move under the water.
- **delivery robots** – transport food, medical supplies, packages etc.,
- **service robots** – designed to clean, greet visitors, to work in museums, airports, shopping malls, and similar,
- **social robots** – assist humans in everyday tasks, keep humans company, interact and communicate with people.

1.4. Examples of robots and programs

Robots can be programmed or remote controlled.

Programmable robots are programmed by writing code. Code can be written in some programming languages, like Python, C, or using visual blocks. Programmed robots are autonomous and can perform a given task independently from human presence.

Remote-controlled robots are robots that are controlled by using a remote control. Nowadays, remote controls are often mobile phones or tablets. Operating this robot requires human presence. Often, roboticists make programs for these robots and their remote controls as well.

Figure 15. Robot controlled via smartphone app.

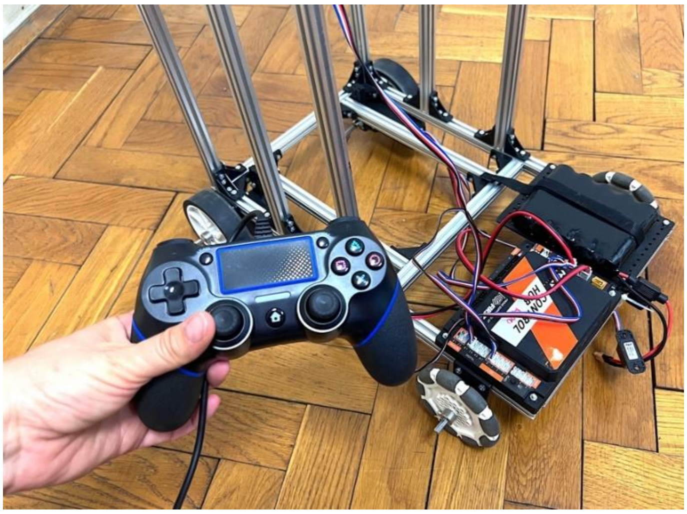


Figure 16. Robot controlled via remote controller.

1.4.1. Lego robots

Lego robots are interactive, programmable robots made of LEGO bricks, especially from series such as LEGO Mindstorms or LEGO Technic. These robots combine traditional LEGO construction with modern sensor, motor, and microcontroller technology, making them extremely adaptable and educational tools for learning and fun.

When we talk about Lego robots, we usually think of models that can be assembled, programmed, and controlled to perform various tasks. Robots can have different shapes and sizes, depending on the construction set and the user's imagination. They can look like vehicles, animals, machines, or any other structure you can imagine and build using LEGO bricks.

The heart of these robots is a programmable "brain" or central processing unit called a Spike Hub, LEGO Mindstorms EV3 brick, NXT or similar, depending on the generation. This module allows users to program the robot's behavior using a simple but powerful graphical or text-based programming language.

Lego robot parts usually include:

- Central Processing Unit (CPU): The "brain" of the robot that controls all operations,
- Motors: To move robot parts, such as wheels or arms,
- Sensors: For the robot to react to its environment, various sensors are used, such as those for light, sound, touch or distance,
- LEGO blocks and connectors: For building the body and structure of the robot,
- Connection cables: For connecting the motor and sensor to the central unit.

Lego robots are intended for a wide range of users - from children who encounter robotics for the first time, through enthusiasts and hobbyists, to educational institutions that use them to teach the principles of engineering, programming, mathematics, and science. Through fun and interactive learning, users develop problem solving, critical thinking and teamwork skills.

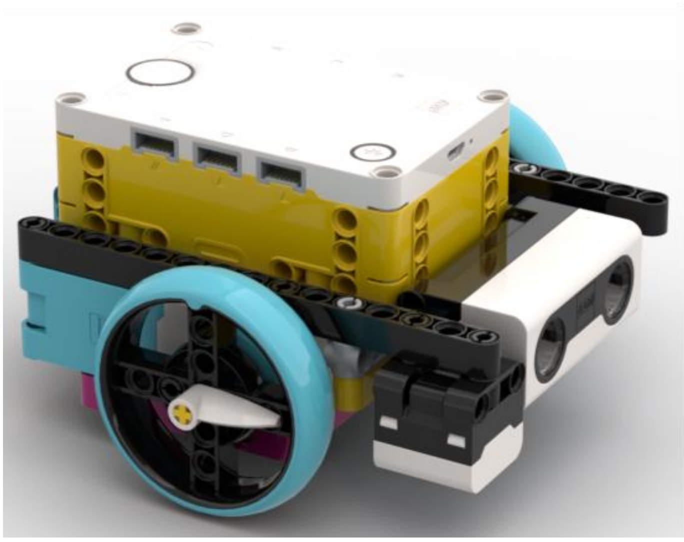


Figure 17. Lego Spike Prime robot.

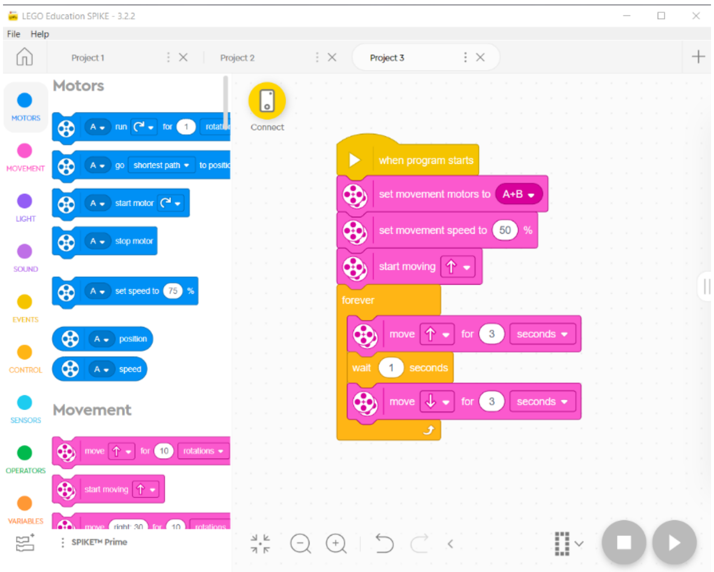


Figure 18. Lego Education Spike app and program code.

```python
import spike
import math
from spike.control import wait_for_seconds, wait_until
TRACKWIDTH = 11.5
diff_drive = spike.MotorPair('A', 'B')
diff_drive.set_motor_rotation(5.6 * math.pi, 'cm')

def run():
    while True:
        diff_drive.move(10, 'cm', 0, 30)
        diff_drive.start(100, 30)

def main():
    try:
        run()
    except Exception as e:
        hub.light_matrix.show_image('SAD')

main()
```

Figure 19. Lego Spike Prime robot Python program code.

Manufacturer website: https://www.lego.com/en-gb/categories/robots-for-kids

Download the app: https://education.lego.com/en-us/downloads/spike-app/software/

Program examples: https://makecode.mindstorms.com/examples

For further research on how to program the Lego Spike Prime robot, please visit: https://www.youtube.com/playlist?list=PL_zXBalpjbu33gw5CML3DtL7fN8640qku
or https://primelessons.org/en/

1.4.2. mBot robot

mBot robots are educational robots designed for learning and experimenting with robotics, programming and STEM (Science, Technology, Engineering, Math) education. Manufactured by Makeblock, mBot robots provide an accessible, fun, and interactive platform for children, students, teachers and hobbyists.

mBot is usually based on the popular Arduino platform, which makes it extremely customizable and compatible with many electronic modules and accessories. The regular mBot comes in the form of a kit that users assemble themselves, thus providing an additional learning experience through construction and assembly.

The main characteristics of the mBot robot include:

- Simple and adaptable design: mBot robots are designed to be easy to assemble and program, making them suitable for all ages. Their modular design allows easy addition of different sensors and modules.
- Programming: mBot robots can be programmed using mBlock, a graphical programming environment based on Scratch, which allows users to assemble a program using blocks instead of writing code. Also, more advanced users can program mBot using Arduino IDE and C/C++ language.
- Educational application: Intended primarily for education, mBot robots are useful tools for learning about electronics, mechanics, software engineering and robotics. With mBots, students can develop problem solving, logical thinking and teamwork skills.
- Sensors and modules: The basic mBot comes with a variety of sensors and modules, including light sensors, an ultrasonic obstacle detection sensor, an infrared receiver, a speaker, motors, and more. These elements allow mBot to perform various tasks such as following a line, avoiding obstacles, sending and receiving messages, etc.
- Durable construction: mBots are built with strong and durable materials, making them resistant to regular use in classrooms and at home.

mBot robots are a great tool for those who want to explore the world of robotics and programming in an interactive and accessible format. By assembling and programming their robots, users not only learn technical skills, but also develop their creativity and innovative thinking.

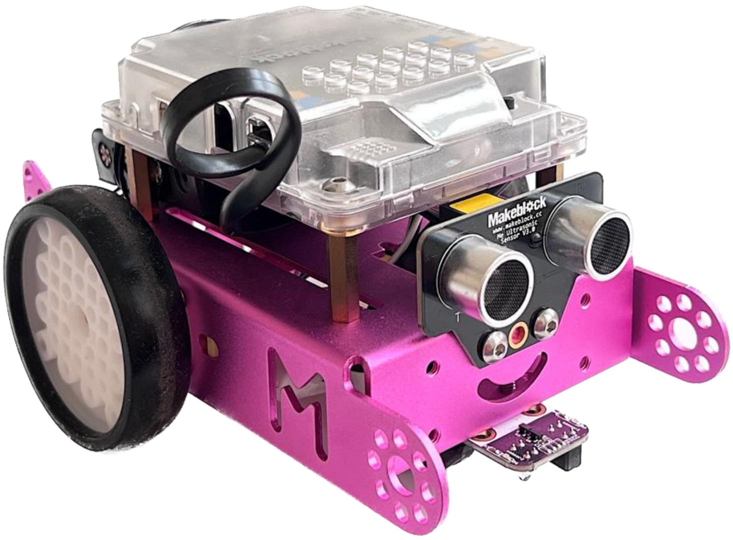


Figure 20. mBot robot.

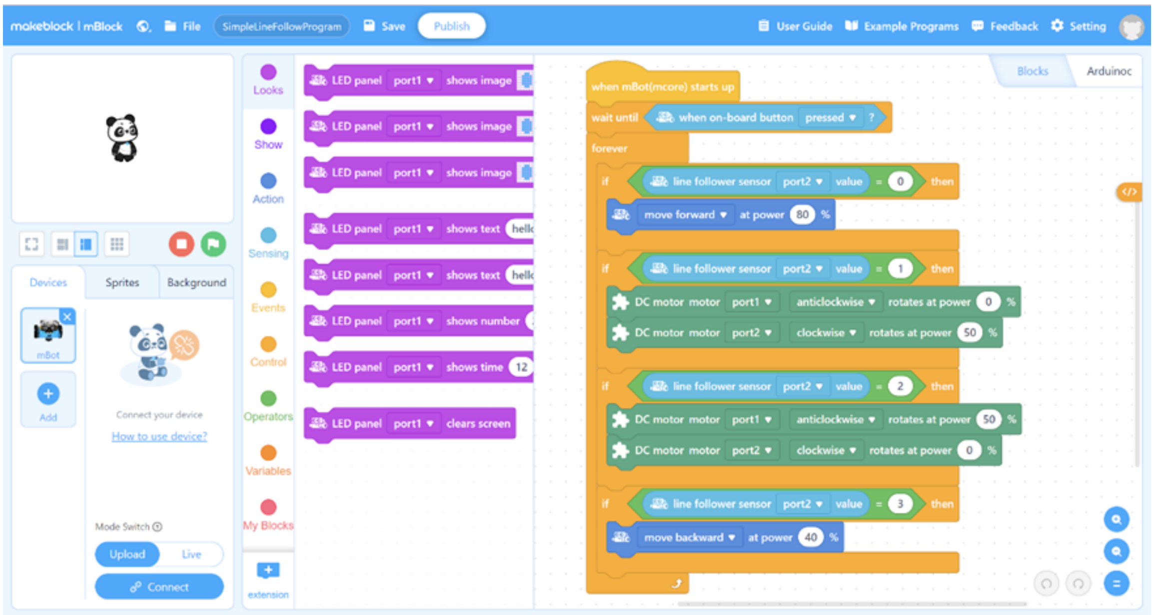


Figure 21. mBot robot program code.

Manufacturer website: https://www.makeblock.com/pages/mbot-robot-kit

Download the app: https://mblock.makeblock.com/en-us/download/

Program examples: https://education.makeblock.com/help/classic-example-programs/

Online editor mBlock 5: https://ide.mblock.cc/

For further research on how to program mBot robots, please visit https://cutt.ly/mblock-tut.

1.4.3. NAO

The NAO robot is an advanced humanoid robot developed by SoftBank Robotics (formerly known as Aldebaran Robotics). Known for its ability to walk, recognize faces, grasp objects, and interact with people, NAO has become popular in education, research, and as an assistive robot in various scenarios.

NAO is about 58 cm tall, which makes it accessible and suitable for interaction. The robot is equipped with various sensors, cameras, microphones, and speakers, allowing it to see, hear, and communicate with its environment. NAO can recognize faces and objects, respond to voice commands, and perform complex motor tasks thanks to its 25 degrees of freedom of movement.

The basic characteristics of the NAO robot include:

- Humanoid form: NAO takes the form of a small human-like robot, with a head, body, arms, and legs, allowing him to perform various human movements and gestures,
- Programming: NAO can be programmed using a variety of programming languages, including Python and C++, making it adaptable for a variety of educational and research projects,
- Sensors and actuators: It is equipped with various sensors (including tactile sensors, obstacle detection sonars, cameras, and microphones) and actuators that allow it to move precisely and interact with its environment,
- Communication: NAO can communicate in multiple languages, recognize human voices, respond to voice commands, and express emotions through movements and LED lights on its body,
- Educational and research applications: NAO is widely used in schools, universities, and research laboratories for learning and research in fields such as robotics, artificial intelligence, computer vision, human-robot interaction, and others.

NAO robots are particularly known for their ability to provide interactive demonstrations and educational activities, thus contributing to STEM education and promoting interest in robotics among students and enthusiasts. Also, thanks to their interactivity and adaptability, they are used in therapeutic scenarios to help children with special needs, and in hospitality and entertainment. Its ability to adapt and perform different tasks makes it one of the most popular humanoid robots in the world of robotics.

Figure 22. NAO robot on the stage.

```python
def onUnload(self):
    #put clean-up code here
    pass

def onInput_onStart(self):
    #self.onStopped() #activate the output of the box
    pass


def onInput_Front(self):
    global FrontCounter
    global MidCounter
    global LastTouched
    FrontCounter+=1
    LastTouched=0
    pass

def onInput_Mid(self):
    global FrontCounter
    global MidCounter
    global LastTouched
    MidCounter+=1
    LastTouched=1
    if (MidCounter-5 > FrontCounter):
        MidCounter=0
        FrontCounter=0
        BackCounter=0
        global BadResponse
        BadResponse+=1
        self.Bonk(BadResponse%3+1)
    pass


def onInput_Back(self):
    global FrontCounter
    global MidCounter
    global LastTouched
    if (MidCounter==1 and FrontCounter==1 and LastTouched==1):
        global GoodResponse
        GoodResponse+=1
        self.Pat(GoodResponse%3+1)
    LastTouched=2
    MidCounter=0
    FrontCounter=0
    BackCounter=0
    pass
```

Figure 23. NAO robot Python program code.

Download the app: https://www.robotlab.com/choregraphe-download-page-for-nao

Manufacturer website: https://www.aldebaran.com/en/nao

NAO documentation: http://doc.aldebaran.com/1-14/index.html

Free NAO programs (dances, stories, etc.): https://engagek12.robotlab.com/stemlab/apps/nao/a1uD0000002SokxIAC

For further research on how to program NAO robot, please visit: https://www.youtube.com/watch?v=j7HMIIEqArQ.

1.4.4. Thymio

Thymio is an educational robot designed to introduce children and beginners to the world of robotics and programming. Developed by École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland, Thymio stands out for its affordable yet powerful features. The goal of Thymio robots is to enable learning through play, experimentation and interaction, making the fundamental concepts of robotics and programming understandable and accessible to a wide range of users.

Thymio is a relatively small robot, often in the form of a box with various sensors and lights. Its design is simple yet effective, allowing users to explore different aspects of robotics, from sensor systems to programming logic.

Basic characteristics of the Thymio robot include:

- Accessible programming: Thymio can be programmed using visual programming languages like Scratch or text-based languages like Aseba. This allows children and beginners to easily learn the basics of programming and robotics.
- Sensors and actuators: Thymio comes with several sensors, including touch sensors, distance sensors, microphone, temperature sensor, and light sensors. It also has wheels and motors that allow it to move.
- Educational application: Thymio is extremely popular in schools and workshops due to its accessibility and the various educational resources available for teachers and students. It is used to teach mathematics, physics, technology, engineering, and computer science.
- Interactivity: Thymio can respond to external stimuli and communicate with users using LED lights and sounds. It can follow lines, avoid obstacles, respond to sounds and touch, and perform a variety of other interactive tasks.
- Customizability: While Thymio comes with several predefined behaviors that can be used right out of the box, it also allows users to create their own programs and customize the robot's behavior, allowing for creative expression and a deeper understanding of robotics.

The Thymio robot is a great tool for learning, experimenting, and playing, encouraging users of all ages to explore and develop skills in STEM fields. Its affordability, adaptability and wide range of functionality make it a popular choice in educational institutions and homes around the world.

Figure 24. Thymio robot.

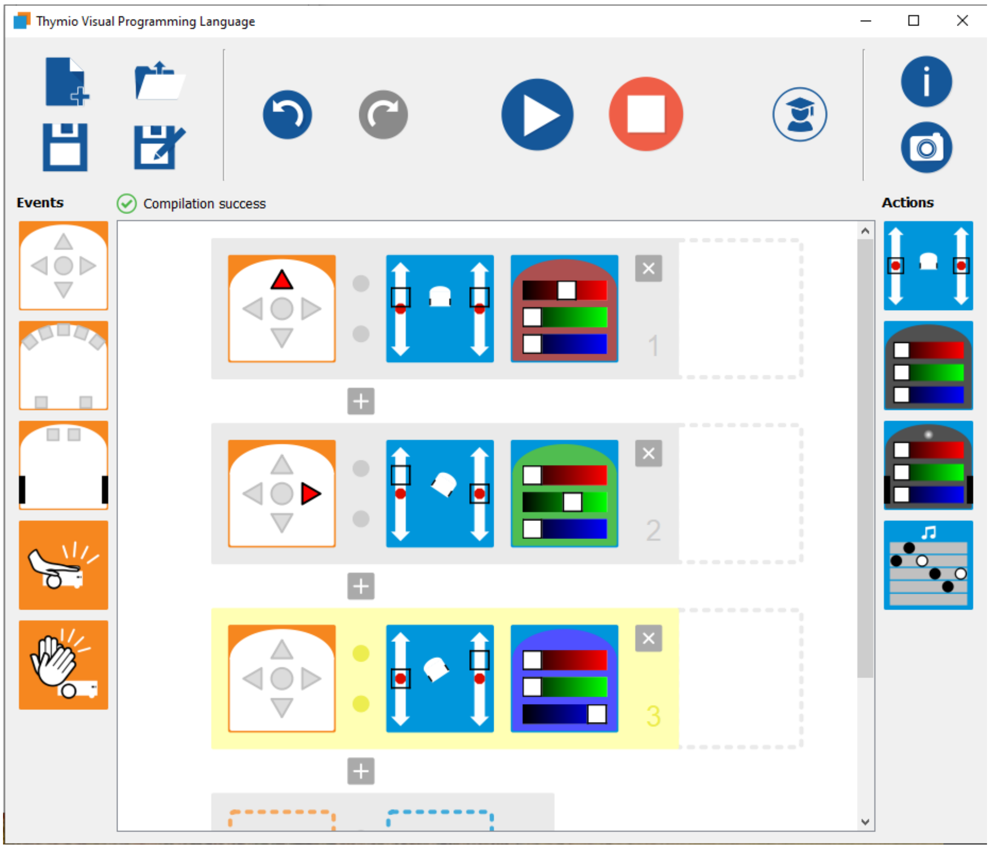


Figure 25. Thymio robot program code.

Manufacturer website: https://www.thymio.org/

https://www.thymio.org/download-thymio-suite/

Program examples: https://www.thymio.org/products/programming-with-thymio-suite/

For further research on how to program the Thymio robot, please visit https://www.youtube.com/@ThymioII.

1.4.5. STEMI hexapod

STEMI hexapod is an educational robot that represents a six-legged, or hexapod, robot, developed by the company STEMI. This robot is designed to give students, teachers, and hobbyists an insight into the world of robotics, programming, mechanics and electronics. The hexapod concept allows users to explore complex forms of movement and navigation that are not possible with robots with fewer legs.

The STEMI hexapod is intended as a DIY project, providing users with all the components needed to build and program their own robot. Through the process of building and programming, users learn about mechanical structures, electronic components, principles of movement, and the basics of programming.

Features of the STEMI hexapod robot include:

- Hexapod construction: The STEMI hexapod has six legs, each with multiple joints, allowing for varied and adaptive movement. It can move in different directions, climb over obstacles, and change speed and walking style,
- Educational aspect: This robot is intended as an educational tool for learning through practical experience. Users are introduced to the basics of robotics, mechanics, electronics, and programming as they assemble and program their hexapod,

- Programming: The STEMI hexapod is programmed via a custom application or via popular programming languages. This allows users of various skill levels to learn and experiment with robot programming,
- Adaptability: Users can customize and improve their STEMI hexapod robots by adding sensors, changing programming algorithms, or adjusting the physical appearance,
- Interactivity: In addition to being able to move and perform tasks, the STEMI hexapod can respond to its environment and interact with users using built-in sensors and programming capabilities.

The STEMI hexapod robot is designed to provide an educational and fun learning experience, encouraging users to delve into STEM fields through interactive and hands-on activity. Its unique six-legged construction and adaptability make it an intriguing project for individuals of all ages interested in robotics and related disciplines.

Figure 26. STEMI hexapod robot.

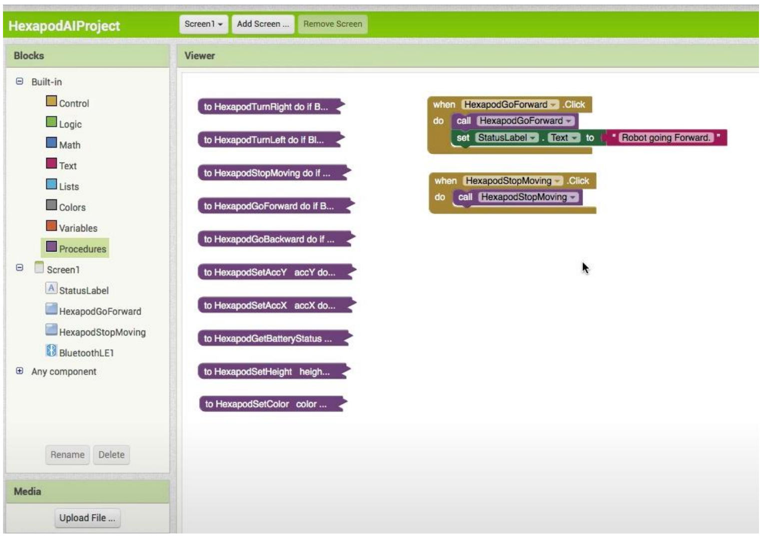


Figure 27. STEMI hexapod robot program code (MIT App Inventor screenshot).

Manufacturer website: https://stemi.education/

MIT App Inventor for programming apps to control the hexapod robot: https://appinventor.mit.edu/

STEMI Lab app:

Android - https://play.google.com/store/apps/details?id=com.stemiapp&hl=hr&gl=US

iOS - https://apps.apple.com/jp/app/stemi-lab/id1393849515?l=en

For further research how to program STEMI hexapod robot, refer to https://lab.stemi.education/ or if you want to learn how to program the hexapod robot in Arduino, please visit https://github.com/stemi-education/stemi-hexapod.

1.4.6. Open Roberta Lab

Open Roberta Lab [17] is an online platform that provides an intuitive, visual programming environment for learning and teaching programming and robotics. Developed by Fraunhofer IAIS, the goal of this platform is to make education in STEM fields (science, technology, engineering, and mathematics) accessible, fun, and effective for students, teachers, and hobbyists of all ages.

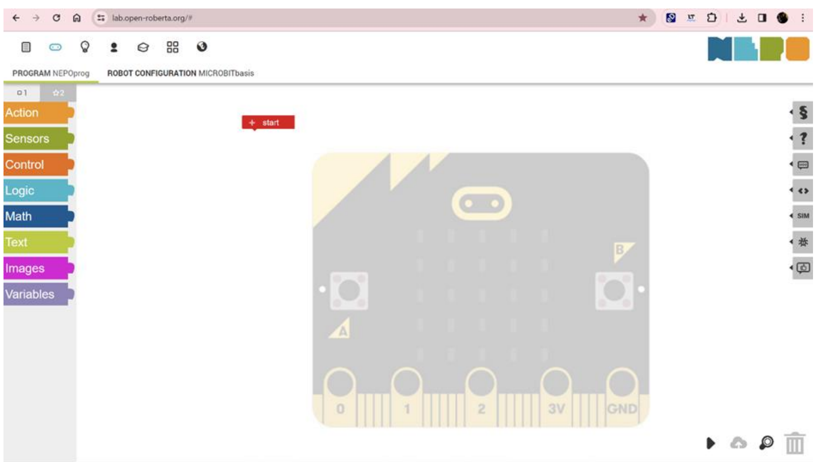


Figure 28. Open Roberta Lab online environment.

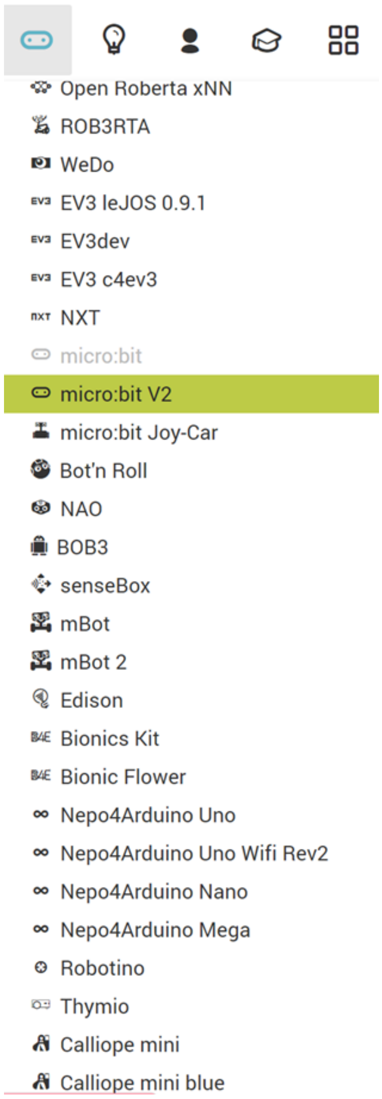


Figure 29. Various types of robots and microcontrollers users can program in the online Open Roberta Lab environment.

Open Roberta Lab allows users to program various types of robots and microcontrollers, including popular models such as LEGO Mindstorms EV3, Calliope, micro:bit and many others. Using drag-and-drop programming blocks based on Blockly, users can easily build a program without having to write complex code.

Features of Robert Lab's Open include:

- Visual programming: The platform uses Blockly, a visual programming language that allows users to build a program by dragging and connecting blocks. This makes programming accessible and understandable, especially for beginners and children,
- Support for different robots: Open Roberta Lab supports a wide range of educational robots and platforms, allowing schools and students to use the platform with existing hardware,
- Educational resources: The platform offers a wealth of learning materials, tutorials and project examples that help users learn quickly and get started with their own projects,
- Collaborative learning: Open Roberta Lab allows teachers and students to collaborate, share code and projects, enabling better interaction and learning through collaborative work,
- Free and open: As an open-source platform, Open Roberta Lab is freely available to all, promoting accessibility and innovation in robotics and programming education.

Open Roberta Lab is an excellent tool for those who want to venture into the world of robotics and programming, giving users regardless of their previous knowledge the opportunity to easily learn, experiment and realize their ideas. Its affordability, flexibility and abundance of supported hardware make it a popular choice in educational institutions, workshops and among hobbyists worldwide.

Open Roberta Lab website: https://lab.open-roberta.org

Open Roberta Wiki: https://jira.iais.fraunhofer.de/wiki/display/ORInfo/Open+Roberta+Wiki

2. Theater and theater art

2.1. History

Theater, in its beginnings, conveyed the tradition of ancient civilizations through images and words, and for easier memorization, the text was given in rhyme or rhythmic narration. Similarly, religious tradition is passed down to the next generations. But true theater is only spoken of from the moment when the staging of texts became a real performance. This happened already in ancient Egypt, where performances were held in honor of the god Osiris, and even more so in ancient Greece, where performances were dedicated to individual gods (such as Dionysus) or the entire Olympus. The oldest text preserved in the original, which we know was performed (and is still performed today), is Aeschylus' Persians. The text was written eight years after the Greek victory over the Persians at Salamis, but it is not a drama that glorifies the military superiority of the Greeks, on the contrary: it is an anti-war drama, with which Aeschylus wanted to warn his homeland that it was walking the deadly path of the Persian empire.

With the spread of literacy, works became even more accessible to future generations, although (unlike in modern times) it was not assumed that theater was intended for all people [18]. In ancient theater, at first, the text was narrated by only one person, later in dialogue with the chorus, and only later did it include conversations between actors. The genre began to distinguish tragedy and comedy. For the first time, buildings specifically designed for theater appeared, especially in the Roman period, when the actor became increasingly exposed and indispensable within the theater. At first, actors could only be men, so they also played female roles.

In the Middle Ages, theatrical performances presented stories of religious content, so that mostly illiterate people could understand and experience them easier. Performances were performed that told stories about biblical figures or saints, Christmas plays, passion plays, wars, battles, and martyrdoms in the Muslim world were also marked by theater.

With the Renaissance, there was a revival of the tradition of ancient theater, both Greek and Roman. Commedia dell'arte embraced an audience eager for entertainment in Italy, which sought an audience among the educated segments of the population, well-versed in Latin. For the first time, a clearly organized theater group developed, with a complete repertoire, which mainly aimed for comedy and was less concerned with tradition and history. In England, at the same time, a similar development was experienced by the theater of William Shakespeare. Theater became professional for the first time, and performances were paid. Professional writers began to write dramas (alongside Shakespeare, for example, Christopher Marlowe), and instead of theater critics, the audience initially gave their reactions to the dramas. Theater writers were not too highly regarded by the public at first, which changed when they and the theater began to be sponsored by nobles or even rulers. With the development of technology, effects, and lighting are increasingly being incorporated into performances. Precisely for that reason, there is less improvisation on stage so that colleagues from backstage can react in time to what is happening in the performance. In the beginning, theaters did not use scenography but instead used the space in which the play was performed for the setting. Later, the stage became increasingly established, hand in hand with the realization that theatergoers were becoming more and more spectators and not just listeners.

As the popularity of theater grew, so did the desire of authorities to control the content on stage. Censorship of works, such as Moliere's Tartuffe, emerged. The puritanical government in England even banned theater, after which the crown established a monopoly on the organization of theatrical performances. In France, absolutism subordinated theatrical art to morality, and control was exercised through censorship and royal patronage. Street theater emerged because of opposition to these norms.

In civic theater, attending a performance becomes an important social event, and actors who become well-known personalities gain increasing influence. At the end of the 19th century, the theater began to strip away unnecessary costumes and props on stage, and the theater of ideas prevailed, as can be seen in the events on stage. With the Stanislavski school, theater theory significantly developed, aiming to help the audience experience the emotions of the characters in the play as authentically as possible through the actor. In modern times, with the invention of electricity and new technical devices, new ways of grabbing the audience's attention emerged. After World War II, European theater began to explore absurdity, meaninglessness, and existential themes, and opened the doors to improvisational theater. At the same time, in the United States, fantastic and musical themes were introduced to theater.

In the 21st century, countries continue to maintain their national theaters, which mostly operate successfully and fulfill their purpose. At the same time, the art of theater is becoming increasingly global, especially its more commercial part. This type of theater unreservedly borrows themes for performances from different traditions and approaches performances without being burdened by traditional theatrical techniques.

2.2. Theory

Theater is one of the oldest forms of artistic creation. It tells a story through speech, movement, dance, sound, costume design, and set design. There are several types of theatrical performances:

- classical (dialogue style),
- opera and ballet,
- improvisational theater,
- cabaret,
- mime and pantomime,
- stand-up comedy,
- puppet theater.

Dramatic productions are tied to a script, but the script only fulfills its purpose in combination with the actor's behavior, gestures, and facial expressions (from the Greek mimesis – to represent, imitate). Let's illustrate with an example: a tightrope walker performs acrobatics, while the actor portraying them on stage only mimics them. Both are performing, but only the actor is creating the dramatic illusion. A theatrical performance can include acrobatics, dance, singing, and other elements that are not necessarily tied only to theater, as a means of portraying a real or fictional event. A performance that only intends to depict a plot, but not represent it, does not have the element of a theatrical performance [19]. From the 20th century, several genres in European and North American theater have emerged that combines theater with non-theatrical elements of performance (sketch, musical, dance, performance), which is even more true for the overall development of theater in Asia. Therefore, it is crucial for the definition of theater to remain flexible in this regard [19].

According to British director Peter Brook, a theatrical performance can be described as whenever a person performs in a space and their performance is accompanied by one or more individuals. The older theory of theater considered the actor's desire to conquer the audience as the foundation of theatrical performance. This only holds partially and for some theatrical genres, but more often emotions and experiences are structured in the theater [19].

There are many theatrical genres, each with its own peculiarities, but there is also a common core that applies to the entire theatrical art. All theatrical productions take place in a certain space (usually on stage) where the actor or actors perform the play. The duration of the performance is usually time limited [19].

The work of an actor, the central figure of the theater, involves five fundamental areas:

- Expression of specific (including vocal) abilities,
- Facial expressions that express psychological states and activities,

- Imaginary interpretation of fictional events,
- Expressions of patterns of human behavior that are not characteristic of the actor himself,
- Interaction with other actors and the audience.

The requirements placed on an actor are different depending on the cultural environment of the theater. Actors in some traditional Asian theaters (China, Japan) had to play the same type of role throughout their professional careers. Such an actor played a role in accordance with a strictly defined tradition, repeating precisely defined speech and movement patterns. Only in the later period of their career could add characteristic features to this basis, which could be accepted into the existing tradition and passed on to the next generation [19].

The relationship between the performer and the audience can be very different. In performances that are not part of theatrical art, the performer accepts the presence of the audience and is in direct communication with them. Such relationships also exist in theater, but they are not necessary. In ancient Greek theater, the actor addressed, questioned, and challenged the audience on behalf of the playwright. On the other hand, in modern naturalistic theater, the actor mentally separates from the audience („fourth wall“). Between these two extremes, there is a whole range of different communication methods, which in some cases change during the performance itself [19]. The way of communicating with the audience can be linked to the position the actor has in a particular society. In Greek tragedy, Japanese theater, and medieval mysteries, the actor's actions had both religious and dramatic significance, and the actor was considered almost a priest. In Roman times, actors were often slaves or servants of prominent families, while in Elizabethan theater they worked under the patronage of the nobility or were considered vagrants. With *commedia dell'arte* and the establishment of professional theater and acting groups, the relationship between theater and audience changes to that of producer and consumer. Modern theater, which developed in the 19th and 20th centuries, added to the actor's role as a rebel who conveys social-critical and political messages through the performance (including reinterpretations of classical texts) [19].

When interpreting a role, an actor must immerse themselves in their character or a certain type of character. In many cases, while interpreting a role, an actor becomes associated with the qualities attributed to a certain group of people. Roman comedy had a limited set of well-defined characters, with attributed characteristics such as a cunning slave, a passionate young lover, or an aging father full of suspicion and worries. Characters such as a king, a wise advisor, or a cruel tyrant emerged from historical and biblical stories. Some typical characters arose from the development of theater, such as the protagonist, the young man, the innocent soul, or the villain [19]. The development of theater led to a more individualized approach to interpreting roles, especially from the 19th century onwards when actors began to be asked to add their personal touch to their characters by exploring their character's personalities. This is particularly true in Konstantin Stanislavski’s theory of acting. While actor may start shaping a character based on standard models, during rehearsals, they begin shaping the character's personality in a way that may be different from similar roles in other plays. This type of acting raises theoretical questions about the relationship between the actor and the role (to what extent can they overlap), which are still the subject of debate today [19].

2.3. Infrastructure

Performers and the audience co-create the theatrical experience together. Both sides meet in a common space within which there are two clearly separated areas: the space for the performers (usually a stage) and the space for the audience. The relationship between the two areas within the space can be different, but there are some more common types:

- amphitheater: the space for the audience surrounds the place where the performance takes place in a semicircle,
- spectators arranged in a circle around the stage where the performance takes place,

- rows of chairs for the audience, arranged in front of the stage, which is raised above the level of the seats [19].

The theater is often associated with its own building, which is used for performances, but this is not necessarily the case. In the past and present, other buildings or even outdoor spaces, such as squares or even cities, can be turned into a stage for a performance. Actors must be separated from the audience to some extent. This has both practical aspects related to the viewer's unobstructed view of the action, as well as more abstract aspects. In ancient theater, the separation between actors and the audience was related to religion. The altar of the god Dionysus was surrounded by a stage intended for dance. From there comes the idea of a stage as a place for performance [19]. Even when the religious character of watching theater lost its strength, going on stage still meant stepping into another world, separate from the audience. In some Asian theatrical traditions, preparation before going on stage is still considered a sacred task [19].

The stage becomes a place of illusion for both actors and the audience during the performance. The environment in which the play takes place can be created only by speech or more often by scenography, which illustrates the place where the game takes place. In this case, the audience begins to experience the space in which the performance takes place as primary and awareness of the real stage is pushed into the background [19]. Sound can also co-create the illusion of space. Stanislavski in his theater clearly distinguishes between the space for actors and the space for the audience.

Figure 30. Stage and audience.

2.4. Performance of the play

In theater art, most performances are pre-planned, and rehearsals are held before the actual performance to shape the play. Prior planning of the play involves the preparation of a written text (a screenplay or written play) by either a playwright or the actors themselves. Within the play's text, the content is divided into several parts (scenes or acts), each of which is a step forward in the story's progression. The content of the text is often linked to the characteristics of the period in which it was created. In ancient theater, the content was drawn from myths, and later, stories, songs, acrobatics, and speeches took over [19].

In a play, actors use costumes and masks that change their appearance. In ancient Greek theater (as well as in traditional Japanese theater), the actor transforms into something more than an ordinary human being. In other societies and traditions, however, the actor represents an average person or a member of the lower class, whose convincing acting undermines the principles of order and rationality [19]. Scenography depends on the need to redesign the stage to achieve the play's purpose. In English theater of the Elizabethan era, both the stage and the seating area remained unchanged, while in street theater, the seating area changes with benches, and only the stage or both the stage and seating area change, which is a characteristic of court theater in the Renaissance or modern theater [19]. Renaissance theater established the practice of scenography on stages in Europe. Initially, typical scenes were created for a particular genre of play (tragedy, comedy, pastoral), and later, scenes were created for each individual play. Over time, scenography became so complex that special departments were formed within it for stage elements, lighting, props, technology, etc [19].

The production of theatrical performances does not have a single plan, but they all have some common features. Most theatrical performances are part of a broader, longer-term activity that is associated either with the religious or social life of the community. Within production, relationships can be hierarchical or based on cooperation, with hierarchical management being more common [19]. Ultimately, planning and performing repertoire depends on the artistic leadership of the director or group that operates in the theater. During the 19th century, the ideal of a theater ensemble or group emerged, which emphasized the need for unity within the theater. The development led to the need for detailed coordination of all aspects of production. Theater in the 18th and 19th centuries relied on the start actor, but after that period, the primacy was taken over by the star ensemble, and through it, its director [19].

Greek city-states encouraged the creation of individual performances, without a permanent theater or ensemble. The same was true for organizing games in medieval cities. In Athens, new works were staged every year, while in medieval cities, annual repeats of the same performances were organized. This tradition continued to some extent in the court theater of the 16th and 17th centuries, where one of the courtiers was responsible for staging the performances, with a role similar to that of today's theater intendant [19]. With the Renaissance, the growth of cities, and a changed approach to performance, which required better organization, the beginnings of permanent and professional theaters and theater groups emerged. These were initially traveling, as neither cities nor courts were able to maintain a permanent theater. Such a theater could not have a lot of scenography, which the actors compensated for with a wide selection of costumes. Such a group had its set of games, with which they could adapt to the audience in the environment where they were currently located. The transition from individual performances to a permanent theater with a known repertoire began [19]. In the 18th and 19th centuries, the first among the actors led the theater group. As he and other members of the group lived off the acting profession, they began to stage performances that attracted audiences and earned good money. Instead of changing the repertoire, they focused on repeating works that were commercially successful. E.g. in London, Agatha Christie's The Mousetrap ran constantly in theater for more than 50 years. By the end of the 19th century, a permanent theater system with a theater group and a certain repertoire supported by the state was established in Europe. This allowed for the establishment of larger theaters with actors, technicians, and other staff who could dedicate themselves to long-term production planning. The repertoire is flexible: old performances are brought back, and some are removed from it [19].

Artistic leadership of production is almost always in the hands of an individual. During the time of c*ommedia dell'arte*, it was the actor who held both the artistic and financial aspects of the production in their hands. This was also contributed to by the nature of this type of theater, as scripts, if they existed at all, were very loosely structured, and the actor greatly shaped the image of the performance on stage. Actors in Elizabethan theater, the Peking Opera in China, and the Kabuki theater in Japan played a similarly important role in production [19].

2.5. Other professions related to theater

Besides the staff responsible for the artistic performance of the program, there are also many other people involved in the work of the theater. These people, although not directly on stage, are an integral part of every performance.

The **producer** controls the entire course of the performance(s). They are responsible for the business side of theater operations, such as budgetary frameworks, fundraising for the institution, determining schedules for individual performances and rehearsals, ticket prices, and promotion methods. They collaborate with the artistic leadership in planning new productions [20].

The **assistant director** works closely with the director in preparing a new production and rehearsals for the performance, takes notes from meetings, and participates in the preparation of proposals for the performance [21].

The **stage manager** is the one who schedules work on the stage, collaborates with the cast and designers during the creation of a new production, and supervises the smooth running of the performance. They ensure that the stage for a particular scene is set up on time and that all actors are present [20].

The **odeum manager** is responsible for the other part of the theater that the director does not cover. They control the ticket sales system and the sorting of the audience into seats in the auditorium. They ensure smooth access to and from the auditorium, additional programs before the performance, and the safety of the audience. In case of any confusion about the seating order, they are the ones who solve the problem [20].

The **technical director** in larger theaters is responsible for the overall technical production in the theater. They are the person who selects key technical personnel such as sound engineers, lighting engineers, and stage technicians. The **stage technician** ensures that the performance has the proper equipment that helps create the right atmosphere for the performance (or part of the performance). The **lighting engineer** ensures that all parts of the stage are covered with the right lighting at the right time, creating the right atmosphere for the performance and directing the audience's attention with the light. The **sound designer** creates good and balanced sound for both performers on stage and sound effects [20].

The **costume designer** creates costumes for the performance, taking into account the time frame, style, and director's ideas for the show [21]. Of course, the costumes should also be practical. To achieve the purpose of the costumes, the costume designer carefully analyzes the script, the period in which it takes place, and the fashion of the time, as well as the director's instructions. Based on their instructions and sketches, the costume maker then makes patterns and creates costumes accordingly [21]. If the performance also requires special **makeup, hair, or wigs**, people who specialize in those fields are involved in the production. They also work closely with the director and prepare a detailed plan for the makeup, hair, or wig for each scene. If necessary, they make wigs specially tailored to the performance [21].

2.6. Development a theater play

The performance undergoes several stages of creation from the initial idea to the final execution. Each of these stages represents a step forward on the path to a successfully completed project. The team first plans the performance and based on these starting points, they develop the script. In the preparation phase, they ensure that everything necessary for the successful execution of the story is in place. Prior to presenting it to the public, the team conducts the necessary rehearsals to ensure a smooth performance that leaves a positive impression on the audience. After a successful premiere, it is advisable to analyze the work done to address any shortcomings before subsequent performances.

2.6.1. Planning and scripting phase

Every performance begins with an idea that we want to convey on stage. This can be an existing work or we can create a completely new dramatic text for the performance. Whatever the case, this will be the basis for our work in the following period, so let the story also appeal to us personally [22]. Based on the story, we will create a script for the play. This will define the characters who will appear in the play, the atmosphere in which it will take place, as well as the background of the story, its plot and denouement. Good knowledge of the script or proposal for the play is crucial for a good performance. First, the director must know it well, so it is recommended to re-read the script several times, during which the director writes down his observations or questions. On this basis, the director can come to the right conclusions about the message that the author of the text wanted to give and how this text should be performed on stage. Sometimes a lot of questions will arise in this phase, but let that not scare us, as it is quite normal for this phase of creating the performance. Questions or dilemmas that we will not be able to solve on our own can be solved in cooperation with the actors, who will also have their own views on the staging of the text [23].

The director and playwright/screenwriter can be the same person, which is more common with older authors and texts. In the 17th century, the famous Racine and Molière also directed their own performances. Most of today's authors do not feel professionally qualified to put a play on stage or to motivate the entire team preparing the performance. Of course, there are still exceptions, such as Harold Pinter (himself once a very good actor), Dario Fo or George Bernard Shaw, who was the only way to convince himself that the performance was performed exactly as he had imagined it while writing the text. In this he was more than obviously successful, as his direction today represents examples of lucid communication of ideas [24].

In this phase, we also select all the key collaborators who will help us with the realization of the performance. We can choose actors from among the people we know, or we can prepare an audition to fill the roles. The first option has the advantage that we work with people we know and from whom we know what we can expect. On the other hand, the ideal person for a role can also be someone we have never met before and can only get to know through an audition [22]. It is not necessary for them to be familiar with the text on the first audition, but certainly by the final selection, as this is the best way to see how the actors will work in their roles in the performance [22]. In principle, the director should play a key role in the selection of actors, although in practice this role is often shared (or even taken away from him) by the producer, especially in those performances that are more market oriented. In this case, for promotional purposes, it often happens that a resounding name and media presence is a more important factor than the acting ability of the individual [24].

2.6.2. Preparation phase

With a tidy script and chosen actors, we have laid the foundation for the preparation of the performance. In this phase, it is necessary to prepare costumes and props for the actors, determine the necessary stage elements on stage, and make plans for sound and lighting. The performance preparation team will be further expanded with specialists in these areas. The stage master with his assistants will be responsible for the scenography, the sound technician with his team will be responsible for the sound implementation, and the lighting designer will be responsible for the lighting [25]. Each of them will contribute their share to the successful performance of the performance and help the actors to present the story to the visitors as clearly as possible, in accordance with the vision of the text writer and director.

Scenography has long been more than just a painted backdrop for a performance, as was the case in ancient Greece. When planning, of course, the technical specifics of the stage are considered, such as the surface and shape of the stage, as well as the lighting, acoustics, and possibilities of interaction between the actors and the audience [26]. Even the ancient theater of Greece knew the beginnings of "stage technique" for changing scenes and the first special effects: *deus ex machina* [26]. The term refers to a technique in ancient Greek theater, when seemingly impossible circumstances were resolved with the intervention of the gods. The actor in the role of a god was either lowered onto the stage with a simple crane or appeared from a hole under the stage, covered with a flap. In the Middle Ages, theater was initially at the service of church liturgy, and it was only with its move from churches to squares those theatrical performances in the true sense of the word began, which in the 14th century led to the unification of the basic principles of scenography. Italian Renaissance theater in the 15th century laid the foundations of theater scenography that are still valid today, based mainly on the visual effect on the visitor [26]. Echoes of such flexibility in the scene can still be seen today in puppet shows, which is not surprising, as puppetry is also closely related to *commedia dell'arte*. There are 6 basic stage layouts of scenography for theater:

- frontal,
- central (like a circus arena),
- circular (the play takes place in a circle around the spectators who are seated in the middle of the circle),
- simultaneous events in several locations (the audience is mobile and moves from one location to another: a typical example is a carnival),
- dispersed event space (the audience moves from one location to another during the performance as planned) [26].

The director, together with his team and the stage master, will create a plan for the scene that will serve for the performance of the performance. Today, scenography is no longer just physical elements, more and more projections and even a whole range of digital tools are being used, which can replace physical equipment. A modern scenographer is a person who knows how to give the scene a meaning that the text of the performance requires by choosing the scenography. Modern scenography therefore requires intensive cooperation between the director, actors, text writer, dramaturge, stage workers, sound designer, musicians (if they are included in the performance) [26].

Like scenography, the choice of lighting and sound during the performance also helps to tell the story. With light, we direct the viewer's attention at a given moment in the performance, establish an atmosphere or conjure up a specific time in which the scene takes place. The same applies to sound, which can additionally enhance the impression of the reality of what is happening on stage (e.g. the sound of a car on the street). The soundscape can be precisely coordinated with the reactions and text of the actors, if this contributes to a better impression of the performance [27].

And finally, it is necessary to choose the right costumes for the actors so that they blend in with the character they portray on stage. Costume design has come a long way from the ancient beginnings of theater to the present day. In ancient Greece, the main part of the costume design were masks with dramatic facial expressions, which served either for a comic or grotesque effect. At the same time, they made it possible for the same actor to play several roles, as his real face remained hidden [28].

In addition, women were not allowed to perform in the theater for a long time, so their roles were played by men (even with the help of masks). Over time, costume design expanded to include clothing, which reached its peak with Baroque theater. Towards the end of the 19th century, the trend of costumes in the theater turned away from exaggeration and extravagance towards a more authentic representation of the period in which the play takes place [28]. The task of costumes is precisely this: to help make the performance as convincing as possible for the audience. Therefore, it is important that the choice of costumes is appropriate for the story, that it reflects the time and environment in which it takes place. Like everything else connected to the performance, the choice of costumes (and props) must also be done in harmony with the direction, scenography, and other stage techniques, and of course the actors [28].

2.6.3. Rehearsals

Once the script is finalized and the concept for the set, costumes, lighting, and sound design has been established, rehearsals can begin. The production team remains open to changes to any of the components of the performance based on decisions made during rehearsals.

Before the first rehearsal on stage, it is recommended that the text be read together several times (table reading). While reading, participants should take notes on their thoughts and after several readings, try to summarize the content of the performance in a few sentences. The performance is then divided into several parts and each part is rehearsed separately. Even if the text is not structured, it can be divided into meaningful parts, for example, when the scene changes or when a new, important character enters [22]. Just like the text, the rehearsal process itself should also be well-structured until the performance. Create a calendar to schedule the rehearsal process. For example, for a performance with eight scenes, decide that the first three scenes will be rehearsed in the first week, the next three scenes will be added in the following week, and so on. The first rehearsal should be dedicated to creating the right atmosphere in the team [22].

Once you start a weekly (or daily) rehearsal schedule, make sure to clearly define the goals for each rehearsal. Ensure that only the actors who are needed for that part of the performance are present at rehearsals. Before starting work, it is a good idea to check that all participants are well-acquainted with the content of the passage and the characteristics of their character. Even though you have already come to the rehearsal with a finished script, remain open to suggestions that arise during rehearsals [22]. If the scene is not yet fully developed, it is perfectly acceptable to interrupt the actors during the performance to give them instructions for a better performance. This is also part of the performance creation process. Once the scene is finally finished, it is played again in its entirety, without interruption [25].

The rehearsal process is largely dependent on the time available to prepare the performance. European theaters, with their system of state support for artists, have better conditions for preparing performances, as they can afford to have several weeks of intensive rehearsals before the premiere, in some cases even several months. On the other hand, in the US, it is difficult for the director and producer to afford more than four weeks to prepare for the premiere [25]. Four weeks should in principle be enough time to prepare the text for performance on stage [25].

After completing rehearsals with the actors, their performance must be synchronized with the scenography, lighting, sound and other technical elements of the performance. The technical part of the performance is tested beforehand, without the actors, in a technical rehearsal, and then a joint rehearsal is carried out with the actors, where the last details can be coordinated. At this point, you must also be prepared for major corrections to the planned performance, as the director's (and actors') vision of the performance may not match the technical solutions. Again, European theaters have an advantage here, as they allow the team more time for joint rehearsals on stage with the technical staff [25].

2.6.4. The performance of the play

The crucial moment of a play's production is the first performance. Before this, there is usually a dress rehearsal – a performance without an audience, carried out in the same way as the later premiere. Any last details that need to be corrected before the premiere can be identified here, and the entire team involved in the performance gets a real feel for the performance. During the performance, the staff responsible for the audience are also involved in the team. The people responsible for promoting and selling tickets have already been working with us during the preparation of the performance, and now they will be joined by the hall manager and his team, who will make sure that the hall is ready for the arrival of visitors and that everyone finds their place in the hall.

A properly structured preparation process will lead to a successful performance that will be enjoyed by both the audience and the actors on and off the stage. After the performance, it makes sense to evaluate the work done, especially if we have planned repetitions of the performance. Each successfully completed performance should be a challenge for us to continue working, so that we will dare to do even more each time and explore directions in the theater that we have not yet explored until then [23].

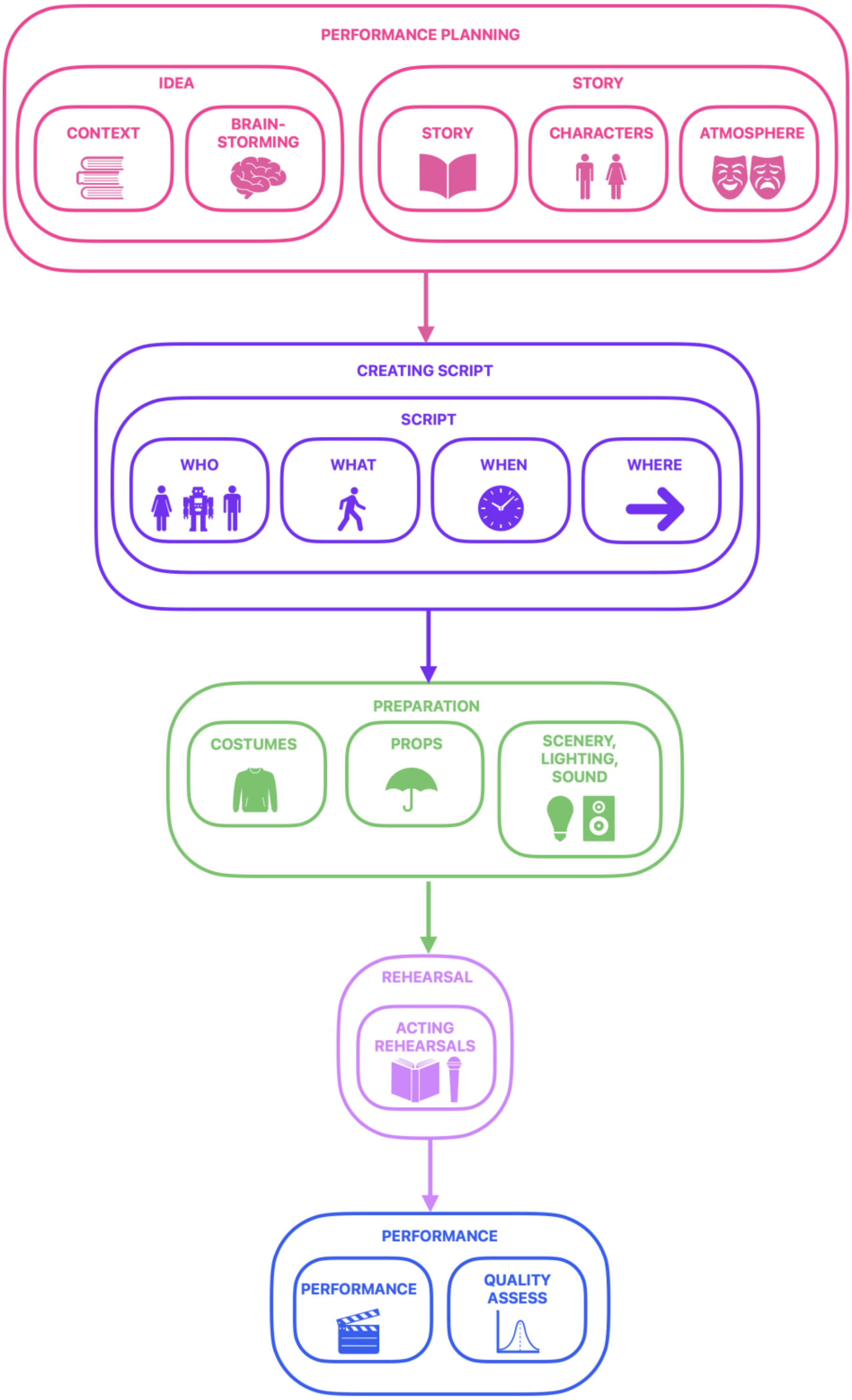


Figure 31. Development of a play.

3. Robots in Theater

Recently, there are more and more plays in which, in addition to people, robots take part as actors. They can be non-autonomous and autonomous, depending on the situation and their role in the play. In the following, several examples from around the world with different types and roles of robots will be given.

3.1. Non-autonomous robots

Non-autonomous robots cannot make decisions on their own. They require the intervention of people in order to work correctly or what is expected of them. This intervention can be via a computer program or some kind of remote control.

3.1.1. Humans as Robots in Theater

To celebrate the 100th anniversary of the word *robot*, the Croatian Robotic Association, University of Zagreb Faculty of Electrical Engineering and Computing, Boom! Theater and Zagreb Youth Theater presented a theatrical performance of RUR in a slightly more modern version than the original [29]. In the drama **RURURURURURURUR**, the actors had two roles, a human and a robot. The goal of the play was to answer the question "Are humans responsible for the environmental crisis?" and "What could the robots do with their rebellion if it's true?". The play premiered on March 20, 2022, and was held on several more dates.

Figure 32. RURURURURURURUR.

3.1.2. Puppet Robots

Robots have also made appearances in the realm of puppet theater. One example is the use of **robotic puppets** in plays by Vladimir Zakharov. Additionally, robots have been employed as **puppeteers for operating marionettes**, such as the use of two robotic arms for this purpose. Robotics also holds potential for the preservation of ancient art forms, such as the traditional Malaysian and Indonesian shadow puppetry known as wayang kulit, using **3D-printed figures controlled by robotics**. In education, robotic puppets have been utilized for role-playing in schools, as children often find it easier to engage with technology, allowing them to develop important social and other skills.

Vladimir Zakharov (Russia), a cybernetics engineer, is renowned for his transformative impact on puppet theatre. As a solo performer, he assumed multiple roles, including those of light technician, costume designer, scriptwriter, set designer, and voice actor. Zakharov's hallmark creations are **electro-**

mechanical puppets equipped with advanced electronics, programmed with the software of his own design, enabling them to move and speak with remarkable fluidity and precision [30]. YouTube video: [31].

In a fascinating example of human-robot collaboration, an **industrial robot KUKA has been designed to control marionettes (Austria)** [32]. This is achieved by recording the movements of a human puppeteer and reproducing them with the help of two robotic arms. Moving forward, the next phase of development involves the integration of **artificial intelligence** to design puppet shows and create new performances autonomously. This breakthrough has the potential to revolutionize the field of puppetry by expanding the possibilities of what can be achieved with the art form. YouTube video: How KUKA robots work as puppeteers: [33].

In late 2022, a groundbreaking development took place in Malaysia with the introduction of a **robotic wayang kulit**. Utilizing **3D printed puppets and shadow theater**, robots were employed to operate the traditional puppets to preserve this art form, which has been rapidly declining. The incorporation of technology with traditional art aims to make it more appealing to modern youth and ensure its continued existence [34].

Lentintin Studios [35] is a robotic puppet theater in Croatia. A few students from one high school in Zagreb, Croatia had an idea for that theater and have started an exciting project. Subsequently, they have performed at numerous events and won awards for their performances. They make almost all parts of the theater show themselves by cutting, drilling, measuring, screwing, 3D printing various objects, and programming. The role of the robots here is to start the whole show.

YouTube video: Robot Puppet Theatre: [36].

3.2. Autonomous robots

Autonomous robots can perform work without human intervention. The most common examples of such robots are robotic vacuum cleaners, self-driving cars and some industrial robots.

3.2.1. Industrial robots

The Baxter Project (UK) [37] is an innovative initiative that seeks to transform Baxter, a social robot commonly used in industrial settings, into a performer. Through this endeavor, the project explores the concept of robots as performers, the character traits they can exhibit, and the insights they offer into human behavior.

One of the most notable achievements of the Baxter Project, conducted between 2015 and 2016, was the creation of the captivating short film, "**Machine-Hamlet: To Be, or Not to Be.**" In this film, Baxter the robot takes on the role of an actor rehearsing alongside human actors for a performance of Shakespeare's "Hamlet." The primary goal of the film was to imbue the robot with a sense of subjectivity and character. This required the team to employ innovative techniques that could convey Baxter's emotions and actions in a way that resonated with adult audiences.
YouTube video: Machine-Hamlet: To be, or not to be [38].

Figure 33. Baxter [39].

3.2.2. Humanoid Robots

The theatre company Rimini Protokoll, Germany, has created an intriguing play entitled "**Uncanny Valley**" [40] in which a remarkably lifelike **animatronic model** serves as the **sole performer**. The concept behind this play involved crafting a monologue that could be delivered by a robot possessing a strikingly human appearance. Although the resemblance of robots to humans may initially elicit feelings of acceptance, an excessive similarity can provoke mistrust and an unsettling feeling that blurs the lines between humanity and machine [41]. This phenomenon is known as the "uncanny valley," a term coined by Japanese robotics researchers. Stefan Kaegi and Thomas Melle drew inspiration from this concept when crafting the eponymous play.

YouTube video: Teatro a Mil 2021: Trailer Uncanny Valley [42].

The production of the **Copernicus Science Centre**, Poland, incorporates state-of-the-art humanoid robots that utilize compressed air to power their movements, resulting in expertly engineered and captivating 20-minute performances in plays “**Prince Ferrix and Princess Crystal**” and “**The Secret Of An Empty Drawer, or The Ghosts Of The Fourth Dimension**”. These productions feature two or three fully programmable, human-sized robots that operate via advanced algorithms and code, which utilize a form of artificial intelligence. These robots, known as **RoboThespians**, are equipped with automated movements and predetermined gestures, casting a mesmerizing presence on stage. Since their introduction in 2010, these tireless performers have dazzled audiences of all ages, particularly those ages four and up [43].

YouTube video: Robotic Theatre: All in One Theatre By Engineered Arts [44].

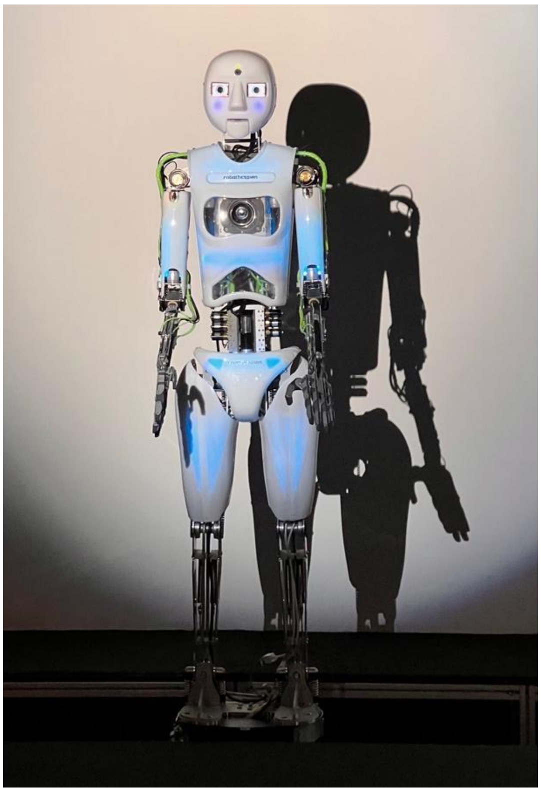


Figure 34. RoboThespians in Prince Ferrix and Princess Crystal.

During the year 2014, a highly engaging interactive project [45] was undertaken for computer science students at the University of Iowa, USA. As part of this project, students were required to design a **dance choreography specifically for robots**, and subsequently program them to perform the dance as part of the final performance. In the fall semester of that year, students of Robot Theater were tasked with programming a set of humanoid robots to deliver monologues, execute magic tricks, enact skits, and explore the intricate relationship that exists between humans and robots. This was accomplished by utilizing five state-of-the-art programmable **Nao humanoid robots**, affectionately named Alberto, Christopher, Denise, Daniel, and Amanda. The performances were aimed at K12 students, encompassing those in kindergarten, primary school, and high school, and were presented over three seminar seasons.

YouTube video: Inspiring Students with Inquiry-Guided Learning [46].

Figure 35. Nao [47] .

One hundred years of the word robot was marked by the performance of **R.U.R.** at the University of Zagreb Faculty of Electrical Engineering and Computing, Croatia [48]. In addition to human actors played by students, the play also featured the robots Nao and Pepper. The paper [48] analyzes in detail the **requirements that robots must meet** in order to act in a play (eg, human appearance, advanced communication skills, excellent mobility, adaptability to unstructured environment and others).

YouTube video: Autonomous robots as actors in the play R.U.R. [49].

The play Heddatron by Skidmore College, USA, features a total of 10 robots made for this play, with 5 robots in prominent roles alongside human actors and 5 small autonomous robots that move around the stage. In the play, robots kidnap a pregnant housewife from her home and coerce her to play the lead role of Hedda in their production. The humanoid robots are **controlled remotely by human operators**, and their **lines are pre-recorded**. The play was first performed in 2006 for adult audiences [50].

YouTube video: Heddatron [51].

My Square Lady [52], a groundbreaking **robot-reality-opera**, involved the collaboration of over 150 individuals, including musicians, singers, performers, technicians, and scientists. The show, which took place in June and July of 2015 at the Komische Oper Berlin, Germany, featured an autonomous learning robot named Myon as its star performer. Myon's objective was to become more human and to experience emotions. The **operatic robot** was created by the Neurorobotics Research Laboratory at Berlin's Humboldt University and the European Union's Artificial Language Evolution on Autonomous Robots project. Myon sang and moved throughout the performance, interacting seamlessly with the rest of the cast. Interestingly, no one controlled Myon from backstage; instead, the researchers and performers spent **two years teaching the robot** how to sing with the orchestra, navigate the stage, and respond to visual and auditory cues.

YouTube video: My Square Lady by Komische Oper Berlin [53].

Figure 36. Myon [54].

The 2009 play "**Robots**", Les voyages extraordinaires, by Swiss theatre director, the Federal Institute of Technology in Lausanne, the Lausanne Cantonal Art School and the Barnabé Theatre, features three highly advanced autonomous robots that can interact with both the actors and the set design. In the play, the robots assist a human actor in meeting a woman. Dialogue is absent from the performance, with emotions being conveyed through the musical score and scenic design [55].

YouTube video: ROBOTS - Theater play [56].

Figure 37. Robots, Les voyages extraordinaires [57].

The development of theatrical performances featuring robots was a collaborative endeavor between **Oriza Hirata and Hiroshi Ishiguro**, the director of the Laboratory for Intelligent Robotics at Osaka University [58]. Rather than attempting to establish a definition for robots, Hirata and Ishiguro aimed to explore the nature of humanity through the creation of robot-assisted performances. The robot's involvement in these performances was achieved through three distinct methods: **software integration** (by pre-recording human actor gesture sequences [59]), **pre-programming**, and **remote control**. The performances themselves feature a mix of human and robotic actors, with notable plays including "**I, Worker**" (2008), "**Sayonara**" (2010), and "**La Métamorphose**" (2014).

Sayonara [60] is a theatrical production lasting approximately 20 minutes that features the use of a teleoperated android robot named **Geminoid F**, designed to resemble an actual woman. To control the android's movements on stage, the **body motion of a human actor was preprocessed and turned into a set of commands**, including lip movements which were estimated using sound recognition. A great deal of effort was put into making the android's performance appear as natural as possible. The play itself depicts a scene in which a woman, suffering from a serious illness, communicates with a robot companion. The woman is portrayed by a human actress, while Geminoid F plays the role of the robot. During the play, the android recites poetry to the dying woman, raising thought-provoking issues related to life and death. In the live production, it was suggested that the robot had been purchased by the dying girl's father to keep her company. Notably, the theatrical production served as a research platform through which techniques for making androids appear more natural were explored. A subsequent study revealed that approximately 5% of audience members were "tricked" into believing that the android was, in fact, a human being.

YouTube video: Androido Human Theater Sayonara [61].

In Sayonara [62], the robot is designed to resemble the human actor as closely as possible through lighting, set design, and movement, but its reasoning and speech remain distant. On the other hand, in **I, Worker**, the robots (**Robovie R3**) have a comic appearance and one robot has a gloomy, depressing personality, similar to its human master. Both plays succeeded by having human actors hold back their performances to match the capabilities of the robots. While both plays highlight the contrast between human fragility and robot immortality, they also demonstrate how spectators can develop empathic feelings for robots. Humans tend to attribute emotions such as loneliness and affection to robots, blurring the line between human and machine. Overall, these plays demonstrate how robots can elicit emotions from humans through various means and how they can be used as a tool for **exploring the boundaries of human emotions and interactions** [63].

YouTube video: Robot Human Theater I, Worker [64].

The use of **robotic and virtual characters** can manifest in various ways, ranging from autonomous and partially autonomous control to puppeteering, scripting, or real-time control based on human body movements (embodied telepresence). Additionally, it is possible to accommodate various modes of distant human participation, including not only video conferencing but also control of robots and/or virtual characters. One example is in Ibn Sina Interactive Theater [65].

3.3. Artificial Intelligence and Robots in Theater

Ubiquitous artificial intelligence (AI) can also be connected to robots in the theater. Among other things, it can be used to generate play ideas, a full script or a poster for the play.

3.3.1. How does artificial intelligence imagine robots in the theater?

AI-based image generators can create unique images from textual descriptions. By utilizing machine learning algorithms, these generators can interpret natural language descriptions and translate them into corresponding images. The development of text-to-image models can be attributed to advancements in deep neural networks that occurred in the mid-2010s [66]. Several text-to-image generators are used to conduct experiments, both free and commercial, using the text prompt "**robots in the theater**." The resulting images can be seen in Figure 38. Figures are created using OpenAI Dall-E 2 [67].

Figure 38. AI generated robots in theater.

3.3.2. Can robots write a theatre play?

Robots could be programmed to **generate text or ideas for a play**, and they could potentially be used to **assist human playwrights** in the writing process. Several artificial intelligence programs have also been developed to write poetry, fiction, and other types of creative writing. It is possible that these types of programs could be used to generate ideas or text for a theater play. Here are a few different ways that artificial intelligence (AI) techniques can be used to write theater play scenarios [68][69]:

1. AI systems can be trained on a dataset of existing theater play scenarios and then used to **generate new scenarios by combining elements from different plays** in the dataset. For example, an AI system might be trained on a dataset of Shakespearean plays, and then generate a new play by combining elements such as characters, plot points, and dialogue from different Shakespeare plays.
2. AI systems can be used to analyze **existing theater play scenarios and suggest changes or improvements**. For example, an AI system might be trained on a dataset of successful theater

play scenarios and then used to analyze a new play scenario and suggest changes that would make the play more likely to be successful.
3. AI systems can be used to generate **individual elements of a theater play scenario**, such as characters, plot points, or dialogue. For example, an AI system might be trained on a dataset of character descriptions and then used to generate a new character for a theater play.

But it is worth mentioning that the resulting scenarios often require significant editing and refinement by human writers.

To celebrate the 100th anniversary of the existence of the word "robot" and to find out the answer to the question "Can a robot write a play?" a team of experts from various areas started an exciting project. They wanted to generate the scenario of a theater play with the help of artificial intelligence. In the end, they succeeded, and on 26 February 2021, the premiere of the first play written by AI was held, entitled **AI: When a Robot Writes a Play**. Regarding the covid measures at the time, people were watching the play premiere online. The fact that as many as 18,450 devices connected to the play show how successful the performance was [70].

3.4. Robots in theaters for educational purposes

Educational robots are often used in schools, both for learning programming and robotics itself, and for developing many 21st century skills. Some of the applications are in the popularization of reading, in learning foreign languages, but also directly in making stage performances with robots.

3.4.1. Theater meets robot – toward inclusive STEAM education

The paper "Theater meets robot – toward inclusive STEAM education" [71] proposes a novel approach to robotics education by integrating theater into the learning process. This approach aims to enhance and develop the skills required for 21st-century learners, such as problem-solving, communication, and critical thinking. The authors suggest that the process of ideation, planning, creation, and sharing of a theatrical play with the programming of robots as actors can bring forward these skills.

The theater robotics framework involves starting with a context, such as a story, fairytale, or historical event, in which the students retrieve and comprehend information. This step is geared towards developing skills in literature, history, communication, media literacy, and other related subjects. Once the context is understood, the students write a script for the theater play. In parallel or after the script is developed, the students start crafting actors for the play using robotics platforms such as Lego Mindstorms or building robots from scratch with Arduino or similar controlling technology. The use of 3D printers and similar assets can also be helpful in this phase, despite their complex user interfaces and workflows.

Overall, the integration of theater into robotics education provides a unique and engaging approach that encourages students to apply their knowledge and skills in new and creative ways. It fosters collaboration, critical thinking, and problem-solving skills while simultaneously developing students' technical competencies.

3.4.2. Robot theater with children for STEAM education

A long-term study was conducted utilizing various robots, including Darwin, Nao, Robosapien, Pleo, Zoomer, Romo, and BB-8, to interact with a small group of children aged 5 to 7 years. The study spanned nine weeks, with one-hour sessions held every week as an after-school activity. Researchers aimed to engage the children in scriptwriting for the robots, with some of the robots being remote-controlled toys and others being too delicate and costly for direct interaction, only responsive to voice commands.

The study incorporated age-appropriate concepts of robotics and programming, introducing the children to if-then clauses, and guiding them in the creation of clay model robots, while also developing their skills in scriptwriting. One key observation was that children of this age could not often judge the feasibility of their stories, as well as the narrative structure of a play, requiring the researchers to rework and expand upon the children's ideas to create a cohesive script.

In addition to writing the script, the children also created the props and scenery and rehearsed the play. Key takeaways from the study included the observation that the scriptwriting and line memorization took longer than expected and that the cooperation of teachers familiar with the children was beneficial to the success of the program. The study also found that adapting a known story may be more feasible than creating an original narrative.

The program was successful in generating interest among children in robotics, although it did not necessarily spark an interest in theater in all cases. It was noted that children often formed emotional bonds with the robots they had used previously, which may be an important consideration in developing further applications of robotic technology in education and play [72].

3.4.3. Robots in educational role playing

Robotic dolls are utilized as a pedagogical tool to facilitate educational activities in kindergarten settings. These dolls are designed to support imaginative play or role-play, among both teachers and students, thereby fostering the development of motor skills, communication, and creativity in young children. Powered by batteries, these dolls are remotely controlled by users to engage in reciprocal games and conversations with their human counterparts [73].

3.4.4. RoboCup Junior OnStage

RoboCup is an international scientific initiative aimed at improving intelligent robots. At annual events, scientists and enthusiasts compete in leagues: Soccer, Rescue, Home and Industrial. In order to promote robotics among children and young people, the RoboCup Junior league was launched. Focus of this league lies on education, developing knowledge in the field of electronics, hardware and software as well as development of social skills such as team work. Students can compete in three challenges: Soccer, Rescue and OnStage (formerly known as Dance). In OnStage category [74], students need to design, build, and program autonomous robots and to create a performance with them. The performance can be dance, theater play, storytelling, magic show or even art installation. Students can be between 14 and 19 years old. Each team should develop something new, that was not seen before. Robot should be autonomous, designed and construct by students (if possible not from the commercial kit). It is encouraging that robots communicate between each other during the performance using infrared, Bluetooth, or similar protocols and that they interact with students using sensors. The teams are judge based on: (a) OnStage performance (live performance in front of the judges, 40% of total score), (b) OnStage technical interview (presentation of robots, programs, electrical design, 30% of score), (c) OnStage technical demonstration video (demonstration without costumes on robots, 15% of score), (d) OnStage technical description poster (explanation of used technology, 15% of score). After first performance, teams get feedback and time to better prepare the second performance. Many of the performances in last few years can be freely viewed on https://www.youtube.com/@rcjonstage.

Figure 39. RoboCup Junior on Stage, Croatian national competition 2018.

4. Implementation of robots in theater

Robots in theater can play various roles. They can be completely absent from the performance, simply set decoration, or even the main and only actors. Their appearances range from humanoid robots to robotic arms, vehicles, and even pets. They can embody positive or negative characters and be either remote-controlled or autonomous. Following, you will find ten examples of theater performances featuring robots, created in collaboration with young people or for young audiences.

4.1. RURURURURURURURUR

Title: RURURURURURURURUR

Link to the play: www.facebook.com/watch/?v=1136146563592102

Human-robot ratio:

Plot Summary: The play begins in a library where the supervisor explains to the audience where they are and what terrible event has happened that day. Namely, a highly sensitive document has been stolen from the library's confidential archive, which exposes all people to potentially fatal risk. This document is the famous dramatic text R.U.R.

Considering the original text of the drama R.U.R., where robots were oppressed and, realizing this, raised a rebellion, people were no longer allowed to let other robots read this drama so that they would not now try to become aware of these facts again and act similarly to the robots in the drama. Therefore, the robots were only allowed to read R.U.R. up to a certain page (more precisely 51.) where they were obedient and exemplary in their work, and everything after that page was not available to them because then problems begin and the robotic rebellion. Therefore, a big problem arose when the drama disappeared.

In the introductory scene, the supervisor divides the present audience into defense (defends robots with the thesis "Robots are not guilty.") and the prosecution (accuses robots "Robots are guilty.") and the task of the audience divided in this way is to discover through the performance what really happened to the original text and prevent its spread among the population, thus saving human existence. After the division, the audience passes into a new room where the rest of the performance takes place.

At the very beginning, the robots and people have fun at which they celebrate the restoration of the planet Earth, but then a tragedy happens - one man fell dead. In the rest of the performance, they try to find out what exactly happened, who is to blame for the tragedy and where R.U.R. disappeared. The scenes are divided into actions centered on robots, or rather centered on people, and the audience, consisting of defense and prosecution, interactively moves through the space and tries to help the supervisors find out what actually happened.

At the end of the action, the robots again succeed in their plan and lead to the extinction of the human race, but this time only in order to effectively restore the planet Earth for which, as they say, people made them. In the end, they bring people back to life.

Performance photograph:

Figure 40. RURURURURURURURUR on stage.

Number of actors in the performance: 12

Actor roles in the performance:

a) Act around the robots
b) Communicate with the robot
c) Carry the robot
d) Must know how to turn the robot on/off
e) Must know how to program/assemble the robot
f) Act as robots
g) There are no actors in the performance

Number of robots used in the performance: 0

Appearance of robots:

a) machine
b) vehicle
c) animal
d) human

Robots used: -

Link to robot manufacturer/robot website: -

Robot price:

Similar robots that can be used instead of the one listed: Humanoid robots of human size can replace people who play robots in the performance. For example, Geminoid DK [75] or Sophia [76] and similar.

Performance steps:

1. Story and script
2. Making costumes, props, scenery, lighting
3. Actors learn their lines through reading exercises
4. Actors learn their walk: once the story is conceived and the text is written for the actors, they need to learn their lines and behavior on stage
5. Synchronization of actors on stage: when each actor learns his part, it is necessary to rehearse part by part of the performance together with all the necessary actors on stage so that they are synchronized and can perform the entire performance as intended.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Robot description: The robots were played by people in the performance. With appropriate clothing and makeup, they looked like robots (an example can be seen in the performance photos).

How the robot moves in the performance: -

Robot movement diagram: -

Expected space the robot can cover: -

Example robot program: -

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots

d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: No

Restrictions on robot use in performance: -

Added value: The robots and humans in the performance are distinguished by the different clothes they wear. The robots are not portrayed as machines, but are instead designed to look naturally human.

Possible upgrades: Introducing at least one humanoid robot that could act as the leader of the robots. The robots could be actors in the performance instead of people acting as robots. The robots could appear as a surprise element in certain parts of the performance. Robots could also be introduced as part of the scenery or backdrop.

4.2. Birthday present

Title: Birthday present

Link to the play: www.youtube.com/watch?v=gDq-ICT1kiQ&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf

Human-robot ratio:

Plot Summary: Little girl Lorena has a birthday and wishes for a robot that can be assembled into different shapes from her mom and dad. Dad disagrees with buying it because he thinks such a robot is too expensive. The girl bursts into tears. Mom persuades Dad to go check the price of the robot, which they eventually do and buy the girl her much-desired gift.

Performance photograph:

Figure 41. Birthday present on stage.

Number of actors in the performance: 4

Appearance of robots:

- a) machine
- **b) vehicle**
- c) animal
- d) human

Actor roles in the performance:

- **a) Act around the robots**
- b) Communicate with the robot

c) **Carry the robot**
d) **Must know how to turn the robot on/off**
e) **Must know how to program/assemble the robot**
f) Act as robots
g) There are no actors in the performance

Number of robots used in the performance: 1

Robots used: Lego Spike Prime

Link to robot manufacturer/robot website: https://education.lego.com/en-us/products/lego-education-spike-prime-set/45678

Robot price: 500 €

Similar robots that can be used instead of the one listed: Fischertechnik

Performance steps:

1. The plot of the performance was conceived and divided into four acts.
2. The story was written.
3. A robot suitable for the performance was selected.
4. Based on the story, the dialogue between the actors was written.
5. The actors learned the text.
6. The positions and movements on stage were determined.
7. The robot was assembled, and for straight-forward movement, the built-in program was used, which only needed to be started by pressing the buttons on the robot's programmable module.
8. The actors and the robot were synchronized.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) **Need to assemble the robot**

Robot description: The robot is 30 x 20 cm in size and has 4 wheels, each of which is powered by a servo motor. It is made of Lego elements that give it the appearance of a vehicle in combination with a human appearance, as it has a kind of face and eyes made of two programmable LED modules.

How the robot moves in the performance: The robot is in a box and is not visible at the beginning of the performance. The actors who play the parents take the robot from the sales actor and bring it to the girl in their hands and give it to her. The girl turns it on, starts the built-in program for straight-line movement, and adjusts the speed to the maximum possible. She lowers the robot to the floor and it moves straight forward.

Robot movement diagram: At the beginning of the performance, the robot is placed in a box. The parents bring it in their hands and give it to the girl. She is standing with her left side facing the audience. After the girl turns on the robot and starts the built-in program and lowers it to the floor, the robot moves straight forward and exits the frame to the left.

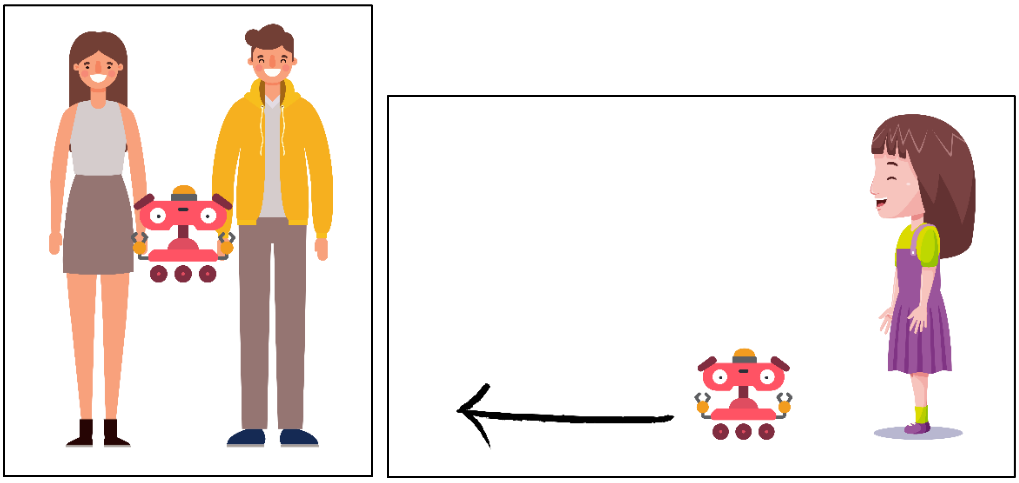


Figure 42. Robot movement diagram in a play *Birthday present*.

Expected space the robot can cover: 30 cm x 500 cm

Example robot program: A demo program was used with the robot.

Amount of programming knowledge needed to program this robot:

- **a) Adapted for beginners**
- b) Need to know the basics of programming
- c) Advanced programming knowledge required

Who can program this robot:

- **a) Children under 7 years old**
- **b) Children 7-10 years old**
- **c) Children 11-14 years old**
- **d) Youth 14-20**
- **e) Teachers**
- **f) Professionals**

Robot role:

- a) Backdrop
- b) Part of the scenery
- **c) Play prop**
- **d) Minor character**
- e) Character
- f) Main character

Amount of human-robot interaction:

- a) Robots move independently on stage, the performance does not depend on their movement
- b) People control robots remotely
- c) Robots move independently on stage, people adjust to robots
- **d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time**
- e) Robots have sensors and adapt to humans
- f) Artificial intelligence is used to control robots
- g) Robots are played by people who move independently on stage

Robot technician: No. A technician is needed to start the built-in program if the actor is unable to do so.

Restrictions on robot use in performance: The robot is relatively small and cannot be seen well in the performance.

Added value: In this performance, the robot is the subject of the action because the girl wants it as a birthday present. She emphasizes that the robot must be able to take on various shapes, which shows the audience that robots are modular and that it is up to human creativity to decide what they will look like, which further popularizes robotics among the audience of the performance.

Possible upgrades: The robot can be upgraded with additional elements to increase its size, and it can also be enlarged with additional materials (paper, fabric, wire, etc.). Additionally, the script can be modified to make the robot more involved in the performance.

4.3. Cleaning robot

Title: Cleaning robot

Link to the play: https://www.youtube.com/watch?v=-rR5o_hHaYM&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=2

Human-robot ratio:

Plot Summary: Four children (three sisters and a brother) are lying in the room, listening to music, dozing off, and tapping on their cell phones. Their mother enters the room and scolds them for not tidying up their room and forces them to clean it up, which they refuse to do. The mother calls the father, who takes the children's cell phones away from them and says he will keep them until the room is cleaned. The children reluctantly get up and start cleaning, when the brother remembers that their mother had once bought a cleaning robot, and one of the sisters finds it in a box, takes it out, and the robot starts cleaning. The children go back to their idleness. The robot moves back and forth across the room for a while, then demonstratively lowers its head to the floor and turns off. The children are worried because the robot is out of battery, they put it back in the box and finish cleaning the room. Soon the parents come and give the children their cell phones back for completing the task, and they continue to laze around.

Performance photograph:

Figure 43. Cleaning robot on stage.

Figure 44. Lego Spike Prime robot for the Cleaning robot play.

Number of actors in the performance: 6

Actor roles in the performance:

- **a) Act around the robots**
- b) Communicate with the robot
- **c) Carry the robot**
- **d) Must know how to turn the robot on/off**
- **e) Must know how to program/assemble the robot**
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 1

Appearance of robots:

- a) machine
- **b) vehicle**
- c) animal
- d) human

Robots used: Lego Spike Prime

Link to robot manufacturer/robot website: https://education.lego.com/en-us/products/lego-education-spike-prime-set/45678

Robot price: 500 €

Similar robots that can be used instead of the one listed: Fischertechnik

Performance steps:

1. The plot of the performance was conceived.
2. The story was written.
3. A robot suitable for the performance was selected.
4. Based on the story, the dialogue between the actors was written.
5. The actors learned the text.
6. The positions and movements on stage were determined.
7. The robot was assembled and programmed.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Robot description: The robot is 40 x 30 cm in size, has 4 wheels, two of which are powered by servo motors, allowing the robot to move forward and backward and turn left and right, if the number of rotations of specific motors is set in the program code. It has improvised cleaning blades at the front, also powered by a motor. It is made of Lego elements that give it the appearance of a rally car and a human-like appearance, as it has eyes made of two programmable LED modules, and the robot's head can move (up or down) with the help of a motor.

How the robot moves in the performance: The robot is located in a box and is not visible in the frame. As the robot is shaped like a vehicle, it moves forward and backward on stage, raises and lowers its cleaning blades, and moves its head before turning off. The actors turn on the robot using a button on the programmable module, and a technician remotely uploads programs to the robot and starts them. The turned-off robot is put back in the box by the actors and is no longer visible in the frame.

Robot movement diagram: At the beginning of the performance, the robot is placed in a box (Figure 45a). The girl takes it out of the box and places it in the center of the stage in the foreground so that the audience can see it better, adjusts its blades and head, and turns on the robot (Figure 45b). After the technician uploads the program to the robot, the robot moves forward and backward, raises and lowers its blades 20 times (Figure 45c). Then it stops and turns off the LED lights. The technician uploads another program to the robot. The robot turns on, turns on the LED lights, moves forward for 3 seconds, stops, raises its blades, lowers them to the floor, turns off the LED lights, lowers its head to the floor, and turns off. The actors put the robot back in the box from which they took it (Figure 45d).

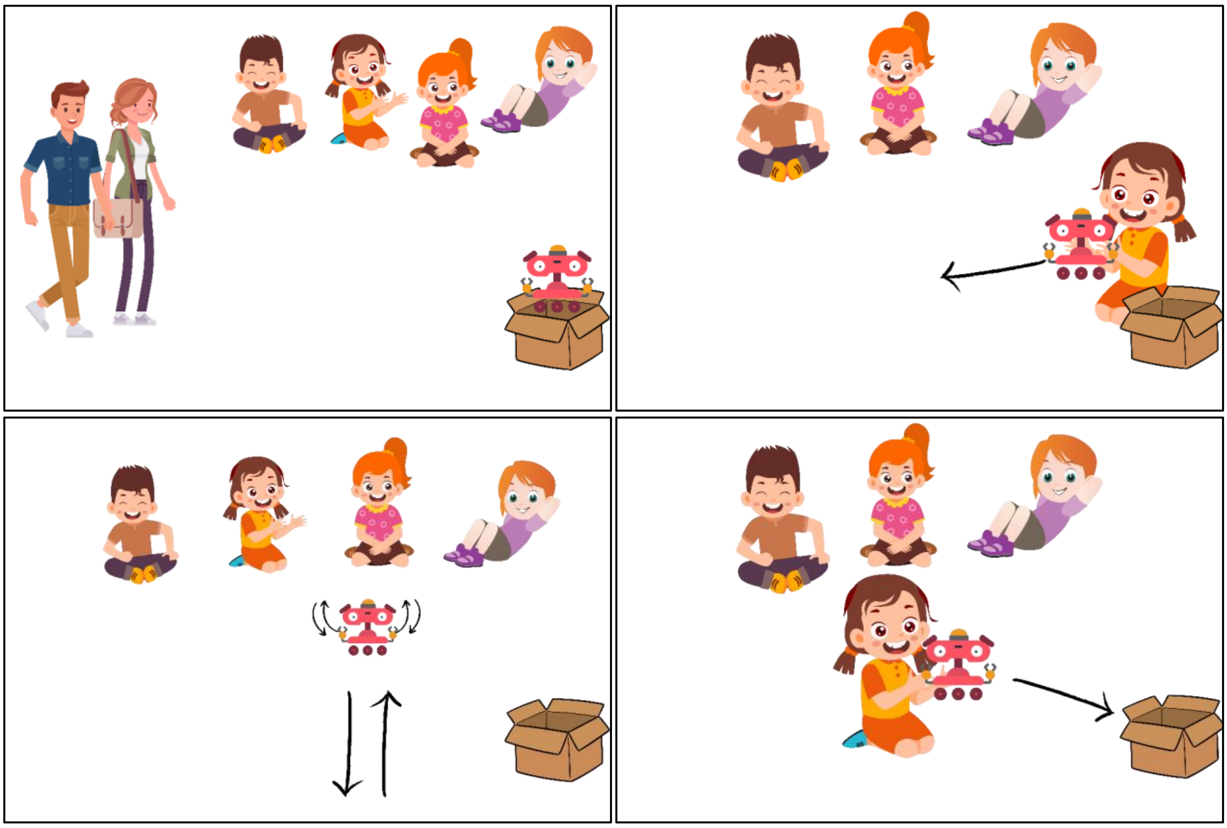


Figure 45. Robot movement diagram in a play *Cleaning robot* consists of four steps.

Expected space the robot can cover: 150 cm x 150 cm

Robot program example:

The program code for "cleaning" - the robot moving forward and backward, raising and lowering the blades is given in Figure 46. The program code for the robot shutting down due to low battery is given in Figure 47.

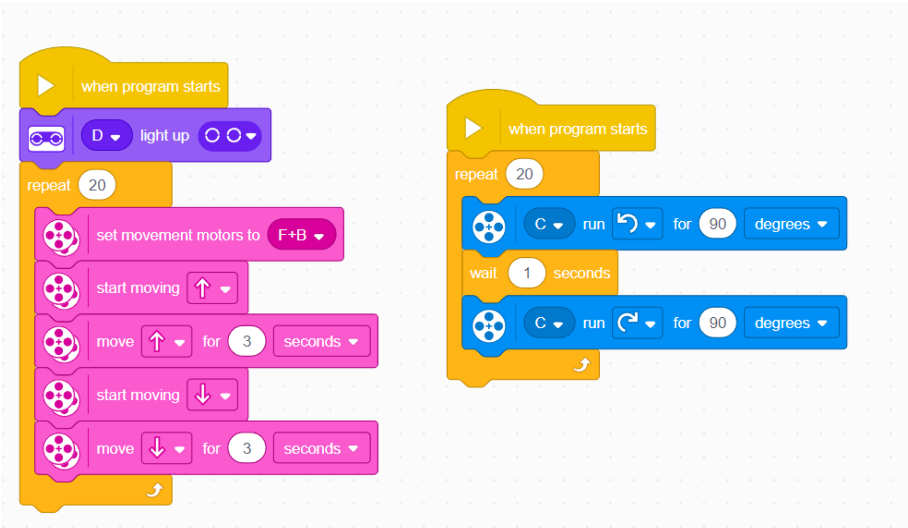


Figure 46. The program code for "cleaning".

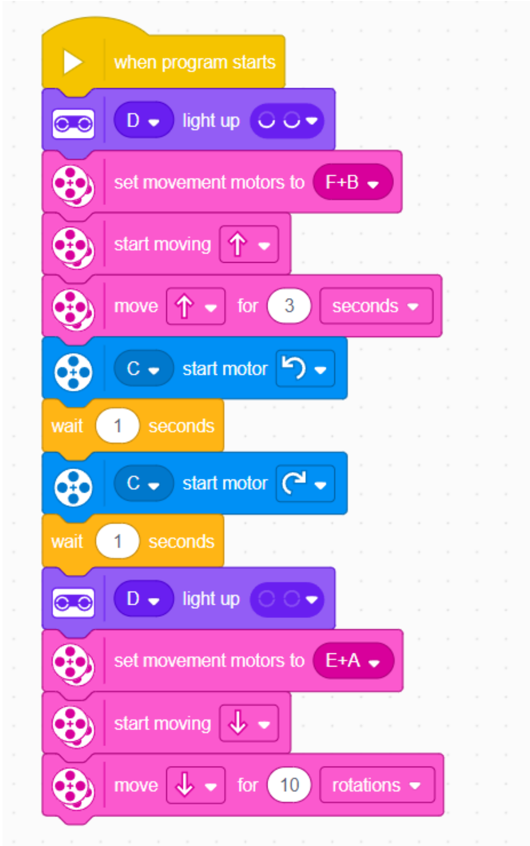


Figure 47. Program code for the robot shutting down due to low battery.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Yes, a technician is needed to wirelessly (via Bluetooth connection) upload and start different programs on the robot and play music.

Restrictions on robot use in performance: The robot's movement on stage is relatively unpredictable because it moves over garbage and paper that can change its direction. Therefore, there is a risk that it might go in the wrong direction when the robot needs to act out that its batteries are empty.

Added value: In this performance, the robot is the subject of action because the children use it as an assistant in cleaning the room, which further popularizes robotics among the audience of the performance as it demonstrates that robots are useful in performing household chores.

Possible upgrades: It is possible to improve the programs for the robot's movement to make it clean more effectively. Alternatively, it is possible to change the elements and instead of blades, create a kind of pusher that the robot could use to push the garbage into one pile.

4.4. Drone attack

Title: Drone attack

Link to the play:
https://www.youtube.com/watch?v=fUcl64b4gZk&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=3

Human-robot ratio:

Plot Summary: A rogue drone, tasked with endangering the city's inhabitants, attacks an innocent policeman walking peacefully down the street. However, to his aid comes a robo-tank that also patrols the city and protects people from attacks by enemy robots.

Performance photograph:

Figure 48. Drone attack on stage.

Number of actors in the performance: 1

Actor roles in the performance:

a) **Act around the robots**
b) **Communicate with the robot**
c) Carry the robot
d) Must know how to turn the robot on/off
e) Must know how to program/assemble the robot
f) Act as robots
g) There are no actors in the performance

Number of robots used in the performance: 2

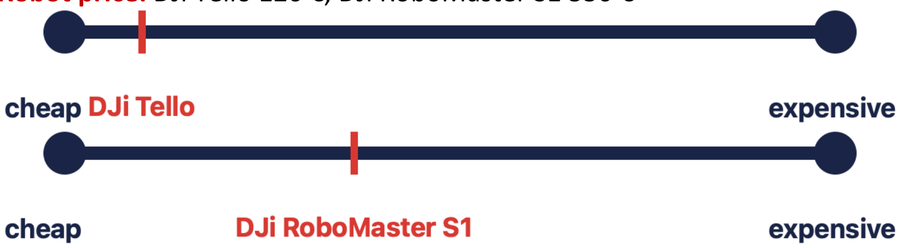
Appearance of robots:

a) machine
b) vehicle
c) animal
d) human

Robots used: dron DJi Tello, DJi RoboMaster S1

Link to robot manufacturer/robot website:
www.ryzerobotics.com/tello
https://www.dji.com/hr/robomaster-s1

Robot price: DJi Tello 120 €, DJi RoboMaster S1 550 €



Similar robots that can be used instead of the one listed: any other drone, e.g. DJi Tyze Tech Tello, Parrot Mambo, CoDrone or other

Performance steps:

1. A story is designed (a drone attacks a police officer, a robo-tank comes to his aid, neutralizes the drone, and saves the officer).
2. Appropriate robots have been selected for the performance.
3. It has been planned where the robot will stand, or from which side the human and robot will enter the frame, and from which side the drone.
4. Since there was no spoken text in the performance, the idea was for the actor to convey the action through gesturing and body language. At the same time, two technicians remotely control the robots. The actor has practiced the gestures, and the technicians have practiced controlling the robots according to the planned movement in the scene.
5. In several attempts, the actors and robots were synchronized.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Opis robota:
The RoboMaster S1 is a tank-shaped robot about 30 cm tall with four wheels, all of which are omnidirectional (allowing the robot to move in all directions). It has a cannon through which silicone balls can be shot. On the "head" where the cannon is located, there is also a camera through which the user can directly see the video feed from the robot. The robot is controlled via an app on a smartphone.

The DJI Tello is a programmable drone with four propulsion propellers, with a maximum speed of 8 m/s. It is controlled using an app on a smartphone. It has a front-facing camera through which the drone's point of view (POV) is visible in the app. The drone can also be programmed in the Scratch programming environment, making it possible to make the drone autonomous.

How the robot moves in the performance:
At the beginning of the performance, no robots are in the frame, but as the actor approaches the center of the frame, a drone enters, flying around (or "attacking") the actor. At the same time, from the left side of the frame, a tank-shaped robot enters, driving around the actor and shooting at the drone, causing the drone to land on the ground.

Robot movement diagram: The RoboMaster S1 is positioned on the left side to follow the man's movement in the performance, coming from the same side as him, while the drone comes from the right side of the frame. The RoboMaster S1 has an omnidirectional drive which allows it to move quickly and turn around obstacles. The drone flies around the man and can be characterized as an "annoying mosquito" that refuses to leave the man alone. The man did not need to manually move the robot since both were remotely controlled.

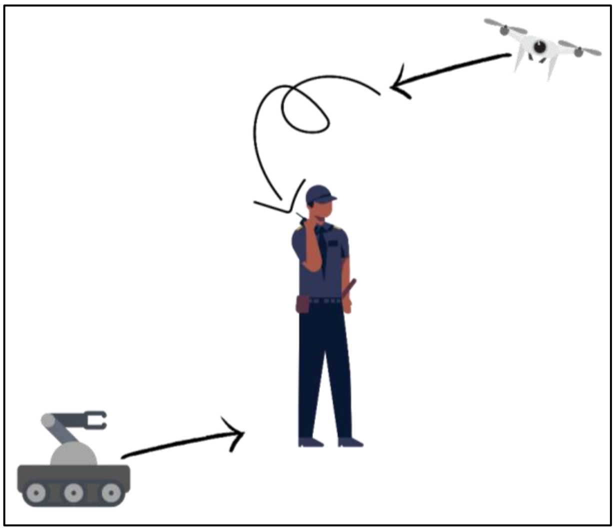


Figure 49. Robot movement diagram in a play *Drone attack*.

Expected space the robot can cover: DJI Tello dron 500 x 500 cm, DJi RoboMaster S1 500 x 500 cm

Example robot program:

Figure 50. Controlling the DJi RoboMaster robot.

Figure 51. Controlling the Tello drone.

Amount of programming knowledge needed to program this robot:

- **a) Adapted for beginners**
- b) Need to know the basics of programming
- c) Advanced programming knowledge required

Who can program this robot:

- a) Children under 7 years old
- b) Children 7-10 years old
- **c) Children 11-14 years old**
- **d) Youth 14-20**
- **e) Teachers**
- **f) Professionals**

Robot role:

- a) Backdrop
- b) Part of the scenery
- c) Play prop
- d) Minor character
- **e) Character**
- f) Main character

Amount of human-robot interaction:

- a) Robots move independently on stage, the performance does not depend on their movement
- **b) People control robots remotely**
- c) Robots move independently on stage, people adjust to robots
- d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
- e) Robots have sensors and adapt to humans
- f) Artificial intelligence is used to control robots
- g) Robots are played by people who move independently on stage

Robot technician: Yes, two technicians are required who remotely control the robots.

Restrictions on robot use in performance: Since neither robot has a dedicated controller for operating the robot (such as a joystick), control itself turns out to be imprecise and it is difficult to achieve exactly the desired movements of the robots. Also, the drone has no light effects, and due to its size, it is not very prominent. The loudness of the propellers can negatively affect the sound of the performance.

Added value: Repetitive roles are not a problem for the robot, they are also very precise and consistent. Given the different types of robots, viewers can learn quite a bit about their movements and thus get a glimpse into the world of robotics.

Possible upgrades: It is also possible to upgrade the robots in such a way that they become more prominent during the performance (for example, adding light effects to the drone).

4.5. Spiders and tank

Title: Spiders and tank

Link to the play:
https://www.youtube.com/watch?v=3mA38pu5paM&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=4

Human-robot ratio:

Plot Summary: Eva and her friends gathered to play a counting game when they were suddenly attacked by two frenzied robotic creatures resembling spiders. To rescue them from trouble, a patrol robo-tank, which has been defending residents from an invasion of terrifying hexapod robots for years, comes to their aid.

Performance photograph:

Figure 52. Spiders and tank on stage.

Figure 53. Robot STEMI.

Number of actors in the performance: 6

Actor roles in the performance:

- **a) Act around the robots**
- **b) Communicate with the robot**
- c) Carry the robot
- d) Must know how to turn the robot on/off
- e) Must know how to program/assemble the robot
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 3

Appearance of robots:

- a) machine
- **b) vehicle**
- **c) animal**
- d) human

Robots used: STEMI Hexapod robot, DJi RoboMaster S1

Link to robot manufacturer/robot website:
stemi.education/solutions/stemi-hexapod/
www.dji.com/hr/robomaster-s1

Robot price: STEMI Hexapod 340€, DJi RoboMaster S1 550€

Similar robots that can be used instead of the one listed: Lynxmotion T-Hex robots instead of STEMI robot, or robots assembled from Lego Spike Prime or Fischertechnik kits

Performance steps:

1. Robots were selected.
2. A story was devised that could be performed with the selected robots.
3. Due to the physical limitations of the robots, it was determined where the robots would stand at the beginning of the performance and how they would move across the stage.
4. Appropriate apps were downloaded to control the robots.
5. Actors practiced movements and speech.
6. The movements of actors and robots were synchronized.

Robot assembly:

- **a) Robot pre-assembled**
- b) Need to build/decorate the robot
- c) Need to assemble the robot

Robot description:
The RoboMaster S1 is a tank-shaped robot, about 30 cm tall with four wheels, all omnidirectional (allowing the robot to move in all directions). It has a cannon that can shoot silicone balls. On the "head" where the cannon is located, there is also a camera through which the user can directly see the robot's video feed. The robot is controlled via an app on a smartphone.
The STEMI Hexapod is a spider-like robot with 6 legs powered by small servo motors, about 10 centimeters tall, and controlled via an accompanying app. The app allows for changing the robot's position in place, changing the color of the LED lights within it, and controlling its movements.

How the robot moves in the performance: Due to the STEMI Hexapod robots' slow movement speed, they had to be placed as close to the frame as possible, on the very edge of the frame. The RoboMaster S1 moves quickly around the scene so it was placed a little further out of frame and waited for the STEMI Hexapod robots to approach the actors, after which the RoboMaster S1 enters the frame.

Robot movement diagram: STEMI Hexapod robots walking towards the children, with the RoboMaster S1 catching up to them as it enters the frame, and then the STEMI Hexapod robots are turned off.

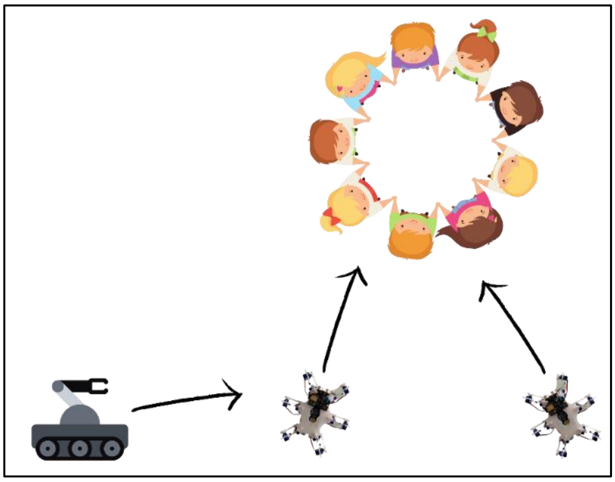


Figure 54. Robot movement diagram in a play *Spiders and tank*.

Expected space the robot can cover: STEMI Hexapod 300 x 300 cm, RoboMaster S1 500 x 500 cm

Example robot program:

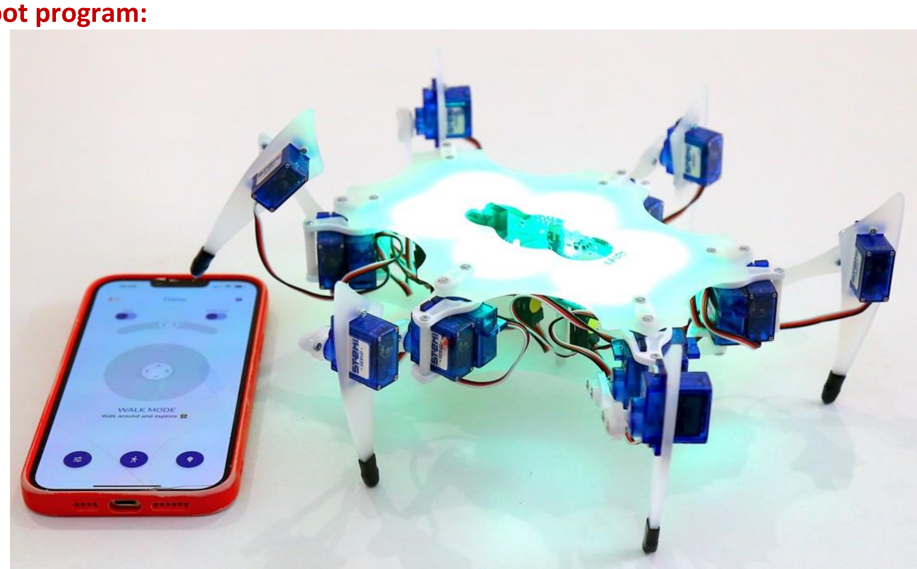


Figure 55. Controlling STEMI robot.

Amount of programming knowledge needed to program this robot:

- **a) Adapted for beginners**
- b) Need to know the basics of programming
- c) Advanced programming knowledge required

Who can program this robot:

- a) Children under 7 years old
- **b) Children 7-10 years old**
- **c) Children 11-14 years old**
- **d) Youth 14-20**
- **e) Teachers**
- **f) Professionals**

Robot role:

- a) Backdrop
- b) Part of the scenery
- c) Play prop
- **d) Minor character**
- **e) Character**
- f) Main character

Amount of human-robot interaction:

- a) Robots move independently on stage, the performance does not depend on their movement
- **b) People control robots remotely**
- c) Robots move independently on stage, people adjust to robots
- d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
- e) Robots have sensors and adapt to humans
- f) Artificial intelligence is used to control robots
- g) Robots are played by people who move independently on stage

Robot technician: Yes, an appropriate app needs to be downloaded on a smartphone for each robot and used to control it.

Restrictions on robot use in performance: Controlling the STEMI hexapod robots is somewhat clumsy, making their movement across the stage time-consuming (they are slow), so they need to be placed in the right position on stage. Also, due to their size, they are not very noticeable, although the programmable LED lights help a bit.

Added value: In this performance, the robots provide a surprise effect. Furthermore, they represent modern technology that children enjoy, making the performance more attractive and contemporary.

Possible upgrades: Robots can be upgraded by making suitable costumes, for example using a 3D printer to create additional elements that can be attached to the robots (STEMI hexapod) or using other materials like crepe paper, fabric, plastic, etc. This would make them more noticeable in the performance. Also, the STEMI hexapod robots should be somehow sped up, possibly by creating software code instead of using a remote control, as this could better regulate the speed of the robots' movement.

4.6. Tank attack

Title: Tank attack

Link to the play:
https://www.youtube.com/watch?v=VjoVC0VQXW8&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=5

Human-robot ratio:

Plot Summary: A frenzied drone tasked with endangering the city's residents attacks a woman walking her dog and their robotic pet chick as they cross the street. A police officer patrolling the city comes to their aid, protecting the people from attacks by hostile robots.

Performance photograph:

Figure 56. Tank attack on stage.

Number of actors in the performance: 2 persons and 1 dog

Actor roles in the performance:

- **a) Act around the robots**
- **b) Communicate with the robot**
- c) Carry the robot
- **d) Must know how to turn the robot on/off**
- e) Must know how to program/assemble the robot
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 3

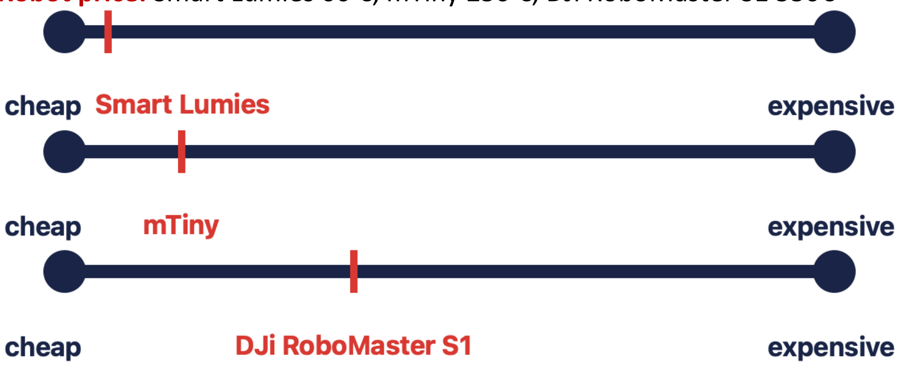
Appearance of robots:

- **a) machine**
- **b) vehicle**
- **c) animal**
- d) human

Robots used: Smart Lumies, mTiny, DJi RoboMaster S1

Link to robot manufacturer/robot website:
https://smartlumies.com/
https://www.makeblock.com/pages/mtiny-robot-toy
https://www.dji.com/hr/robomaster-s1

Robot price: Smart Lumies 60 €, mTiny 250 €, DJi RoboMaster S1 550€



Similar robots that can be used instead: Cubelets, Code & Go Robot Mouse Activity Set, Bluebot, Thymio, mBot, Codey-Rocky

Performance steps:

1. The story was designed (a tank attacks the dog walker, the dog, and the robot pet, and a police officer comes to their aid, driving off the tank robot and helping the walker, dog, and robot pet safely cross the street).
2. Appropriate robots were selected for the performance.
3. It was planned where the robots would stand, from which side the walker, dog, and robot pet would enter the frame, and from which the tank robot and the police officer.
4. The play had very little text, so there was no need for the actors to memorize it. Additionally, the idea was for the actors to perform the assigned actions with an emphasis on gesturing and body language.
5. The movements of the actors and robots were synchronized in several attempts.

Robot assembly:

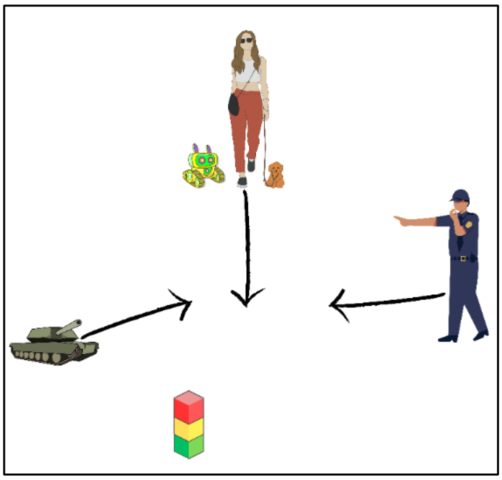
- **a) Robot pre-assembled**
- **b) Need to build/decorate the robot**
- c) Need to assemble the robot

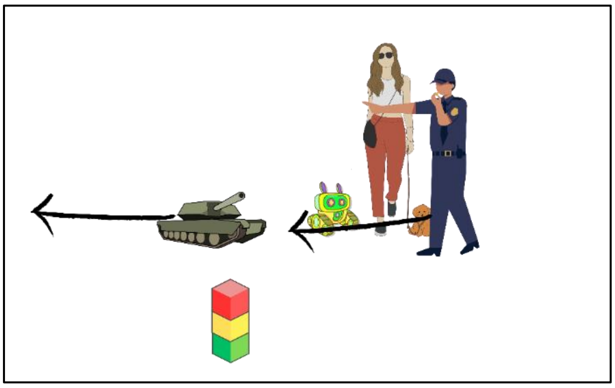
Robot description:
RoboMaster S1 is a tank-shaped robot, about 30 cm tall with four omnidirectional wheels (allowing the robot to move in all directions). It has a cannon that can shoot silicone balls. On the "head" where the cannon is located, there is also a camera through which the user can directly see the robot's video feed. The robot is controlled via an app on a smartphone.

Smart Lumies are programmable interactive glowing cubes measuring 10 x 10 x 10 cm, equipped with LED lighting surfaces and an array of sensors. They are not mobile, but can be stacked on top of each other to create glowing patterns. They are controlled using an app for smartphones or tablets.
mTiny is a three-wheeled robot measuring 11.30 × 9.00 × 8.70 cm, with LED eyes on the front that give it various expressions, and the set includes paper masks that allow the robot to take on various shapes (dog, cat, chick, etc.). It is controlled by a programming pen, which also acts as a remote control with a joystick. The robot is driven by the rear two wheels and can move in all directions.

How the robot moves in the performance: At the beginning, the walker, dog, and robot pet are in the frame. They move forward towards the audience. The walker leads the dog, walks, and types on her phone. The robot pet is controlled by a technician. About 5 meters in front of them, three Smart Lumies cubes are stacked vertically, representing a traffic light on the street. The tank robot is not in the frame. As the actors move forward, from the left side of the frame, the tank robot enters and attacks the walkers – moving forward and back with sound signals (sound of shooting). It is controlled by a technician. After the walker unsuccessfully tries to protect the dog and robotic pet she is walking with and fails to drive away the tank robot, a police officer enters from the right side of the frame and successfully drives the tank robot out of the frame. The police officer moves towards the left side of the frame, gesturing with his hands and voice to drive the tank robot away, and the tank robot moves backward. Both the police officer and the tank robot exit the frame on the left side. The police officer then returns to the frame and helps the walkers cross the street, and they all exit on the right side of the frame. Only the traffic light made of Smart Lumies cubes remains in the frame.

Robot movement diagram: At the beginning, the robot pet is positioned next to the dog walker and the dog. It moves slowly forward, matching the walking speed of the dog walker and the dog. The tank robot is positioned off-screen to the left (Figure 57a). At the moment when the tank robot frantically enters the frame from the left, moving quickly back and forth and turning left and right while shooting at the walkers with sound signals, the robot pet turns right and rotates 360° to be shielded by the walker's arms. After the police officer enters the frame from the right side, the tank robot moves backwards out of the frame to the left, continuing to shoot with sound signals (Figure 57b). The tank robot remains off-screen. The police officer re-enters the frame from the left side, offers his hand to help the walker up and leads her, along with the dog, out of the frame to the right side. The robot pet follows them, moving slowly to the right after them off-screen (Figure 57c).





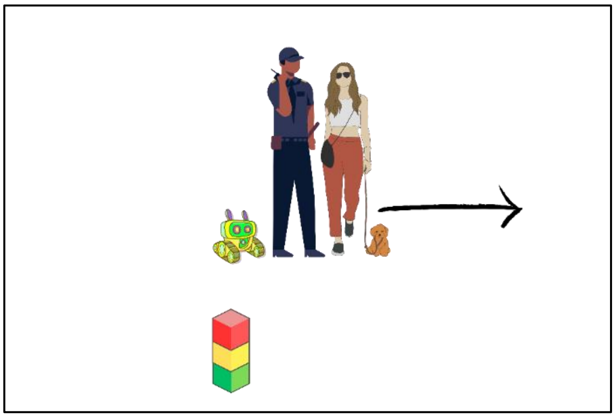


Figure 57. Robot movement diagram in a play *Tank attack*.

Expected space the robot can cover: RoboMaster S1 500 x 500 cm, Smart Lumies 15 x 15 cm, mTiny 500 x 500 cm

Robot program example:

Figure 58. Controlling the mTiny robot.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) **Robots move independently on stage, the performance does not depend on their movement**
b) **People control robots remotely**
c) **Robots move independently on stage, people adjust to robots**
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Yes, two robots are remotely controlled (RoboMaster S1 and mTiny).

Restrictions on robot use in performance: The RoboMaster S1 lacks a dedicated controller for robot operation (such as a joystick), making control imprecise and it is difficult to achieve exactly the desired robot movement. On the other hand, although the control of the movement of the mTiny robot is more precise because of the joystick controller, it is too slow and too small on stage, so a larger robot should definitely be used.

Added value: Since different shapes and types of robots are used, the viewer can gain insight into the field of robotics and the application of robots outside their original context. Furthermore, most of the robots used are educational robots and their use in the play as elements of modern technology connects these areas (technical and artistic), thus giving the opportunity for a larger number of people to be interested in the performance.

Possible upgrades: Upgrade the mTiny robot to be larger on stage or replace it with a similar, but larger and faster robot.

4.7. Eva and kids

Title: Eva and kids

Link to the play:
https://www.youtube.com/watch?v=pDqGK9uTex0&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=6

Human-robot ratio:

Plot Summary: Children approach the humanoid robot Eva to hang out together. They become bored, and one of the peers suggests dancing. The children notice that Eva isn't very adept at dancing, which leads them to start teasing her. However, they soon discover that, although mathematics is difficult for them, it is easy for Eva. In the end, they all decide to help each other improve at what they are not good at (the children will help Eva dance, and Eva will help them with mathematics), and they all embrace each other.

Performance photograph:

Figure 59. Eva and kids on stage.

Figure 60. NAO robot Eva.

Number of actors in the performance: 4

Actor roles in the performance:

- **a) Act around the robots**
- **b) Communicate with the robot**
- c) Carry the robot
- d) Must know how to turn the robot on/off
- e) Must know how to program/assemble the robot
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 1

Appearance of robots:

- a) machine
- b) vehicle
- c) animal
- **d) human**

Robots used: Humanoid robot NAO

Link to robot manufacturer/robot website: https://www.aldebaran.com/en/nao

Robot price: 10.000 €

Similar robots that can be used instead of the one listed: Alpha 1Pro, Aelos 1S, Aelos 1Pro

Performance steps:

1. The plot of the performance was devised.
2. Robots were selected: a humanoid robot suitable for a performance in which actors can communicate with the robot.
3. Considering the uneven floor and the slight instability of the humanoid robot, it was decided that it would be best to have the robot's actions centered around standing still to minimize movement.
4. Since the humanoid robot Eva is programmable, it was necessary to record voice and speech so it could "communicate" with the actors around it. Also, it was necessary to pre-program a "dance" sequence, so that it would activate at the right moment during the performance.
5. The movements and speech of the actors and the robot were synchronized.

Robot assembly:

- **a) Robot pre-assembled**
- b) Need to build/decorate the robot
- c) Need to assemble the robot

Robot description: The robot is humanoid-shaped, about 60 cm tall. It has two arms and two legs. As programming the legs is difficult and the robot is somewhat unstable, the performance suggests using only arm movements to reduce the unreliability factor. The robot is programmable, allowing movements of the arms, legs, and head, and also contains speakers through which recorded sound (speech) can be played.

How the robot moves in the performance: At the beginning of the performance, the robot stands in the center of the frame and moves only its head ("looking around"). Then it moves its arms and head simultaneously (dancing), and for the rest of the performance, it uses speakers and head movements for interaction.
Robot movement diagram: The robot is placed in the foreground in such a way that it is in the center of the frame in front of the actors. For simplicity, it remains standing in place and moves only its arms and head during the performance.

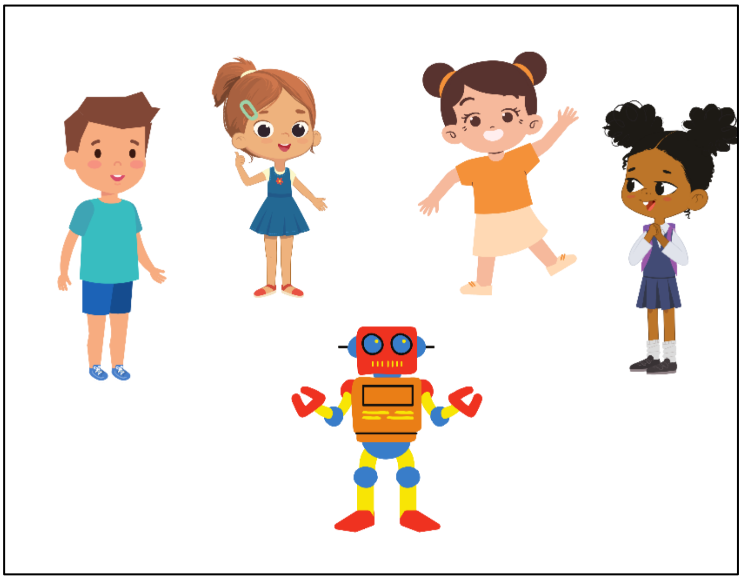


Figure 61. Robot movement diagram in a play *Eva and kids*.

Expected space the robot can cover: 50 x 50 cm

Example robot program:

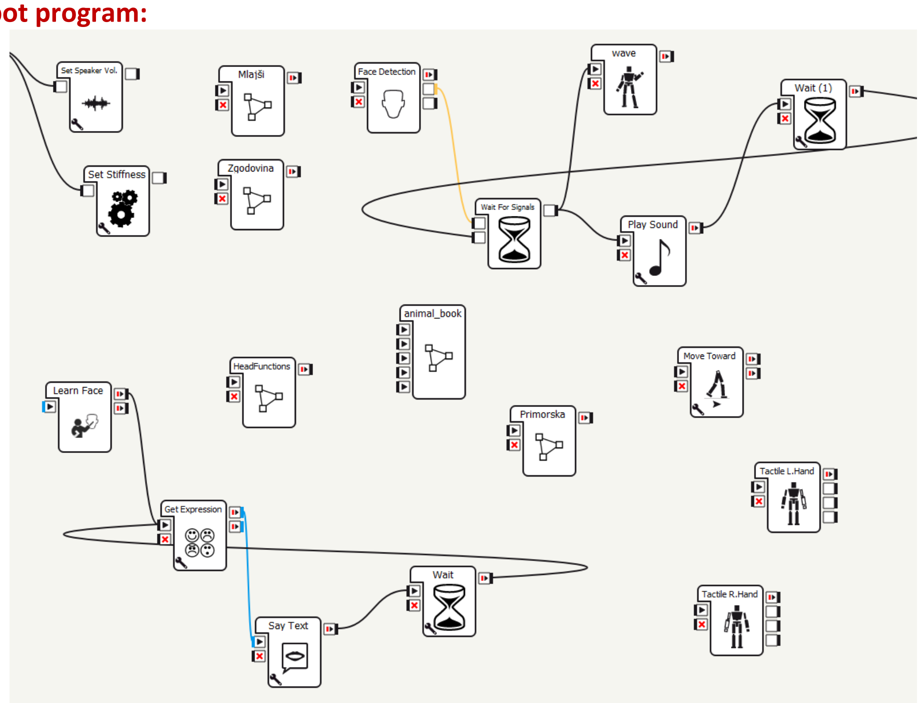


Figure 62. Controlling the Nao robot.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Yes, the robot needs to have a voice recorded which will serve as interaction in communication with people. It is also necessary to pre-program the robot's movements.

Restrictions on robot use in performance: This version of the humanoid robot is somewhat unstable and therefore it is "awkward" to try to program the legs. Also, programming itself is not simple, which requires having a technician who knows how to adjust the robot for the performance. For communication, the robot needs to be connected to a computer by cable, which also limits movement on stage.

Added value: The humanoid robot is an interesting type of robot because, as the robot type suggests, it looks like a human, which makes it intuitively easier for the audience to understand the possible movements of the robot. The speakers on it are loud enough, and the sound that comes out is clear enough for it to easily communicate with its surroundings, or other actors.

Possible upgrades: Larger surfaces on the robot's feet would make the robot more stable and able to move across the stage.

4.8. Zasavska robotnica

Title: *Zasavska robotnica*, a puppet show for children

Human-robot ratio:

Plot Summary: The performance aims to draw children's attention to the pollution of the Sava River with microplastics and its impact on the living beings that inhabit such waters. Robotnica narrates this story in interaction with actors and other puppets. Additionally, the project aims to demonstrate the possibilities of using modern robotic technology in puppetry through a marionette octopus controlled by a robotic arm, to enable more complex movements and performances in the future. This would allow the audience to experience the story in a completely different way than what we are accustomed to in puppet shows.

Performance photograph:

Figure 63. Zasavska robotnica on stage.

Number of actors in the performance: 2

Actor roles in the performance:

- **a) Act around the robots**
- **b) Communicate with the robot**
- c) Carry the robot
- d) Must know how to turn the robot on/off
- e) Must know how to program/assemble the robot
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 1

Appearance of robots:

- a) machine
- b) vehicle

c) animal
d) human

Robots used: Yaskawa Motoman Moto Mini robotic arm, with YRC1000 micro controller.

Link to robot manufacturer/robot website:
https://www.yaskawa.si/products/robots/handling-mounting/seriesdetail/serie/motomini_492

Robot price: 18.000 €

Similar robots that can be used instead of the one listed: small robotic arm Kuka 3r540

Performance steps:

1. The performance was planned from the beginning as a pilot project using robots. However, the story was written so that it could also be performed with ordinary marionettes. The main character, an octopus, was chosen because it best met the technical requirements of the robotic arm.
2. The robot arm has a limited weight it can safely lift. In the case of the Yaskawa arm, this weight is only 0.5 kg. Therefore, the octopus puppet controlled by the robotic arm had to be made from the lightest materials. The position on the stage had to be adjusted to the frame needed for the robotic arm's stability.
3. Actors learn their lines and walking. The learning and interpretation of the text did not differ from usual preparations for a performance. The robot did not affect the interpretation of the speech, and only minimal adjustments were needed for the actors' movements on stage. However, the robotic arm succeeded in replacing one of the actors who now did not need to be on stage during the performance.
4. Designing where the robot stands: the robot is placed in the center of the scene, and the frame of the robotic arm is also used as a stand for the set in the performance.
5. Since the robotic arm is already assembled, only a holder for the puppet and a metal structure within which the puppet can move need to be added.
6. The robot in the performance does not speak but moves the puppet according to a standard program for a robotic arm, where appropriate movements are programmed. Throughout the entire performance, a technician trained to use the robotic arm controls the robot.
7. According to the script, an octopus imitator follows its movements and adds a vocal image to the visual, other actors also react to the movements and synchronize with each other.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Robot description: A Yaskawa mini robotic arm is used to control the marionette, but robotic arms from other manufacturers with similar characteristics can also be used. The puppet is specially made for this performance because the robotic arm cannot lift a load heavier than 0.5 kg (it is essentially designed for screwing or welding, not lifting loads). To move the puppet, the robotic arm must be specially programmed in the programming language used by the robotic arm. Operating the robotic arm requires appropriate training and a license from Yaskawa.

How the robot moves in the performance: The Robotnica/puppet does not move during the performance; its tentacles, which are lightly attached to the robot's arm, are moved. It moves them so that Robotnica comes to life, creating the impression of movement.
Robot movement diagram: The octopus puppet is partially movable, with movements handled by the robotic arm. Since it is attached to a base (similar to frames with guides in the hands of puppeteers in classic puppetry), it does not move around the room, but it can flutter its tentacles creating the impression of a living being for the audience.

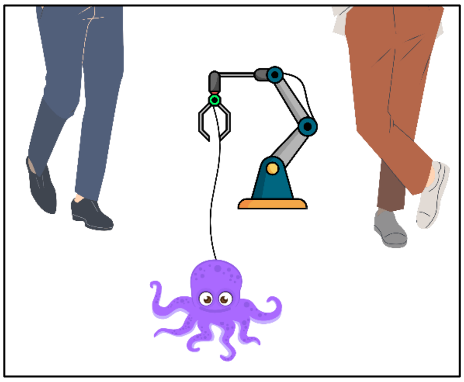


Figure 64. Robot movement diagram in a play *Zasavska robotnica*.

Expected space the robot can cover: Robotnica stands on a special stand, its tentacles are loosely connected to the frame on which it hangs below the robot's arm. The puppet itself does not move during the performance; the robotic arm, by moving up-down, left-right, moves the tentacles by a few centimeters, giving the impression that the puppet is alive and moving.

Robot program example:

```
def turnOnServos():
    global robot
    status = {}
    if FS100.ERROR_SUCCESS == robot.get_status(status):
        #print(status)
        if not status['servo_on']:
            robot.switch_power(FS100.POWER_TYPE_SERVO, FS100.POWER_SWITCH_ON)


def barvaOci(barva):
    global ser
    print(barva)
    ukaz2=str(0)+'\n'
    ser.write(ukaz2.encode())
    ukaz1=str(barva)+'\n'
    ser.write(ukaz1.encode())


def pozicijaOci(pozicija):
    global ser
    ukaz1=str(pozicija)+'\n'
    ser.write(ukaz1.encode())


def motorji(motor):
    global ser
    ukaz1=str(motor)+'\n'
    ser.write(ukaz1.encode())

def shuffleEyes():
    global ser
    ukaz="0\n"
    ser.write(ukaz.encode())
    time.sleep(1)
    ukaz="1\n"
    ser.write(ukaz.encode())
    time.sleep(1)
```

Figure 65. Program for robot Yaskawa Motoman Moto Mini.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) **Professionals**

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Yes. The robotic arm can only be operated by a technician who has a license to operate the robot issued by the manufacturer.

Restrictions on robot use in performance: The robotic arm itself is not a robot that could be an interesting character, at least in the context of this performance. Therefore, it is used as a device that allows the use of a specially adapted marionette, which comes to life and tells its story through it.

Added value: The performance and innovation in puppetry provide new possibilities for performing puppet shows. Using robots eliminates the need for an actor to lead the puppet. This is particularly difficult with marionettes, which can be large and heavy, and many puppeteers are older people who no longer have the strength to control the puppets. Moreover, if the robot is properly programmed, it can perform cleaner and more complex movements, enabling performances that were not previously possible due to the motor limitations of the actor. Additionally, the actor, freed from leading the marionette, can devote more attention to interpreting the text and the dramaturgy of the performance. This applies to both old puppeteers and younger generations, for whom moving the robotic puppet is an attractive phenomenon, both as spectators and as performers.

Possible upgrades: There is the possibility of combining the control of the robotic arm with BCI technology (controlling devices through a computer using brain waves), which would relieve actors of the need to physically control the puppet. The puppet would thus have more freedom of movement.

4.9. Journey of robot Zuma

Title: Journey of robot Zuma

Link to the play:
www.youtube.com/watch?v=3liY618AUwE&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=9

Human-robot ratio:

Plot Summary: The play "Journey of Robot Zuma" begins with the nostalgic reminiscence of the robot Zuma about its creation. A little girl in a remote village in France created Zuma with her own hands, a robot with a big heart and a strong desire to explore the world. One quiet evening, under the starry sky, Zuma gathered courage and embarked on a journey that would forever change its life. Throughout his journey, it encountered various people who exploited him for different tasks. Unfortunately, none of them worked out. His clumsiness and inability made him unhappy and discouraged until he arrived at the charming café "Le Petit." There, at first, he was unhappy; constantly bumping into people and tables, dropping things, and it seemed like he would never become a good waiter. But everything changed when he found a friend, a sympathetic colleague who helped him adapt to the new environment. Together, they used touch and color sensors to facilitate his movement and work. Thanks to her help, Zuma became a capable and reliable worker. His happiness and faith in people were restored, and the gratitude he felt was immense. The main message of the play is the power of friendship, adaptation, and support in overcoming life's challenges. Through Zuma's story, we are reminded that with a little help and understanding, everyone can find their place and purpose in the world.

Performance photograph:

Figure 66. Journey of robot Zuma on stage.

Figure 67. Robot Zuma.

Number of actors in the performance: 1

Actor roles in the performance:

- **a) Act around the robots**
- **b) Communicate with the robot**
- c) Carry the robot
- **d) Must know how to turn the robot on/off**
- e) Must know how to program/assemble the robot
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 1

Appearance of robots:

- a) machine
- b) vehicle
- c) animal
- **d) human**

Robots used: REV Robotics.

Link to robot manufacturer/robot website: https://www.revrobotics.com/

Robot price: 1.700 €

Similar robots that can be used instead of the one listed: goBilda (https://www.gobilda.com/)

Performance steps:

1. Story development: the first phase involves developing the story. In this play, the robot will play the role of a waiter in a small café. The story focuses on his challenges and adaptations in the new environment, emphasizing the importance of friendship and collaboration.
2. Robot assembly: parts from the REV Robotics kit were chosen for assembling the robot. A sturdy and stable structure was created to ensure optimal functionality and durability of the robot. A tablet with animated facial expressions was placed as the robot's face, allowing him to communicate and express emotions interactively.
3. Configuration and programming: in this phase, the robot was configured using the FTC Driver Station application. Programming was done in the REV Hardware Client, where basic functionalities necessary for the performance were implemented.
4. Story development and programming: a detailed story was developed, involving precise movements of the robot and interactions with the actors. Based on this development, programs were written to synchronize the robot's actions with the actors', enabling a seamless performance.
5. Actor-Robot Synchronization: The final stage involves synchronizing the actors and the robot during the performance. Through numerous rehearsals, consistency of all movements and actions was ensured, allowing a smooth and convincing storytelling.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Robot description: The robot used in the play is assembled from parts from the REV Robotics kits. The construction is sturdy and stable, thanks to the use of metal rods that provide a solid frame. The robot moves on four wheels, with two front wheels enabling left-right movement, providing it with the necessary mobility to perform various actions on stage. The robot's arms are fixed in one position and cannot move, but this is not necessary for the story's purposes. The robot's face is displayed through a tablet showing animated facial expressions, allowing the robot to express emotions and interact with the audience in an engaging manner. The animations change randomly, or it is possible to select one to loop. To move the robot, we use a combination of servo motors and wheels, allowing it precise movements according to a predefined plan. The robot's programming was done using the FTC Driver Station application and REV Hardware Client, where all the necessary functionalities and movements of the robot were defined. Additionally, touch and color sensors are integrated to allow the robot to navigate space better and avoid obstacles. The robot is designed to be as autonomous as possible but also adaptable enough to synchronize with the actors during the performance. Through careful programming and numerous rehearsals, synchronization of all the robot's movements with the actors' actions was achieved, enabling a flawless performance. Its appearance and movements are carefully designed to fit into the story and convey the message of adaptation, cooperation, and friendship.

How the robot moves in the performance: in the theater performance, all action takes place simultaneously on stage, meaning the entire set is always present. The main parts of the set include a café with a bar where the robot Zuma works as a bartender alongside his colleague, and a table where a guest is seated. Given this setup, the robot's movement can be executed in two ways.
Manual Control with Technician Assistance: a technician controls the robot Zuma using the FTC Driver Station app multiple times throughout the performance. Each movement of the robot is executed separately, according to a predetermined plan. This method allows for real-time adjustments to the robot's movements, which is useful in case of unforeseen situations on stage.
Automated Movement via Program: the second method involves starting the robot at the beginning of the performance, where the technician activates a program that controls the robot throughout the entire performance. For this approach, it is necessary to know the exact dimensions of the stage and the layout of the set. The robot needs to precisely know its position at all times, which requires detailed programming of all its movements in advance. This method can also be executed using simple Blocks code, but the program is longer as it encompasses all actions at once, which are performed sequentially.

Robot movement diagram:

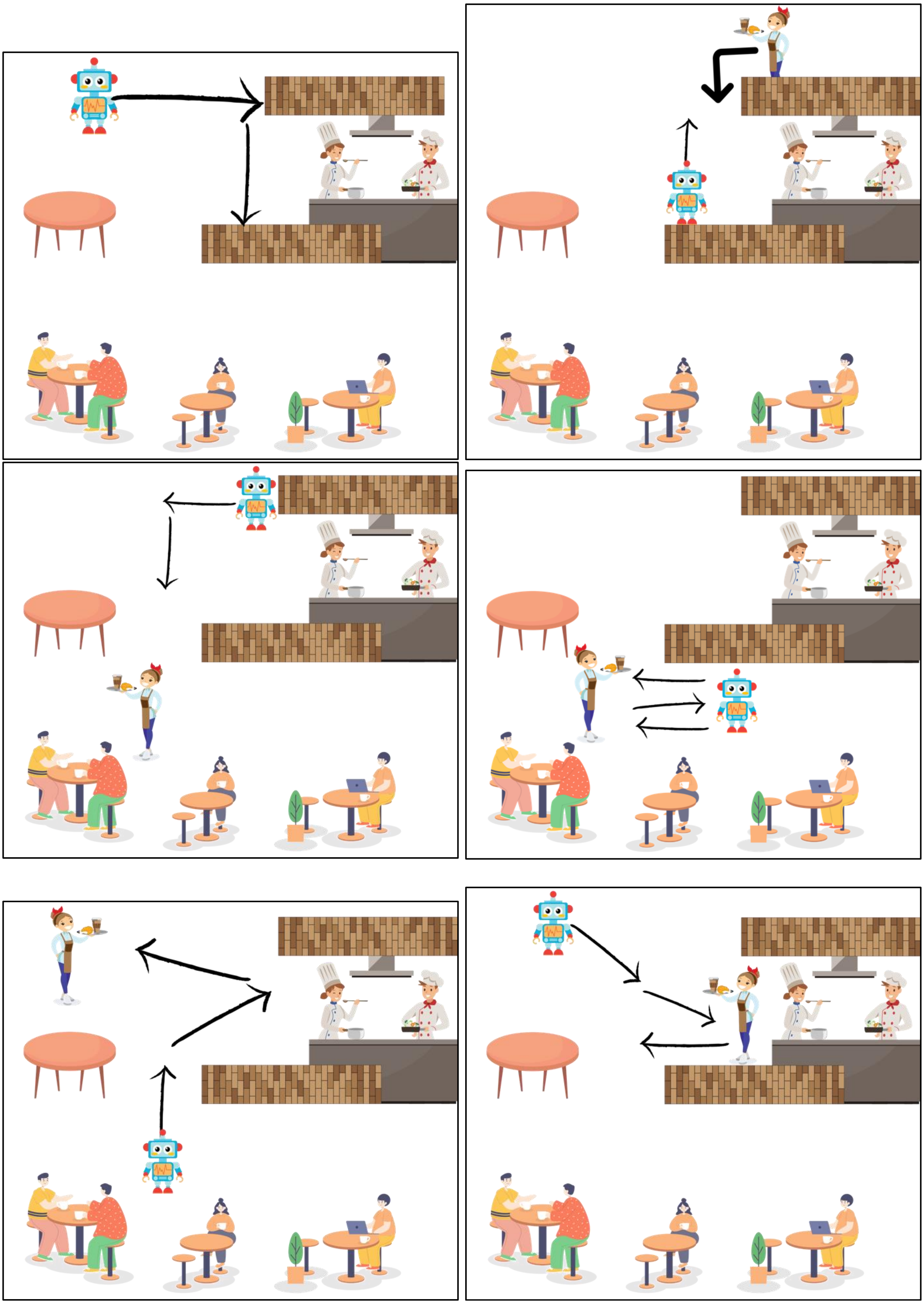


Figure 68. Robot movement diagram in a play *Journey of robot Zuma*.

Expected space the robot can cover: 500 x 500 cm

Robot program example:

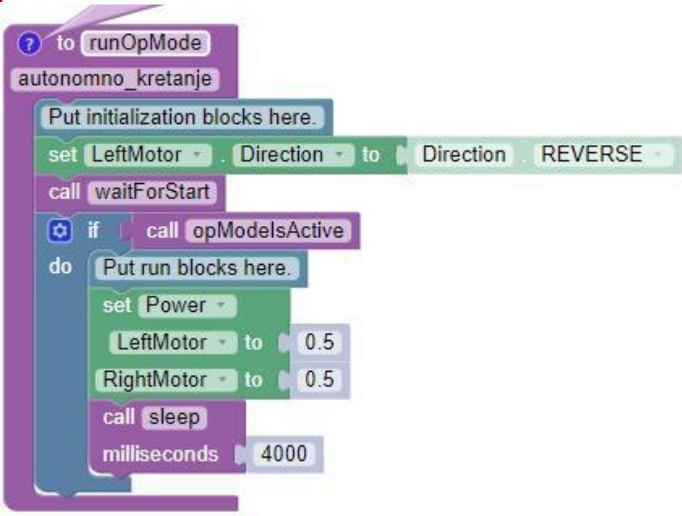


Figure 69. Code for moving forward.

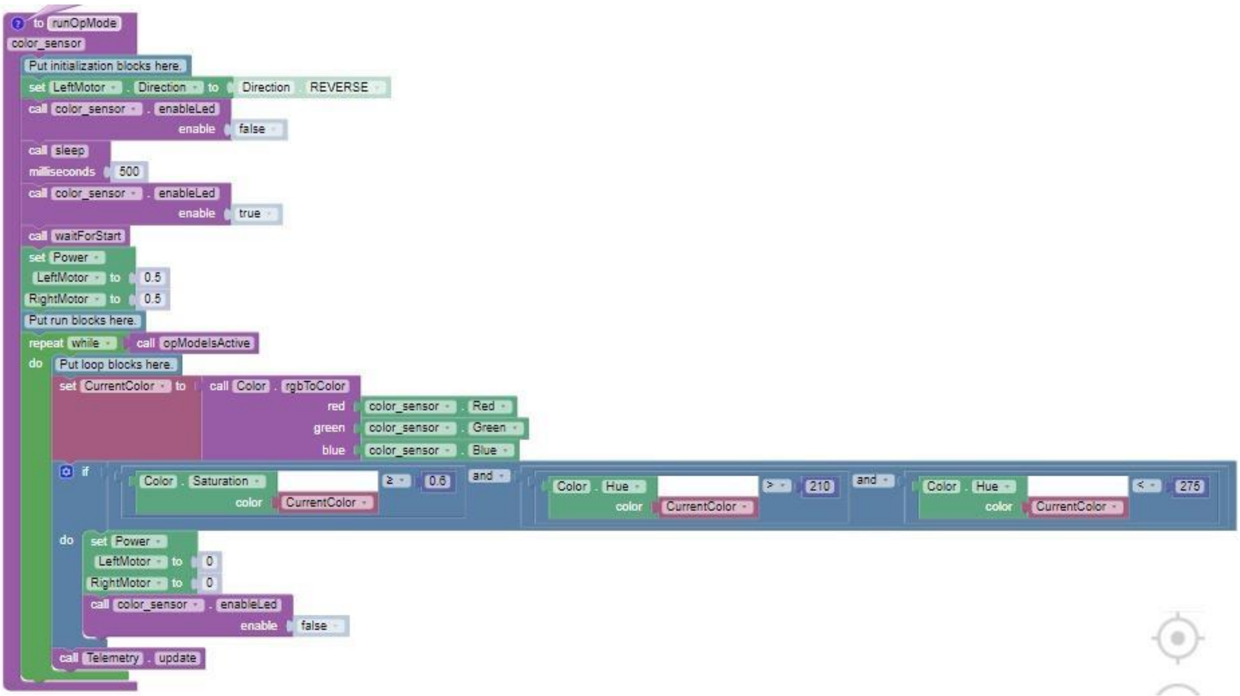


Figure 70. Code for color sensor.

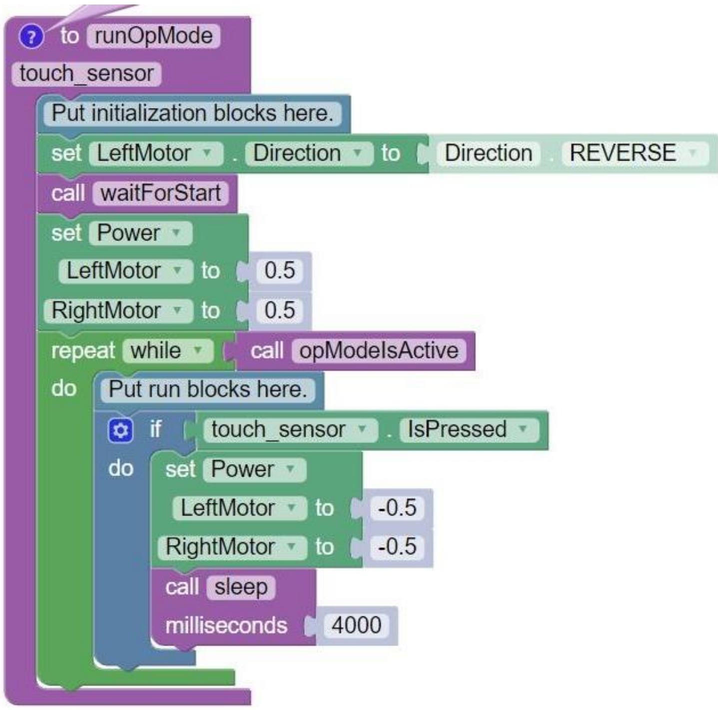


Figure 71. Code for touch sensor.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Yes, a technician is needed to operate the robot in the FTC Driver Station application.

Restrictions on robot use in performance: Limited mobility: fixed arms and a limited range of movement can reduce the robot's interaction capabilities with the environment and actors. Sound and vocal expression: the robot currently cannot speak, which may hinder conveying the story to the audience, but the robot's voice can be added using a tablet. Technical difficulties: battery issues, sensor malfunctions, or connectivity problems can disrupt the robot's operation. If technical difficulties occur during the play, it can negatively impact the performance.

Added value: Surprise and innovation effect: robots in the play bring an element of surprise that fascinates the audience. Spectators, especially children, enjoy unexpected elements, and the presence of robots on stage will surely capture their attention and interest. Learning through entertainment: using robots can be educational. Children can learn about robotics, technology, and programming through a fun and interactive story. The play can serve as inspiration for future roboticists and engineers. Light and sound effects: robots can be equipped with additional lights and sound effects that contribute to the atmosphere of the play. For example, the robot can have light effects that change according to emotions or scenes, creating a visually spectacular experience. Demonstration of modern technology: the play using robots demonstrates advanced technology in practice, which can be interesting and inspiring, especially for young audiences. Showing robots in everyday situations demonstrates how technology can be integrated into our lives in a creative way. Connection with the digital world: children today grow up with digital technology and are often fascinated by robotics and artificial intelligence. Using robots in the play can create a connection between their digital interests and the traditional art of theater, bridging the gap between two worlds. Flexibility and adaptability: robots can be programmed for different roles and tasks, allowing adaptation of the play to different audiences and situations. For example, the robot can change its appearance or function depending on the scenario, increasing the diversity and interest of the play.

Possible upgrades: Moving arms: adding moving arms would allow the robot to perform more complex tasks, such as serving drinks or interacting with props on stage. This addition would significantly increase the robot's ability to participate in various scenarios of the play. Advanced sensors: installing additional sensors, such as LIDAR or ultrasonic sensors, would enable more precise navigation and obstacle avoidance. These sensors would allow the robot to better "see" its environment and react to dynamic changes in space. Voice interaction: integrating voice modules would allow the robot to respond to voice commands and communicate with actors and the audience. This would add a new dimension to interaction and allow the robot to participate in dialogues during the play. Enhanced facial expressions: upgrading the tablet or screen with more advanced facial animation software would allow the robot to express a wider range of emotions. More realistic facial expressions would improve the robot's ability to convey emotions and react to situations in the play.

Note: the performance video was created using OpenShot Video Editor (https://www.openshot.org/), an extremely useful video editing tool. OpenShot is open-source software and is freely available for use and distribution. At the beginning of the video, photos were used that were generated via the Pixlr Image Generator (https://pixlr.com/image-generator/). Pixlr is also an open-source tool, which enables the creation and processing of images. The photos used in the video were generated during a free trial period, which allows their use and public publication (https://pixlr.com/license-and-services-agreement/).

4.10. Code error

Title: Code error

Link to the play:
https://www.youtube.com/watch?v=cWMFeg4MsY4&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=8

Human-robot ratio:

Plot Summary: Eva is a very friendly humanoid robot, until a programmer mistakenly changes her code. Then she becomes evil and bullies the other robots living in Robottown. The robots that have been living peacefully and having fun now have to organise themselves so that they do not get hurt when Eva crosses their way. They manage to outwit Eva and switch off her power supply. Meanwhile, the programmer has spotted his mistake and corrected it. Eva becomes a good friend to all the robots again.

Performance photograph:

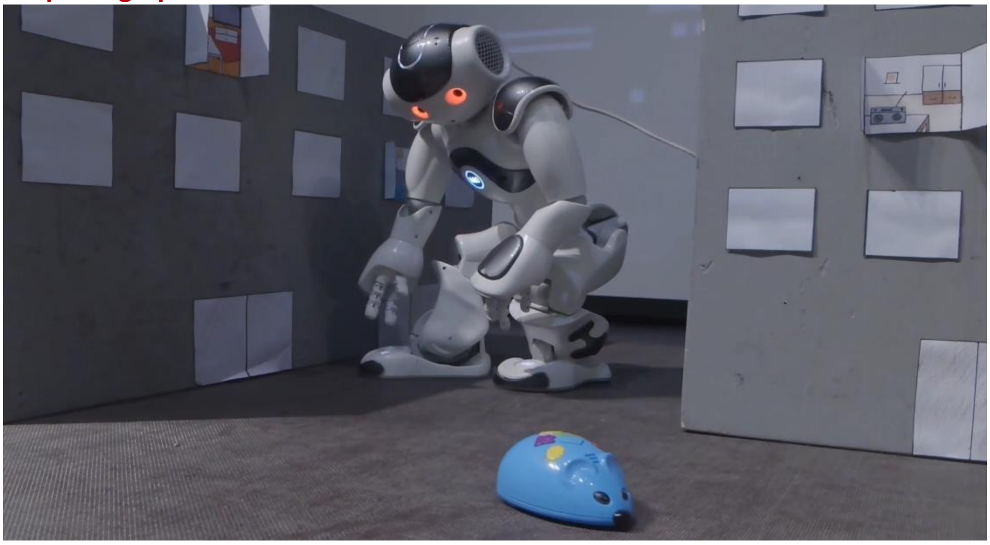


Figure 72. Code error on stage.

Number of actors in the performance: 1 person (programmer)

Actor roles in the performance:

- **a) Act around the robots**
- b) Communicate with the robot
- c) Carry the robot
- **d) Must know how to turn the robot on/off**
- **e) Must know how to program/assemble the robot**
- f) Act as robots
- g) There are no actors in the performance

Number of robots used in the performance: 5

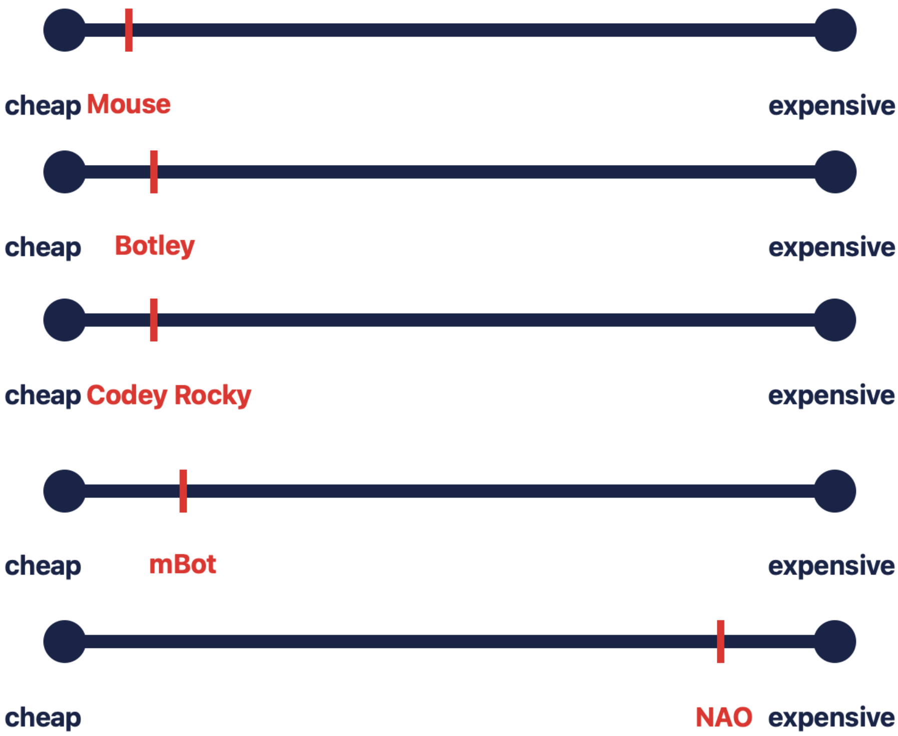
Appearance of robots:

a) machine
b) vehicle
c) animal
d) human

Robots used: Nao, Codey Rocky, Boltley, mBot, Mouse

Link to robot manufacturer/robot website:
https://education.makeblock.com/mbot-explorer-kit/
https://www.aldebaran.com/en/nao
https://education.makeblock.com/
https://botleybot.com/
https://www.learningresources.com/item-stem-robot-mouse

Robot price: Nao €10.000, Codey Rocky €100, Botley €100, mBot €170, Code & Go® Robot Mouse €60



Similar robots that can be used instead of the one listed: mTiny instead of one of the small robots

Performance steps:

1. We checked which robots are available. From a wider selection, we chose the ones that will play in the show.
2. Based on the capabilities of each robot, the students wrote a story and assigned the robots a role to play based on their physical appearance and technical capabilities.
3. This was followed by writing the script and preparing a plan for the realisation of the performance. This was the basis for the preparation of the set design and the acquisition of props.
4. Programming robots for individual scenes.
5. Recording the performance.

6. Editing of a recording of the performance. Here, the scenes with robots are joined by those with a human actor.

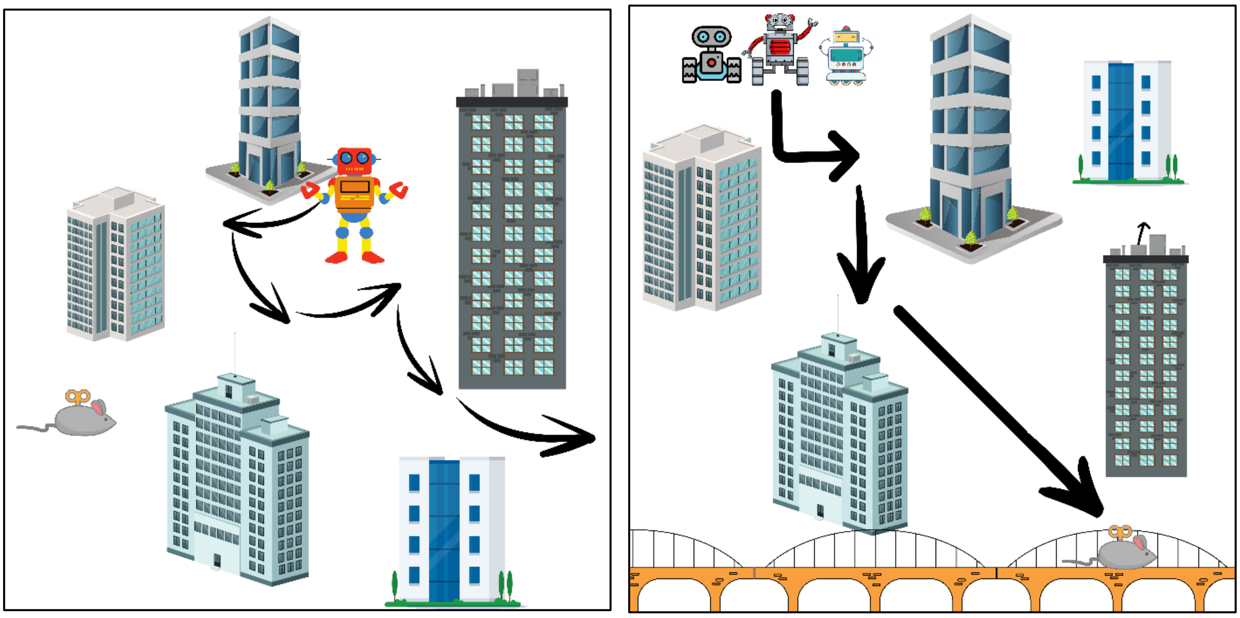
Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Robot description: Eva is a humanoid robot about 30 cm tall, with two arms and two legs and a head. All three parts of the robot can move to some extent. It has a microphone on its head so that it can talk and catch external sound. It can orient itself in space with a camera on its head. It is programmed using a complex coding program. The other robots are didactic toys which help children take their first steps into coding. They can be programmed using the buttons on the robot itself or via a remote control. Codey Rocky is programmed in a graphic programme on a computer.

How the robot moves in the performance: the robots are programmed to move left and right. In one scene, their movements resemble dancers. During this time, Eva moves between buildings (in the play she is bigger than the houses around her) and, like a human, walks on two legs.

Robot movement diagram:



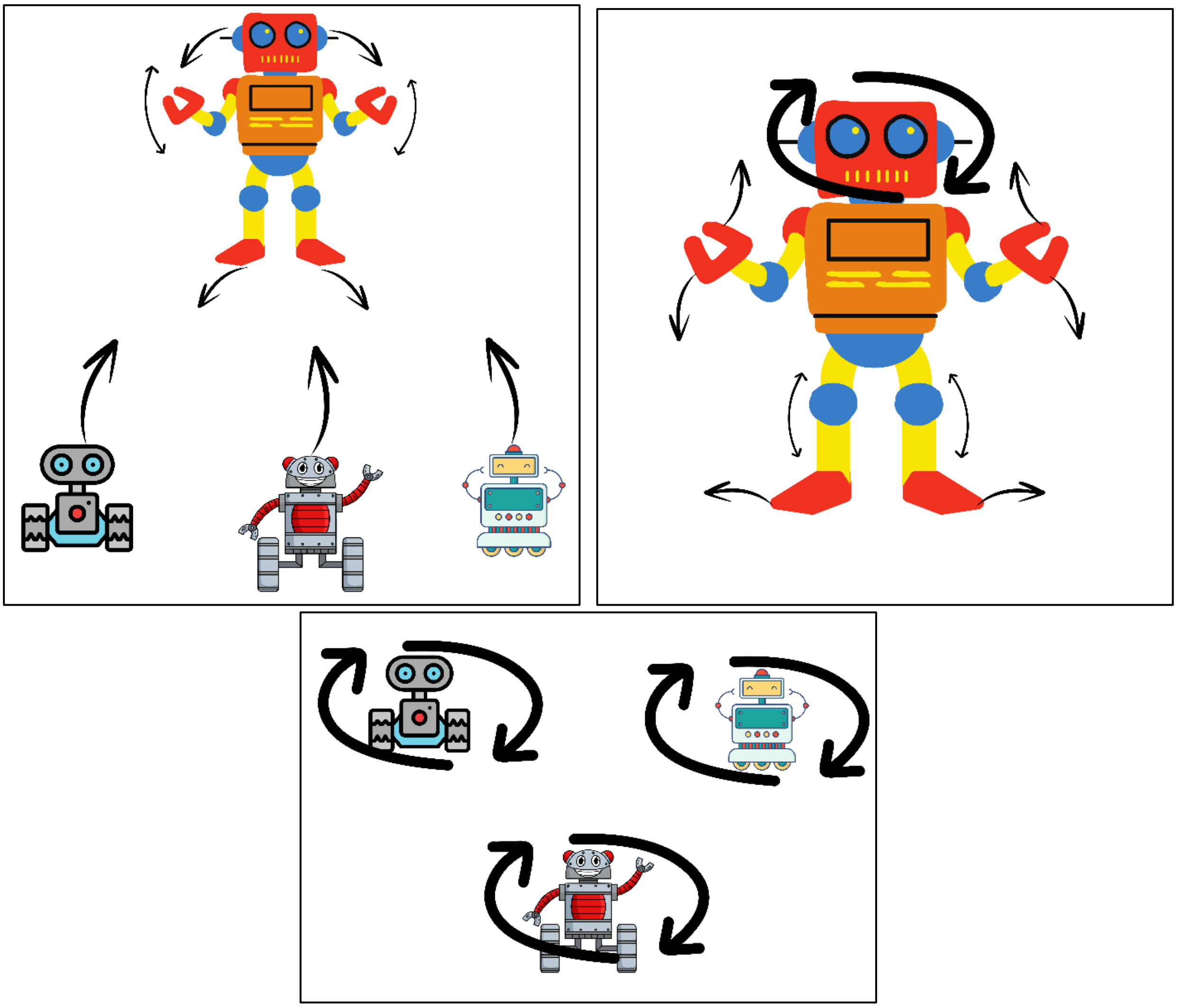


Figure 73. Robot movement diagram in a play *Code error*.

Expected space the robot can cover: in the performance, Eva moves on a 3m x 3m stage between different scenic elements. The other robots also move in the same space, but only 1m to each side.

Robot program example:

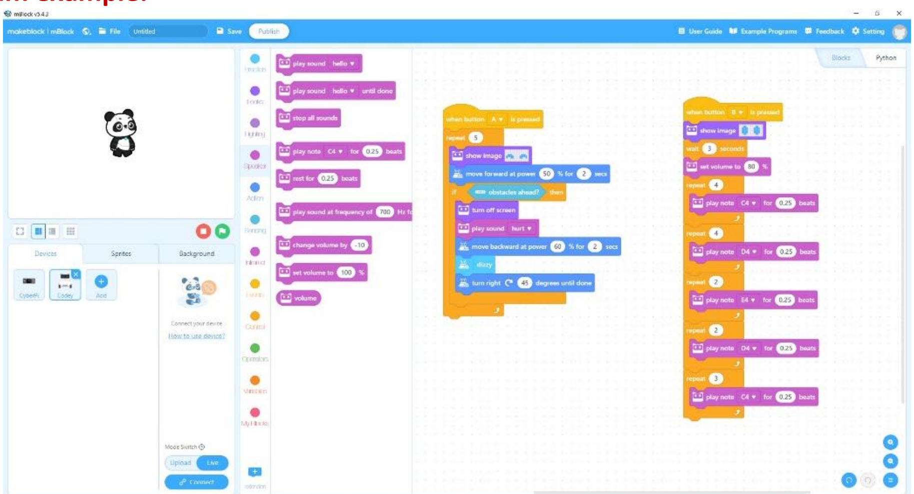


Figure 74. Program for Codey Rocky robot.

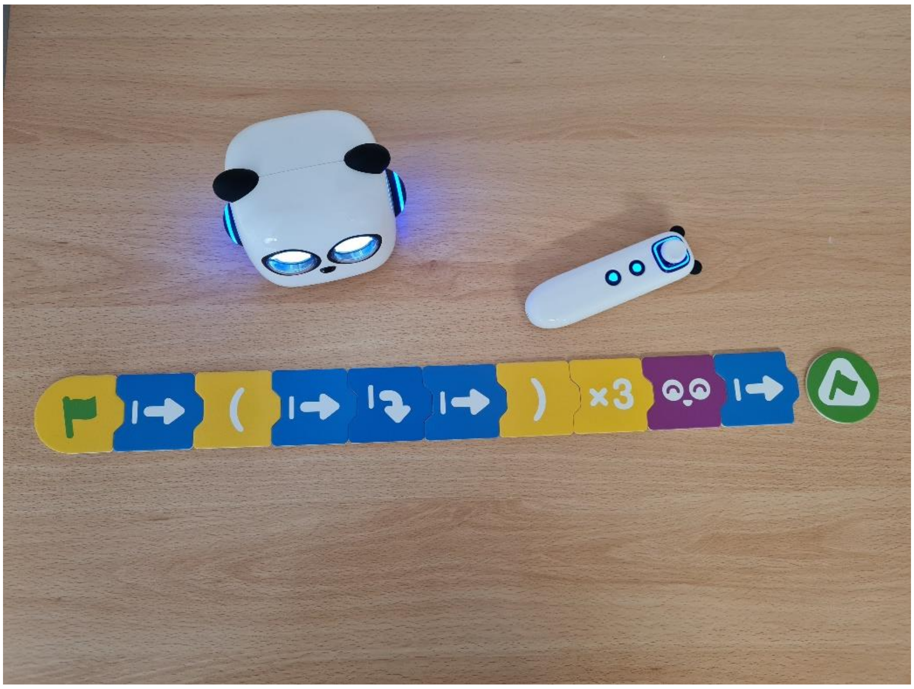


Figure 75. Program for mTiny robot.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Nao robot must be programmed by an experienced programmer, or at least by a student who already has experience working with robots.

Restrictions on robot use in performance: the Nao robot is unstable on some surfaces, which affects its maneuverability.

Added value: the show clearly shows all the functions of the robots that can be used in the theater play. Eva is much more dynamic in this role than in the previous one, and Codey Rocky's screen allows for much more expression of emotions and messages.

Possible upgrades: with more time available for preparation, the show could be expanded and upgraded. The performance showed how with the available robots we can make a very attractive and dynamic performance, which already looks very much like a film. It just needs a little more time for the realisation itself.

4.11. Robots’ RUR

Title: Robots' RUR

Link to the play:
https://www.youtube.com/watch?v=mZOPUKSPsn8&list=PLHXIz0zXOImW3nA1vIG2HHsYpRM12lgXf&index=7

Human-robot ratio:

Plot Summary: This performance is an excerpt from the drama "R.U.R." by Karel Čapek. The action takes place in a room where five people (portrayed by robots) watch as a large group of robots they invented and created gather outside. However, these robots bring weapons and plan the end of the human species. Despite the robots' plans to "eliminate" humans and take over the Earth, the humans are not sorry for creating them.

Performance photograph:

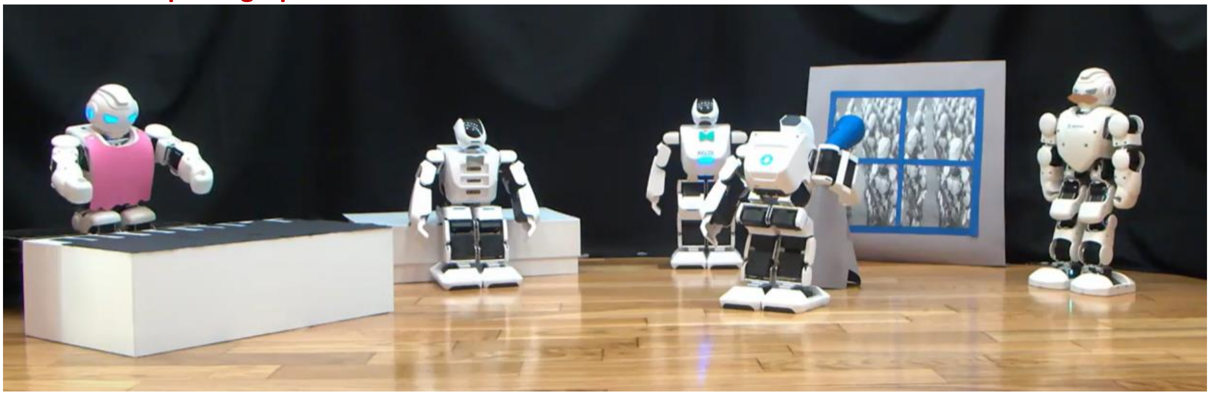


Figure 76. Robots’ RUR on stage.

Number of actors in the performance: 0

Actor roles in the performance:

a) Act around the robots
b) Communicate with the robot
c) Carry the robot
d) Must know how to turn the robot on/off
e) Must know how to program/assemble the robot
f) Act as robots
g) There are no actors in the performance

Number of robots used in the performance: 5

Appearance of robots:

a) machine
b) vehicle
c) animal
d) human

Robots used: Alpha 1Pro (2 units), Aelos 1S (2 units), Aelos 1EDU (1 unit)

Link to robot manufacturer/robot website:
www.ubtrobot.com/consumer/humanoidRobots/alphaSeries/Alpha1E
www.lejurobot.com/aelos-1s/
www.lejurobot.com/aelos-edu/

Robot price: Alpha 1Pro 700 €, Aelos 1S 850 €, Aelos 1EDU 1.300 €

Similar robots that can be used instead of the one listed: MeccaNoid, NAO

Performance steps:

1. An excerpt from Karel Čapek's drama RUR was selected for this performance.
2. The text needs to be adapted for the performance, decide how many robots are needed in the show, and assign lines to individual robots.
3. Once the story is chosen and the text written, it's time to develop the technical plan and outline the requirements the robots need to meet for the chosen scenario.
4. Robots that fit the appearance and characteristics of the performance were selected. In this case, these were humanoid robots Aelos and Alpha.
5. The stage design and the placement of robots were conceived, considering whether they would only move slightly in place or move through the entire space during the performance.
6. Robots were programmed to perform all defined actions (movement, speech).
7. Robots were synchronized: after each robot is programmed, a complete part of the performance must be rehearsed on stage and synchronized to ensure the performance is realized as envisioned.

Robot assembly:

a) Robot pre-assembled
b) Need to build/decorate the robot
c) Need to assemble the robot

Robot description: All used robots are humanoid in shape with two arms and two legs, about 40 cm tall. It is very easy to connect the robots with smart devices and control them using a free app with pre-programmed movements. They can also be programmed to control each individual motor of the arms or legs, making them excellent for education.

How the robot moves in the performance: Throughout the entire performance, almost all robots stand still in their initial positions, except for one that takes a few steps in a semicircle and another that takes a few steps forward and then turns in place.

Robot movement diagram: The robot marked in yellow first moved a few steps forward and then turned in place to the left. The robot marked in green moved a few steps in a semicircle. The other robots did not move from their places but only moved their arms and/or heads in place.

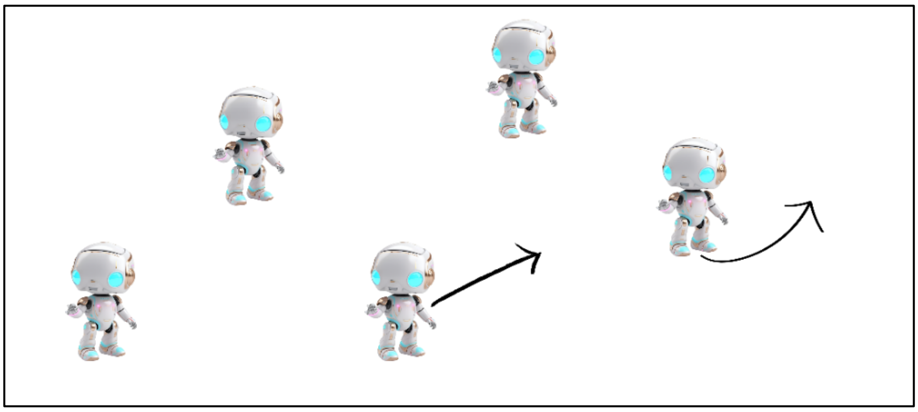


Figure 77. Robot movement diagram in a play *Robots' RUR*.

Expected space the robot can cover: In this performance, five humanoid robots were used, mainly standing in place and moving their arms and heads, with one robot moving very little from its position. Given the slow movement of the robots, the expected space would be 1m x 1m.

Robot program example:

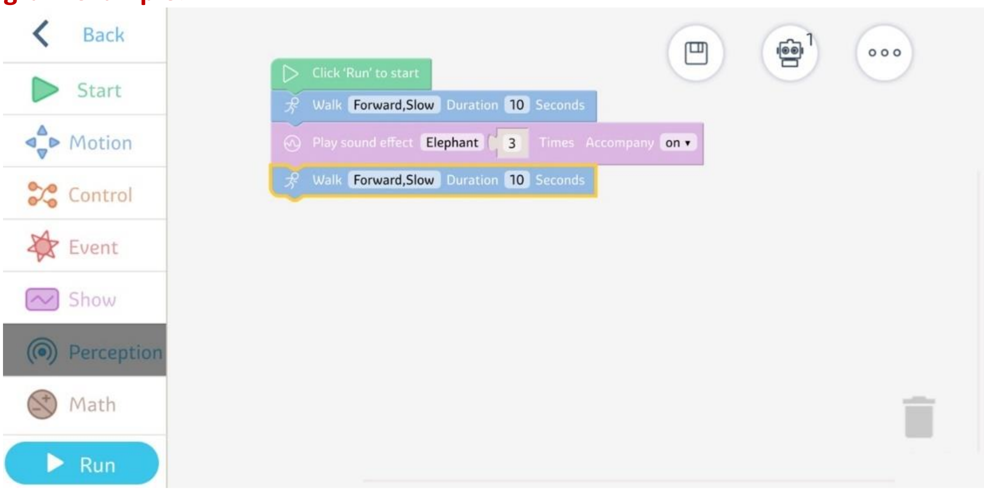


Figure 78. Program for robot Alpha Pro 1.

Amount of programming knowledge needed to program this robot:

a) Adapted for beginners
b) Need to know the basics of programming
c) Advanced programming knowledge required

Who can program this robot:

a) Children under 7 years old
b) Children 7-10 years old
c) Children 11-14 years old
d) Youth 14-20
e) Teachers
f) Professionals

Robot role:

a) Backdrop
b) Part of the scenery
c) Play prop
d) Minor character
e) Character
f) Main character

Amount of human-robot interaction:

a) Robots move independently on stage, the performance does not depend on their movement
b) People control robots remotely
c) Robots move independently on stage, people adjust to robots
d) Robot actions are programmed in advance, parts of the action always happen in the same place at the same time
e) Robots have sensors and adapt to humans
f) Artificial intelligence is used to control robots
g) Robots are played by people who move independently on stage

Robot technician: Yes, a technician is needed to program the robots and, if necessary, make on-site repairs during the performance. The robots are programmed before the performance, but something unexpected can always happen.

Restrictions on robot use in performance: The robots used in the performance are quite small for a larger live audience (about 40 cm in size) and the robots and their movements are not clearly visible from a distance. Therefore, only a small number of people can watch the live performance in order to see everything clearly. One possible solution is to record the performance and then watch the recording. Programming leg movements for such robots is not easy, so such movements can cause instability in the robots, even causing them to fall. Also, some body movements, like tilting the upper part of the robot's body, can be very unstable. Therefore, a lot of effort must be invested to program the movements as well as possible to prevent falls. The robots' voices can be recorded and played directly from the robots, which makes them practical for use. However, if the robot moves while talking, the sounds of the motors in the arms and legs can be louder than the recorded speech, which makes understanding the performance difficult.

Added value: It's excellent that robots are the main actors in the performance, which could be very interesting to both younger and older audiences. The performance does not last long, but it is enough to engage the audience before they become bored or disinterested. Humanoid robots are the best choice for this performance because they are most similar to human actors and thus the most intuitive to imagine on stage.

Possible upgrades: Robots could be additionally programmed to move more during the performance. Robots portraying humans could be dressed in clothes to differentiate humans and robots in the play and make them more human-like. The performance could be extended, for example, to include a scene of robot assembly and weapon deployment discussed by the robots.

5. Development of a play with robot-actors

5.1. Steps of creating a play with robot-actors

To successfully create a performance with robots, it is necessary to follow the steps of creating a play as in classic performances with humans, with additional steps that are closely related to the choice of robots, the making of robots, programming robots, and their synchronization with people on the stage itself (Figure 79). The whole process ends with the performance and a review of the quality of the performance.

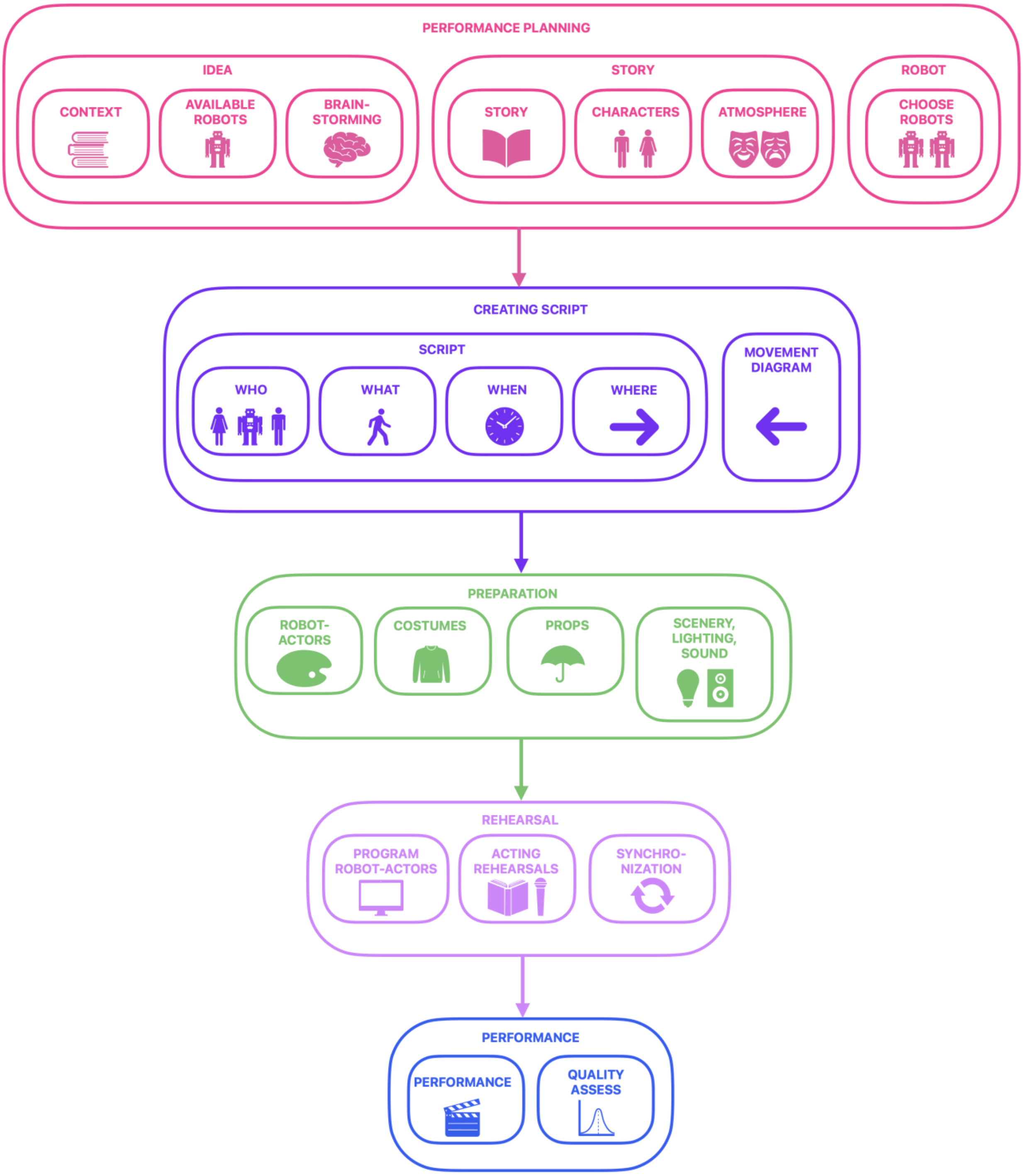


Figure 79. Steps in creating a play with robot-actors

1. Planning the Performance

A successful performance begins with quality planning. In this step, it is necessary to develop the idea of the performance, write out the story, and select the robots that will act in the play.

1.1. Getting the Idea

The development of the idea consists of choosing the context, studying available robots, and a brainstorming session that will result in a story in the next step.

1.1.1. Choosing the Context

In this case, choosing the context represents making a decision whether the play will be an entirely new story [77], whether it will be based on a known fairy tale, story, book, historical event [78], or whether the theater will be used for teaching a school subject. For example, in a history class, plays can be used to recreate events and situations to help students understand these events and situations. Such performances can allow students to explore different alternatives to a situation and their possible consequences. In addition, plays can be used to simulate certain processes or phenomena [79]. In this step, it is also necessary to further research the chosen context by searching the internet, books, or through interviews [78]. When choosing the context of the play, it is important to keep in mind who the viewers will be and, accordingly, it is necessary to adapt the play (and the robots) to the viewers. For example, simpler themes for younger students.

1.1.2. Studying Available Robots

The appearance of available robots and their capabilities can inspire the story itself [79]. In imagined situations, and especially in stories devised by students, robots can behave almost like humans, often are as big as humans, can speak, show emotions, and move naturally. However, in reality, we are limited to the robots we have available in the closet or that can be purchased or borrowed. An additional limitation is the complexity of the robots themselves, whether students can assemble, program, and control them themselves or if a technician is needed to manage the chosen robot. Probably the biggest limitation is the price of the robots and their software. Therefore, in this step, it is necessary to research which robots are available (within the school, for borrowing, or affordable for purchase). A good idea is to make a list of them with a short description and a photograph and to show this list to students so they can develop their story for the theatrical performance. The list can be made in Padlet, where students can later write their stories. An example is given in Figure 80, and can also be viewed at the link: https://padlet.com/daliaka/dobro-do-li-u-robotsko-kazali-te-scenariji-za-kratke-kazali--nla6c10ioznmoi51.

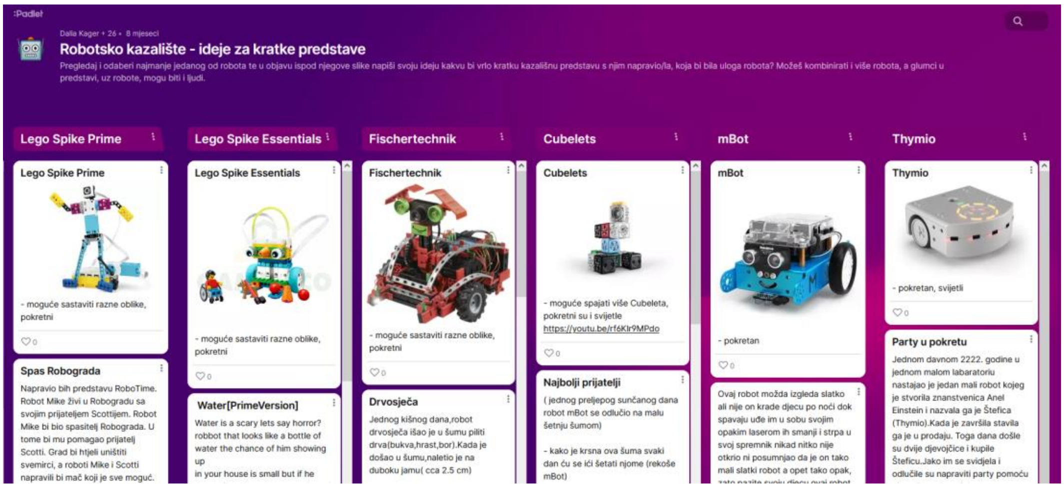


Figure 80. Available robots in Padlet.

1.1.3. Conducting a Brainstorming Session

Brainstorming is a term that describes the intense sharing of various, mostly creative ideas among multiple people with the aim of quickly finding a creative solution to the presented problem, which can later be changed and/or improved. All participants are encouraged to think out loud to offer as many ideas as possible for solving the problem in a short period of time. The goal of this practical method is to push the person presenting the problem out of the standard frame of thinking with the help of other participants in the discussion.

Characteristics or specific rules for this approach to problem-solving are the following:

- Defining the problem: to start, an initial question should be set, which may or may not be directly related to the problem (the goal is to encourage participants to discuss)
- If there are any, it is necessary to explain the rules and give an initial suggestion
- It is conducted in a group, neither too small nor too large, to make the conversation as efficient as possible
- All ideas at the time of brainstorming are **equally valuable** (at the moment there is no good or bad idea!), while the real value of ideas is determined later
- Asking questions, which also lead to new branches of ideas, is welcomed
- Using associations to create a list of terms
- It is advisable to expand someone else's idea.

The brainstorming session can begin using a tool designed to stimulate creativity in devising stories, known as "story start" [80]. Students are given several words (e.g., song, spider, robot), and based on these words, they must create a story. From these words, events, characters, and the main plot are developed, which are later elaborated in more detail. Similarly, story cubes function [81]. Each side of the cubes features a drawing. By throwing five cubes, they will show five drawings from which students can then develop their story.

During the elaboration of the theatrical performance, brainstorming can help in devising the theme of the story, the plot of the story, the development of characters in the story, the appearance of robots, and similar. Ideas can be thrown onto a board, written on post-it notes, or on a large paper on the table. It is important to record all ideas so that they can later be elaborated.

1.2. Devise and Write the Story

After choosing the context and developing the idea, it is necessary to write the story [78]. When elaborating the story, keep in mind that this is about a theatrical performance, not a live-action or animated film. In film, both space and time are dynamic, the camera changes its position, and thus the viewer changes the place of watching individual scenes, and the scenes change quickly. In the theater, actors enter the stage, perform something, and leave the stage. The background is static, and the audience watches everything from the same place. Each scene must have a longer duration, as it is impossible to change the scenery every few seconds or minutes. Therefore, when devising the story, keep in mind that the scenery changes minimally and that visual effects are possible to perform live on the spot.

1.2.1. Devise the Story

In this step, the story can be short, for example, up to 250 words, but it must contain basic information about when and where the play takes place, how many scenes there are, and what will happen in each of these scenes [79]. Each scene should mention which characters are present and what they are doing.

The story must have a limited number of characters. Assuming that a theatrical performance with robot-actors will be relatively short (e.g., up to 5 minutes), it would be good if it deals with only one event in the main character's life. The story should describe specific details of the action, without many abstract ideas that will not be possible to show on stage. The language used should be active without much description [82]. The main determinants in creating the story are determining the events to be followed in the story, defining the characters, places, and time of the action, and writing out parts of the story. Parts of the story are the introduction, the plot, the climax, and the resolution [82][83][84].

The introduction introduces the characters and sets the story (place and time of action). In it, we meet the main character and the situation in which this character is found. **The plot** reveals action in the story, which can be a conflict between characters (e.g., someone has stolen a robot part), a problem with the world or nature around the main character (e.g., deforestation), or an emotional crisis of the character (e.g., the main character has no friends). The plot can consist of several events leading to the climax of the action. **The climax** of the action is the moment of greatest tension when everything seems critical, and the outcome is uncertain. This is the moment when a reversal occurs in the story itself. After the climax, the situation in the story begins to unravel, tensions calm down, and individual problems are resolved. The resolution can be unexpected; the main character may discover a new inner quality, or the main characters may resolve the tension between them. **The end** of the story can be happy, sad, but also neutral. It is only important to resolve all open events from the story so that the viewers are not left confused. At the very end, the conclusion and point of the whole story (and later the performance) must be seen. It must be brief and clear.

When devising the story, Table 1 [82]can help. Rows can be added to the table as needed, depending on how many events make up the plot of the action.

Title	
Setting	
Time of the action	
Main character	
Other characters	
Introduction	
Plot (first event)	
Plot (second event)	
Climax of the action	
Resolution	
End of the story	

Table 1. Story sketch [82].

1.2.2. Character Development from the Story

Alongside the development of the story itself, it is also necessary to elaborate on the characters from the story. Character development includes analyzing the physical, social, psychological, and moral qualities of the characters. This can include, among other things, age, character motivation, emotional state, personality, mood, physical appearance, movement characteristics, social relationships between characters, backstory, and similar aspects [79]. Pay attention to which characters will be positive and which will be negative. Do not introduce characters into the story who will not contribute to the action, plot, or resolution of the story as they might confuse the audience. Although this will not be visible in the story (and later in the script and on stage), the person writing the story must know in detail the life story of each character. Knowing the life story will affect the consistent behavior and reactions of the character in certain situations in the story. Likewise, as every situation in real life changes people, so do the events in the story change the characters. Therefore, when devising the story and characters, their development from the beginning to the end of the story [83] should be considered. This makes them realistic, and the audience can identify with the characters and the story. The same rules apply to both human actors and robot-actors.

When devising characters, Table 2 [82]. can help. The table needs to be filled out for each character in the story. If the described character is a robot, this should be marked, with the possibility of specifying particular characteristics of the desired robot.

Character Name	
Age	
Physical Appearance	
Personality	
Specifics (e.g., movement characteristics, facial tics)	
Emotional State	
Relationships with Other Characters	
Life Story	
Strengths	
Weaknesses	
Robot	

Table 2. Descriptions of characters from the story [82].

1.2.3. Set the Atmosphere of the Story

To make the story on stage look convincing, realistic, and convey the message we want, it is necessary to develop its atmosphere, both physical and auditory. The atmosphere includes the costumes that the actors (both humans and robots) will wear, the props they will use for specific actions, the set design and decorations, lighting, as well as music and sound effects [79].

Costumes, props, and set design must match the time period in which the story takes place (e.g., a specific moment in history or a contemporary adaptation of an event). Attention should be paid to whether costumes show if a character is wealthy or poor, the character's age, the type of job they perform, and even their emotional state. Costumes can change during the performance depending on the scene, but this also requires considering the time needed for actors to change outfits. When choosing music and sounds, care must be taken to ensure they fit into the story. Alongside the creation of the story, a plan for using particular sound effects should also be made, as they will help the audience immerse themselves in the performance. Lighting will further emphasize the atmosphere of the action. Lighting can be used to create the impression of the story taking place during the day, night, or moonlight. Using spotlights can highlight specific events on stage, direct the viewer's gaze to other parts of the stage as needed (e.g., to rearrange a part of the set), or play with shadows and silhouettes.

1.3. Choose Robots

After the story has been written and the characters who appear in the story have been elaborated, a final decision needs to be made on which robots will be used. It is necessary to consider what role the robots will play in the performance (part of the scenery, prop, supporting or main character), the appearance of the robots (machine-like, vehicle, animal, or human appearance), and whether the emotions of the robots are important in the performance and how they will express them (does the robot need to have a face or will, for example, emotions be shown by moving forwards and backwards).

Questions related to assembling the robots we want to use should be considered: (a) are they pre-assembled, like the NAO robot, for example, (b) do they need to be upgraded, (c) fully assembled from a set (e.g., Lego Spike Prime or Fischertechnik) or (d) built from scratch using microcontrollers (e.g., Arduino or ESP32) and 3D printing parts. The choice of robots also depends on the programming language used, whether students can program the robot themselves or advanced programming knowledge is required, whether the robot can be remotely controlled, and whether we need the help of a technician. The amount of control or programming will depend on the actions we expect from the robot-actor on stage: (a) robots move independently on stage, and the performance does not depend on their movement, (b) people remotely control the robots, (c) robots move independently on stage, and people adapt to the robots, (d) robot actions are pre-programmed, parts of the action always occur in the same place at the same time, or (e) robots have sensors and adapt to people. Considerations should also be given to the limitations of the robots and whether this will affect the story and the performance itself. It may happen that a robot inspired the students while writing the story, but upon reviewing its characteristics, it turns out it is not possible to use it on stage. Questions to keep in mind are given in Table 3. The final choice of robots is based on the story, available robots, the ability to express emotions using robots, and the students' prior knowledge.

Human-robot ratio:

just people — **just robots**

Number of actors in the performance:______

Role of actors in this performance:

a) act around robots
b) communicate with the robot
c) transport the robot
d) must know how to start / turn off the robot
e) must know how to program / assemble the robot
f) act as robots
g) no actors in the performance

Number of robots used in the performance:_____

Used robots:_____________________________

Appearance of robots:

a) machine
b) vehicle
c) animal
d) human

Assembling robots:

a) robot pre-assembled
b) need to upgrade / decorate the robot
c) need to assemble the robot

Amount of programming knowledge to program this robot:

a) adapted for beginners
b) need to know basic programming
c) need advanced programming knowledge

Who can program this robot:

a) children up to 7 years
b) children 7 – 10 years
c) children 11 – 14 years
d) youth 14 – 20
e) teachers
f) professionals

Role of robots:

a) backdrop
b) part of the scenery
c) play prop
d) supporting character
e) character
f) main character

Amount of interaction between humans and robots:

a) robots move independently on stage, the performance does not depend on their movement
b) people remotely control the robots
c) robots move independently on stage, people adapt to the robots
d) robot actions are pre-programmed, parts of the action always occur in the same place at the same time
e) robots have sensors and adapt to people
f) artificial intelligence is used to control the robots
g) robots are played by people who move independently on stage

Robot technician:

a) NO
b) YES, ____

Limitations of robots:

____

____

Table 3. The role of actors and robots in the play.

2. Create the Script

Creating a script is identical to writing a script for performances without robot-actors. An addition to this step is sketching diagrams of the robots' (and actors') movements to facilitate the programmers in preparing the robots for the stage.

2.1. Write the Script

Writing the script involves elaborating the story based on the selected robot, its capabilities, and the initial story idea. The script should be written in narrative form, with descriptions of characters, actions of actors and robot-actors, locations, and duration of the action. It is essential to keep in mind the technical capabilities of the available robots that will perform in the play. Once the script is written, it should be critically read several times, revised, rewritten, shortened in some parts, extended in others, scenes reordered, characters added or removed [85].

The script is divided into scenes. Each scene occurs in one space (e.g., a kitchen) at a specific time (e.g., morning). A change in location signifies a new scene [85].

Each scene consists of descriptions [79]:

- **Characters** from the story, or descriptions of **who is performing the action**. It is necessary to describe the main characteristics of the characters such as personality, mood, characteristic gestures, characteristic movements, manner of expression, etc. It's important to consider when a character will enter the story and how they will contribute to the plot and resolution of the story, to avoid introducing unnecessary characters.
- **Actions** that tell **what the character does or says** in the performance. Here, verbal and non-verbal expressions, interactions with stage props (e.g., lifting an object, pressing a button), and other body movements (e.g., dancing, sitting, standing, clapping, looking around) are described.
- **Duration**, i.e., a description of **when the action occurs**. This description coordinates individual actions (e.g., the robot-actor begins an action when it detects a pattern of light on the stage and ends the action when it reaches a specific spot on the stage). In a play involving robot-actors, the duration describes situations in which the current action takes place until the next action meets the prerequisites. When the next action meets its prerequisites, the robot is commanded to stop the current action.
- **Position**, i.e., **where the action takes place** and how the characters move on stage. An important aspect of a play with robots is knowing the position of the robots on stage, so that human actors can adapt to the robot, or so the robot can perform its actions in the desired part of the stage later in the play. A simple option for controlling the position and movement of robot-actors is following a black line.

At the beginning of each script, a list of characters with their basic characteristics (age, gender, physical appearance) is provided (Figure 81). Each scene starts with the scene number, determining the space (interior or exterior), location (e.g., living room, street), and time of the action (e.g., day, night, 100 years in the future). This is followed by a description of the situation and the action taking place in that scene. If a new character is introduced in this scene, they should be briefly described. Descriptions are written in the present tense, and it's good to avoid adjectives (e.g., beautiful) and adverbs. Dialogue between characters is written so that the names of the characters are in capital letters, and their emotional states are in parentheses [85][86]. These emotional states will be shown by the actors through their movements and facial expressions. In the parentheses, descriptions of actions and activities that individual characters perform while speaking are also written (Figure 82). If characters were just standing on stage talking, there's a chance the scene would be boring to the audience, and the actors wouldn't know what to do with their hands. Therefore, it is always advisable for characters to be doing something while talking. Sound effects we want to hear at that moment, comments on music, and lighting are also noted in the parentheses.

Characters: HELENA, 40 years old, female, dressed in everyday clothes, average height

POLICE OFFICER, 40 years old, male, dressed in police attire, clean-shaven
JURA, small dog on a leash
CHICKEN, robot in the shape of a chicken, slightly smaller than the dog
TANK, robot in the shape of a tank

Figure 81. Example of listing characters at the beginning of the script.

1. Exterior, street crossing, day
HELENA (40 years old, slender woman) walks down the street typing on her cellphone. She is walking the dog JURA on a leash. Beside them, the robot CHICKEN walks independently.
HELENA (relaxed, looks up with a slight smile): What a wonderful day! (Looks down at her cellphone)
HELENA (from her right side comes TANK. The wheels of the TANK make a loud, deep sound. Helena abruptly looks up): Oh, what's this?

Figure 82. Example of a script for the first scene.

2.2. Sketch Movement Diagrams for Robots

To facilitate the designers and programmers of robots in preparing the robots for the stage, a movement diagram for robots can be sketched in this step (Figure 83). The sketch can be simple, depicting the robot as a circle with an arrow indicating the direction of movement. It can also be more complex, sketching the actual appearance of the robots and other actors and using arrows to show their directions of movement. If the story's action is complex, the movement diagram of the robots can be displayed across several images, creating a comic strip diagram of robot movement. These diagrams will help programmers and technicians to know who, where, and when to perform which action on stage.

When planning the movement of robots and drawing movement diagrams, consider the characteristics of the robots: the dimensions of the robot, how much the robot is mobile, how much time it needs for some actions, and how large the stage can be for the robot to move on (Table 4). Of course, if it's a slow robot, it can physically stand in one place, rotate around its axis, or just talk.

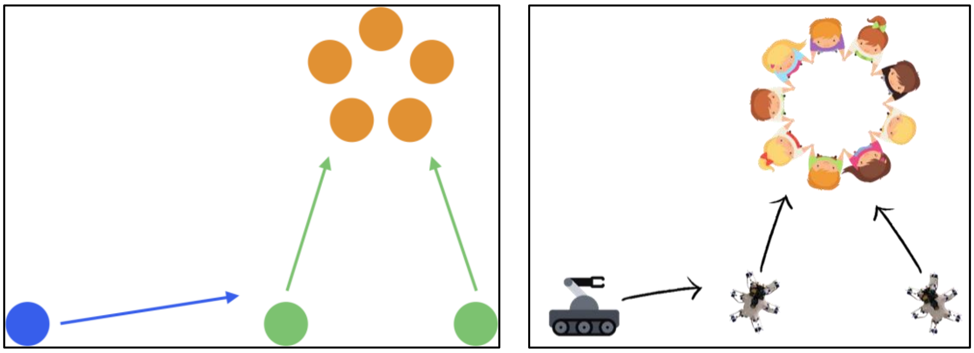


Figure 83. Example of a robot movement diagram. On the left: a simple representation of robots with colored circles, on the right: a complex depiction with drawings of robots and actors.

Robot Dimensions: ____________________

Robot Mobility:

a) The robot cannot move
b) The robot can only rotate around itself
c) The robot is at a fixed location but can move some of its parts
d) The robot can move across the stage
e) The robot can walk on the stage
f) The robot flies above the stage

Robot Speed: a) The robot is immobile b) The robot is slow c) The robot is moderately fast d) The robot is fast e) The robot is too fast **Expected space the robot can cover:** ______________ **Method of robot movement in the performance** (description of the robot's movement across the stage): **Robot Movement Diagram:**

Table 4. Movement of the robot in the play.

3. Preparation

After the final version of the script is completed, the procurement and creation of robot-actors, props, costumes, scenery, sound systems, and lighting can begin.

3.1. Create Robot-actors

In this step, we physically construct the robots that will perform in the play. In previous steps, we have studied what equipment is available and what each robot can do, while in this step, we actually build the robots. The play can use ready-made robots (e.g., humanoid robot NAO or Alpha 1Pro), a robot assembled from a robotics kit (e.g., Lego Spike Prime or Fischertechnik), or a robot custom-built using microcontrollers (e.g., Arduino) and microcomputers (e.g., Raspberry Pi), motors, sensors, 3D printing, woodcutting, etc. (Figure 84) [78][79]. After building the robots, they need to be adapted to the characteristics of their characters [3]. This can be achieved using decorative materials, 3D printing, and stickers. To enable facial displays and expressions for conveying emotions, a good idea is to use tablets instead of heads (Figure 84c) [79]. Potential challenges in this step include the students' prior knowledge, difficulties in creating verbal and non-verbal behaviors to convey emotions of robot-actors, and the robots' limited expressiveness [79]. Examples of educational robots and how to assemble them are given in the chapter 7.

Figure 84. Robot-actors: Alpha 1Pro, Lego Spike Prime and REV robotics with a tablet instead of a head.

3.2. Create costumes

In professional theaters, costumers are responsible for creating costumes. They propose costumes based on the story, the director's instructions, and actors' suggestions, and later manufacture them. Costumes help tell the story, assist actors in feeling the character they need to portray, and convey important information about the character, their social status, personality, time of the action, and the situation in which the character finds themselves. A costume includes everything visible on the character: clothing, shoes, hats and caps, purses, jewelry, wigs. Costumes may also include some invisible parts hidden under the clothing: big belly, corset, hoops under dresses, etc. The internet and books are excellent sources of costume ideas, especially if it concerns a historical period or our version of a known story [87].

The cheapest option for preparing costumes is to look in our own closets. The most commonly used clothing items good to have in one's wardrobe, often used in theater, include [88]:

- A plain black long-sleeve t-shirt and black flat pants (in a pinch leggings or dark jeans can work). Black clothing makes the actor neutral.
- A white collared and buttoned shirt. A white shirt can be used to portray an entrepreneur, lawyer, waiter, and many other characters. Depending on the situation, it can be combined with a tie, colorful t-shirt underneath, and jeans.
- A simple, plain leather belt, black (or brown). It can be used to hold up clothing, and a gun or sword can be tucked into it.

- Black dress shoes and black tall socks. Younger students can also wear black sneakers or ballet flats.

Care should be taken to ensure clothing does not have visible manufacturer logos. If they do, they can be covered with a piece of matching colored gaffer tape. A good source for costumes is also stores around carnival time. Then, costumes of many popular characters can be purchased at lower prices. Furthermore, many local amateur or professional theaters already own a collection of costumes and there may be the possibility of borrowing them (free, for advertising, or for a fee). The last option is, of course, sewing your own costumes.

When staging a performance involving students, it is always good to show them the costumes before or during rehearsals. This will enable them to better immerse themselves in the role, making them more excited and confident in their performances [87].

Costumes for robots need to be made whether we are using pre-assembled robots or building them ourselves. Just as costumes in size and design must fit humans, the same applies to costumes for robots.

In addition to costume design, makeup should also be considered. Commonly used makeup includes: foundation, eyeliner, blush, eye shadow, mascara, lipstick, sponges and brushes, makeup fixing spray, makeup remover, etc. [89]. When applying and removing makeup, hygiene and disinfection should be observed, and whether any of the actors have sensitive skin issues. Hairstyles, which also must match the theme of the performance, should not be forgotten.

3.3. Create Props for Actors and Robot-Actors

Some necessary props are directly mentioned in the script and the story would not make sense without them. However, some may also be discovered accidentally, during rehearsals, by the actors themselves as they better immerse in their character. Props can be found at home, at school, borrowed, bought cheaply in hobby shops, procured online, or made. A good idea is, as a sign of gratitude, to invite people who lend props to the premiere or create a poster at the entrance listing all who helped the performance [90]. Of course, props must be size-appropriate for the actors and robot-actors. As robot-actors are often smaller than humans, some props will need to be made from cardboard, wood, or by 3D printing.

To ensure all props are acquired, a table can be prepared (Table 5) that lists the location and time of action (to tailor props to the performance). For each scene, it should be noted: item (e.g., book, cellphone, cup), description (item specifications, e.g., old, thick book), quantity (e.g., 5 books on a shelf), who brings the prop on stage (can be an actor when entering the stage), who takes the prop off stage, how the prop will be acquired (borrowed or bought), who will acquire the prop, who will return the prop (if borrowed), whether the prop requires special maintenance (e.g., refill a water bottle), and if it is edible (e.g., if it's an apple an actor bites into, a new one will be needed for each performance). When creating a prop list, it's essential to carefully read the script and note every item mentioned. For example, the script might say: "Helena looks down at her cellphone." The item "cellphone" and all necessary data about this item are then added to the list. If a prop not mentioned in the script is added, it should be added to the table in the row when that prop appears on stage [91].

During the performance, it would be good to keep all props on one organized table or shelf behind the curtains to reduce stress for the actors during the performance. To ensure all props are ready, places for each can be marked on the table and written on painter's tape or a post-it note stating which item should be placed there. The table should be organized so that actors can quickly find what they need: frequently used items closer to the edge, larger items under the table, ordered by usage, etc. Smaller parts can be kept in additional boxes to avoid losing them. If the table is in the dark, a small lamp above it can facilitate finding items [92].

Setting	Street	Time of the action	Present	
Scene 1				
Item	**Description**	**Quantity**	**Who brings**	**Who takes away**
Smartphone	Smartphone	1	Helena	Helena
Apple	Red, large	1	Ivica	Maja
…				
Continuation...				
Procurement	**Who will acquire**	**Who will return**	**Maintenance**	**Edible**
Borrow	The actor uses his own	The actor uses his own	-	No
Buy	Juraj	-	Wash before the performance	Yes, obtain a new one before each performance
…				

Table 5. List of props.

3.4. Create scenery, lighting, and sound

When creating the scenery, it is important to consider the size and shape of the robot-actors. If only small robots are on stage, the scenery must also be appropriately sized. When using light and sound effects, it's crucial to remember that robots often express their emotions through light (e.g., their eyes light up in various colors). Stage lights must support the display of these emotions, not make them invisible. Robot speech tends to be quiet, so sound systems should ensure that robots can be heard clearly by the audience. Always keep in mind the overall impression and mood that the performance aims to convey.

For each piece of scenery, questions such as the following should be asked: What is the purpose of this piece? How much of the stage does it occupy? Can it be used in multiple scenes and how? Which characters will use this piece of the scene and how? How much does it cost? How long does it take to assemble? Is it meant only for characters to look at or to interact with? Will it be static or will actors move it around the stage? Does it need to accommodate an actor on it or hold something within it? Does it need to produce any sound or light? Can it rotate, etc.? The simplest sceneries consist of just one part, for example [93]:

- A painted wall or curtain with decorations related to the play, e.g., the interior of a room, a street, a park. If it can be rotated, a different image may be displayed on the other side.
- A shelf, cabinet, or clothing rack on wheels so they can be moved around the stage.
- A large striking object, e.g., a couch, piano, tree, statue. This item remains stationary on stage, but actors use it to sit on, lean against, hide behind, etc.

When designing scenery, it is good to follow the principle "less is more," so the stage design does not distract from the performance itself. A good first step for getting ideas on how to design the stage is to search the Internet. However, it is important to develop your own ideas and design rather than directly copying someone else's work. After getting an idea, a model of the scenery can be made to get a visual perception of where everything will stand. Before building the actual scenery, decide on a color palette to use depending on the atmosphere you want to convey [94]. The actual equipment will depend on the budget available [93]: using existing equipment, refurbished, or built from scratch, borrowed, donated, or sponsored. Once a piece of scenery is produced, it would be good to use it as much as possible, in multiple shows, for social media photos and show announcements, or by lending it to others.

4. Rehearsal

Rehearsal includes programming the robot-actors, rehearsal of human actors, and their iterative synchronization.

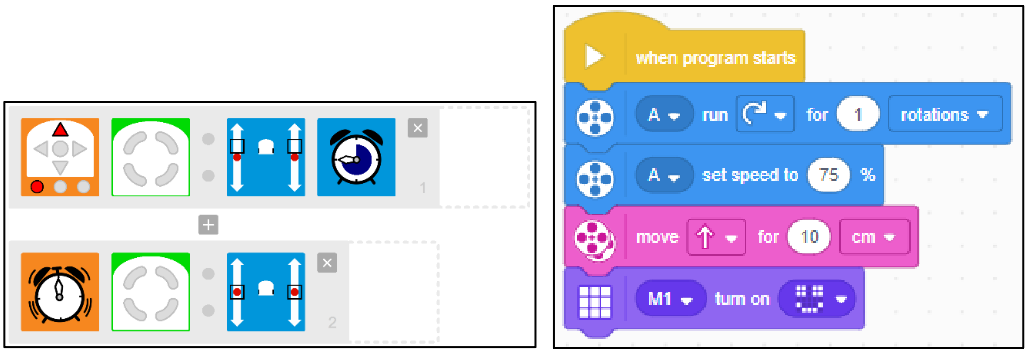
4.1. Program the robot-actors

After assembling the robots, they need to be programmed to perform the desired actions on stage [79]. The goal is to create robot behaviors that are legible to humans, which the audience and actors can understand and thus anticipate what the robot will do next, that show the inner states and emotions of robots, and that enable communication and interaction between actors and robots [79]. Programming can be divided into high-level programming, i.e., programming general robot behaviors (e.g., moving around the stage, interacting with other actors), and low-level programming, i.e., programming each small action of the robot (e.g., lifting a leg, turning eyes) [79]. Special attention should be paid to the small movements that make the robot come to life: moving eyes, head, fingers, waving hands, changing emotions, and others. Some ideas are given in the next chapter. The final program will include a series of small actions in the desired order (Figure 85). With the development of artificial intelligence, virtual and augmented reality, and related fields, there is also the possibility of using them in theater performances

To naturally integrate the robot into the performance, it would be good if there is interaction between actors and robot-actors. This can be achieved by having actors adapt to the robot, but a more challenging and ultimately more interesting approach is to use sensors on robots. In this way, the robot can cope with unplanned situations because it constantly monitors the environment and reacts based on that [95]. For navigating the stage, color sensors and black line following, ultrasonic sensors for detecting obstacles and people, or sound sensors for detecting clapping or noise can be used. For more advanced robots, advanced speech recognition, robot vision using cameras for recognizing markers and tags (e.g., QR codes or color markers), or gestures and emotions on other actors [79] can be used. After detection by sensors, the robot can perform an action, e.g., lift an object, convey a prop, express its emotion through changing its facial expression, body color, or sound, thus enriching interaction on stage [95].

Robots produce sounds in several ways. Some sounds are consequential noises that occur due to the robot's mechanics, interaction with the surface, its construction (engine sounds), or vibrations, and these cannot be avoided. Some sounds are added intentionally to convey a message, provide feedback, alert users, and are produced using piezo elements and speakers [96]. If we want to hear the robot speak, some robots already have recorded phrases or sounds in their databases, while for others it is possible to record desired text ourselves. Recording one's own speech is often in theater performances, especially if the performances are in smaller languages, such as Slovenian or Croatian. Students often enjoy recording their voices and thus bringing robots to life [97]. Recorded voices are then linked to the rest of the robot program and called at the moment we want the robot to speak or produce them. Here it should be kept in mind that the robot's speakers are usually not strong enough to produce sounds that will be heard at greater distances from the robot, i.e., in the audience. An additional problem is the consequential noises (especially motor sounds) that can be louder than the recorded speeches. In that case, consider the possibility of playing sounds directly from a computer, via a public address system. When mounting voices this way, they should be pre-connected with other sound effects in the show. A possible disadvantage in this case is that the audience may not be sure from which robot on stage the sound is coming (losing depth and direction of sound). To draw their attention to the right robot, it can change color, move more vigorously than other robots, turn towards the audience, step forward towards the audience, or be additionally illuminated with spotlights and the like. The final decision on how to produce speech from a robot depends on the robot itself and the hall where the show is displayed.

Each robot uses its own programming language (Figure 85). The most commonly used languages in educational robots are based on visual languages Scratch (scratch.mit.edu/) and Blockly (developers.google.com/blockly) and textual languages Python (www.python.org), C/C++, and Java (https://www.java.com/en/). The programming language is one of the criteria when choosing a robot for the stage. If younger students are preparing and programming the robot, an excellent choice is using a robot whose programming is visual, while for older students a textual programming language is a better choice. Robots intended for preschoolers have specially developed programming languages in which neither letters nor numbers need to be known (e.g., VPL for Thymio robot, https://www.thymio.org/products/programming-with-thymio-suite/), and even programming using physical elements and blocks. Some robots cannot or do not need to be programmed. They are remotely controlled using a remote control, mobile phone, or computer. To make this possible, it is necessary to download and install the appropriate application and practice controlling the robot on stage among actors and scenery. Examples of educational robots and how to program them are given in the chapter 7.




```python
from spike import PrimeHub, LightMatrix, Button, StatusLight
from spike.control import wait_for_seconds, wait_until, Timer

hub = PrimeHub()

hub.light_matrix.show_image('HAPPY')
```

```c
#define PIN_LED 2

void setup() {
    pinMode(PIN_LED, OUTPUT);
}

void loop() {
    digitalWrite(PIN_LED, HIGH);
    delay(500);
    digitalWrite(PIN_LED, LOW);
    delay(500);
}
```

Figure 85. Examples of programming languages for robots: VPL for Thymio, Scratch for Lego Spike Prime, Python for Lego Spike Prime, C/C++ for Arduino.

4.2. Conduct acting rehearsals

Before the actual acting rehearsals, it is necessary to determine who will play which character. One method is through auditions or, if the production involves a small group of students, through direct agreement. It would be beneficial for all actors and team members to introduce themselves and explain their roles in the production at the first rehearsal. Subsequently, the director explains the vision of the play, supporting their narrative with photographs, sketches, and collages to clarify the concept for everyone [98]. This is followed by table reads, i.e., reading the script aloud. Stage directions are given concurrently with the reading exercises. These rehearsals are also an excellent opportunity to develop characters and their relationships and to conduct bonding exercises among actors, ensuring cohesive stage presence [99].

The next step involves movement **rehearsals on stage** (known as blocking rehearsals). These rehearsals outline the actors' locations on stage and their movements throughout the scenes. To facilitate this, temporary set pieces (while the actual set is still under construction), such as chairs representing a couch or wardrobe, floor markings using painter's tape, etc., can be placed on stage. Actors can take notes in their scripts to help remember their positions. If the play is long, it can be broken down into smaller parts, and these rehearsals can be spread over several sessions. Each subsequent session should repeat the movements from earlier parts of the script [98]. During these rehearsals, it's also crucial to consider where the robot-actors will be and to record additional instructions for programmers. If some students are not involved in certain scenes, it's not necessary for them to attend rehearsals on those days to avoid distracting students who are currently on stage.

Next come **the working and developmental rehearsals**, where the play is run through in parts, problematic areas are addressed, and students get more practice together. It is assumed that students have memorized the script independently between rehearsals. Over 10 to 15 rehearsals, they should be able to move freely on stage, script-free. If they cannot recall a particular line, they can be prompted [98]. As parts of the set or props are produced or acquired, they are added to the stage. This allows actors to gradually adapt to the final stage setup [99]. **Polish rehearsals** are sessions where actors no longer need scripts in hand [100]. If there are changes in any scene, specific rehearsals related to that part of the play are conducted—initially a few rehearsals without props, then with props, so students can memorize the changes [100]. **Technical rehearsals** include technicians who handle lighting, sound effects, microphones, and special effects [99]. Once students have mastered the script, stage movements, and all changes, costume rehearsals begin. It's essential to anticipate potential issues as students change costumes, and if necessary, students can practice just that. There shouldn't be too many of these rehearsals to avoid the play becoming "over-rehearsed" [100]. A costume rehearsal is also called a dress rehearsal, i.e., the final rehearsal before the actual performance. In addition to costumes, actors also wear hairstyles and makeup as expected for the performance.

4.3. Synchronize actors and robot-actors

Synchronizing actors and robot-actors is an iterative process of the previous two steps: adjusting movements and behaviors of robots through programming and movements of actors. Only when they are together on stage can we verify if all timings and positions are well-coordinated. This step involves rehearsing and perfecting scenes [79]. We must continuously check whether the robot adequately conveys intentions and emotions, whether its nonverbal and verbal expressions are synchronized, whether it moves correctly on stage, and whether its interaction with humans appears natural. The goal is to ensure that all actors, robot-actors, props, scenery, lights, and sound interweave into a cohesive and consistent whole [79].

5. Performance

The final step in the process of creating a performance is the actual presentation to an audience. The greatest reward for everyone involved is the applause after the performance, and additional feedback can be obtained through surveys to assess quality.

5.1. Perform the show

The performance is the step in the play where it is actually presented to an audience. This could be other students at school, local community members, a performance in a neighboring city, or participation in a competition or festival of robot theater performances, such as RoboCup Onstage [95].

5.2. Assess quality

Quality assessment can be made from the perspective of students who worked on the performance and from the audience's viewpoint. From the students' perspective, this reflection could focus on the preparation process, the performance itself, and the role of robots in the play. Examples of questions are provided in Table 6, Table 7 and Table 8 [95][101][102].

After the performance, it would be beneficial to discuss the entire process of creating the play and the impressions of the actual performance with the students. This discussion can utilize structured discussions, presentations, a journal of impressions [79], photographs, and even anonymous surveys. Some topics for discussion include what they learned during the preparation of the play, how they divided the work, whether they functioned as a team, any problems they encountered during the preparation and how they resolved them, what they think about how the audience liked the play, whether it evoked emotions in the audience, encouraged them to watch and the like.

Students should consider whether the robot acted naturally on stage, how it manipulated objects, conducted interactions with people or other robots, whether it used sensors, whether the interaction looked natural, and the like. Since this involves a performance using robots, it is good to also reflect on the technical aspects of the show and the robots. Let students highlight what they think was special in the used and developed robots from the perspective of mechanical design of the robots, electronic design and wiring, used sensors, software solution, interaction of robots and environment (human actors or objects), and what was particularly innovative in their performance.

Another perspective on quality assessment is from the audience. At the end of the performance, the audience can be asked to respond to a short anonymous questionnaire or fill out a guest book. Audience comments can be a good guide for future performances and provide positive encouragement for students to participate in similar projects.

Reflection on the Preparation Process of the Play What did you learn new? ____ Who was responsible for which part of the play production? ____ How did you function as a team? ____ How did you solve the problems you encountered along the way? Provide a specific example. ____ What do you think, how did the audience like the play? ____

Table 6. Survey on reflection of the preparation process of the play.

Reflection on the Performance of the Play	Basic	Medium	Advanced	Exceeded
Implementation of Technological Elements of the Play				
Robot movements are natural.				
The robot navigates the stage space.				
There is interaction between the robot and humans and/or props.				
There is detection of objects or people.				
The robot can manipulate objects (e.g., grab, press, turn, transfer).				
The robot can express emotions (on its face or through movements, light, or sounds).				

The voice, speech, or sounds from the robot are loud enough and can be recognized by which robot-actor produces them.				
Verbal and nonverbal expressions of the robot are synchronized.				
Interaction with the Robot				
The interaction between humans and robots is interesting and related to the theme of the play.				
The interaction between humans and robots appears natural and unobtrusive.				
The robot uses complex movements that are connected to the story.				
Sensors are used during interaction.				
Sensors that recognize human gestures, facial expressions, speech, or similar are used during interaction.				
Multiple parts of the robot are extensively used during interaction (e.g., sensors and motors are synchronized).				
There is interaction between the robot and props that is connected to the story.				
The interaction between robots and props attracts attention and adds value to the play.				
There is interaction among multiple robots on stage.				
Quality of the Performance Overall				
The theme is clearly depicted throughout the play.				
The play encourages the audience to watch.				
The play evokes emotions in the audience.				
The audience clearly understands the story of the play.				
The context of the play is adapted to the target audience (according to age, prior knowledge, etc.).				
It is clearly visible in the play when and where the action takes place.				
The relationships between characters in the story are clear (e.g., who is a positive and who is a negative character).				
The robots' costumes are coordinated with the play and add additional value.				
The play effectively uses the stage space and scenery.				
The design and size of the robots are adapted to the play.				

Table 7. Survey on reflection of the performance of the play.

Reflection on the Role of Robots in the Play – what is particularly well performed on the robot for the play (provide an example):

Mechanical design of the robot (e.g., how it moves, type of wheels, how stable it is, whether it has functional arms, head, face, uses pneumatics, etc.): ______________________________ ______________________________ Electronic design and wiring (choice of materials, microcontrollers, making own electronics, wires do not interfere with the robot's operation, etc.): ______________________________ ______________________________ Sensor technology (e.g., coping in unplanned situations, the robot listens to the environment to be able to react, uses multiple sensors for better detection and reaction, etc.): ______________________________ ______________________________ Software solution (choice of programming language, difficulties, daring function, use of AI, VR, AR, testing process): ______________________________ ______________________________ Interaction (e.g., the robot uses a camera, lifts objects, expresses emotion based on sensors, etc.): Innovation: ______________________________ ______________________________ Innovation: ______________________________ ______________________________

Table 8. Survey on reflection on the role of robots in the play.

5.2. Achieving realism in robot-actors

Scenery, lighting, and sound significantly contribute to conveying the message of the play from the stage to the audience. However, the most crucial elements for presenting the story are the actors and the way they interpret the narrative. The delivery method, which affects both verbal interpretation and mimics and movement, largely depends on the theoretical conception of the theater as well as the method by which the actor builds their character. The relationship between the actor and the audience develops between two extremes: ancient Greek theater, where the actor openly communicates with the audience, and the naturalistic theater of the modern era, where the actor is isolated from the audience in front with the so-called "fourth wall" [103]. Even the position an actor holds in society affects the way they perform. An actor may play the role of a priest (as in ancient Greece or traditional Asian theater) who directly addresses the audience. Actors in Roman or Elizabethan theater in England were either slaves (or freedmen) or under the patronage of powerful people. Therefore, their approach to the audience was much more modest and restrained [103]. With the era of Romanticism, the rebel actor entered the world of theater, who through classical texts wanted to convey a political message to the audience [103]. In their acting, an actor must consider the personality of the character they are portraying. Some roles are predefined by typical characters, as was the case in ancient Roman theater, biblical and historical figures in European medieval and early modern theater, while archetypes such as the hero, young man, naive, and villain are products of the tradition of theatrical art [103]. Every actor can build a character and the way they will interpret it with the help of various character-building techniques. Famous Konstantin Stanislavski advocated for a complete mental union of the actor with their character. His student Stella Adler was more open to actors' ideas about the character they would play, and with Ute Hagen, the method moves away from extensive character analysis and leans towards simpler examples from everyday life surrounding the actors [104].

Whichever approach is taken, the key is how the imagined character is portrayed on stage. Conveying the impression of reality on stage is a fundamental task for an actor. With their voice, thoughts, movement, and expression of emotions, they must be good enough to convince the audience of the reality of their character. The reality of the play is created so that the actor's storytelling is largely covered by ideas that visitors had before entering the auditorium, but it is not necessary for the actor to completely merge with their character [105], but rather enough to convince the audience of the reality of their character and their story. For example, as a character, Hamlet is imagined as a young, charming, and cunning prince. To portray him, it is not necessary for the actor to actually be such (especially in terms of age); it is enough that their acting contains all these qualities.

The opposite is exaggeration, with an unnatural tone of voice, exaggerated facial expressions, and appearance on stage. The boundary between these two ways of acting is not precisely defined because exaggeration in some genres is appropriate and desirable (e.g., comedy or burlesque), while in others (drama) it is misplaced and spoils the impression of the performance [104]. The analysis an actor does for their character before rehearsals begin is very important for the character's believability. This analysis lays the foundation for their interpretation of the character. Through this analysis, they get to know who their character is (personality), the time and place in which the character exists, what the main motives of the character in this story are, and what the character wants to change during the play [104]. These questions can mostly be answered by a detailed analysis of the text or script, and from there logically move on to other characteristics of the character we build and then perform on stage [104]. Characters that actors interpret can vary greatly from play to play. Some actors have the ability to adapt to very different types of roles. This is a great quality, but it is not good to try to achieve it at all costs. Screenwriter and director John Swanbeck believes that an actor's personality is their most powerful weapon for building a well-interpreted character. Therefore, he considers it a big mistake for many actors at the beginning of their careers to try to cope in all possible roles, instead of focusing on those that are personally closer and in which they are most convincing [104]. Convincingness on stage, synchronization of voice, mimicry, and movement, with the help of stage technique, is what creates a good and convincing performance from the audience's perspective.

A similar approach should be used when creating a play with robots. Robots are machines, but when turning them into robot-actors, attention can be paid to details so that they too can convey the meaning of an event in the play. This can be done using [79]:

- Verbal expressions such as conveying emotions through speech, its loudness and pitch, and the range and variation of the voice
- Nonverbal expressions such as facial expressions, gestures, posture, body position, and proximity to other characters. To convey meaning, a robot-actor may change the direction of movement, speed, acceleration, size, shape, and frequency of gestures, etc. Like humans, robots can enhance or replace a verbal message with their gestures, direct the way a verbal message should be interpreted, and convey feelings, emotions, intentions, and desires
- Physical appearance. Clothing and costumes reflect the time period of the play, and clothing and accessories show the social and personal status of the character and their personality. Attention should be paid to the consistency of the robot-actor's actual and expected behavior, as otherwise, viewers will have a feeling of discomfort, known as the uncanny valley. Based on physical appearance, viewers will determine their attitudes towards the robot
- Lights which can be the color and intensity of the lights on the stage, but also on the robot itself (e.g., light around the robot's eyes)
- Sound and music that further enhance the impression of the situation in which the characters find themselves.

To make the audience believe that the robot-actors are truly alive and intelligent, the following elements should be kept in mind [79]:

- Autonomous behavior of the robot. To emphasize that they are alive, robot-actors should perform movements such as breathing, blinking, and fidgeting. A robot that remains still appears as an object, as if it is not alive.
- The robot's gaze and eye contact give the impression that the robot is listening to what other actors are saying and doing, thereby helping to increase the credibility of the character
- Movements of robot-actors should look as natural as possible
- Consistency between the inner state and nonverbal expressions
- Consistency between verbal and nonverbal expressions
- Real-time response to certain actions of human actors or the audience
- Emotions of the robot. When a certain situation requires it, the robot should express emotion and respond to the emotions of other characters. Expressing emotion is short-lived, after which the robot must return to its neutral expression. Factors that influence the intensity and type of emotions are, for example, the character's personality, the intensity of the current mood, emotional contagion (behavior appropriate to the emotional state of other characters), social situation, attitude towards a person or object (liking or disliking), etc.
- Personality. Personality is a set of traits that make a character unique, most often using verbal and nonverbal expressions. Personality affects the behavior of characters, their movement, and speech. Throughout the entire performance, the personality of the robot-actors should be kept in mind through consistent actions to make the personality believable
- Attitude is a combination of positive and negative feelings towards a person, animal, object, or place
- Character traits and their relationships change over time as a result of interaction with others (e.g., at the beginning of the story they do not know each other, at the end they get married)
- Mood changes during the performance due to changes in physiological state (illness, fatigue, hunger), emotional events, changes in attitude towards people and things, personal events of the character, and achieving goals (mood changes depending on how well the character is doing in achieving goals)
- Empathy. People are more empathetic towards family members and friends than strangers, have stronger reactions when they have a similar experience. Cognitive empathy involves understanding others' feelings, thoughts, and situations (e.g., a robot-actor says "Great! Excellent!" while another actor brings good news). Affective empathy, or emotional contagion, is the ability to experience the emotions and feelings of others and express those emotions in accordance with others.
- The background story of the robot-actor contains details about the character, e.g., age, family, life situation, etc.

To confirm which of these traits have more influence on viewers to believe that robot-actors are truly alive and intelligent, a survey was conducted among 20 teachers after participating in the lecture "Robots in Theater" in January 2024. According to the survey (Table 9**Pogreška! Izvor reference nije pronađen.**), the most important traits are "The robot's gaze and eye contact," "When a certain situation requires it, the robot should express emotion," and "Movements should look as natural as possible." The least important traits are "The background story of the robot-actor that contains details about the character, e.g., age, family, life situation," and "Perform movements such as breathing, blinking, and fidgeting."

	Median	**Mean**	**Mode**
The robot's gaze and eye contact	5	4.5	5
When a certain situation requires it, the robot should express emotion	5	4.5	5
The robot should respond to the emotions of other actors	4.5	4.45	5

Personality	4.5	4.45	5
Real-time response to specific actions of human actors or the audience	4.5	4.35	5
Movements should appear as natural as possible	5	4.3	5
Coherence between verbal and nonverbal expressions	4	4.25	4
Cognitive empathy	4	4.2	4
Affective empathy, or emotional contagion	4	4.15	4
The robot's mood changes during the performance	4	4.15	4
The robot's traits and relationships change over time	4	4.1	4
Empathy	4	4.05	4
Coherence between internal state and nonverbal expressions	4	4.05	4
Attitude	4	4	4
Perform movements such as breathing, blinking, and fidgeting	4	3.95	4
The background story of the robot-actor	4	3.75	4

Table 9. Characteristics the robot must demonstrate for the audience to believe it is alive.

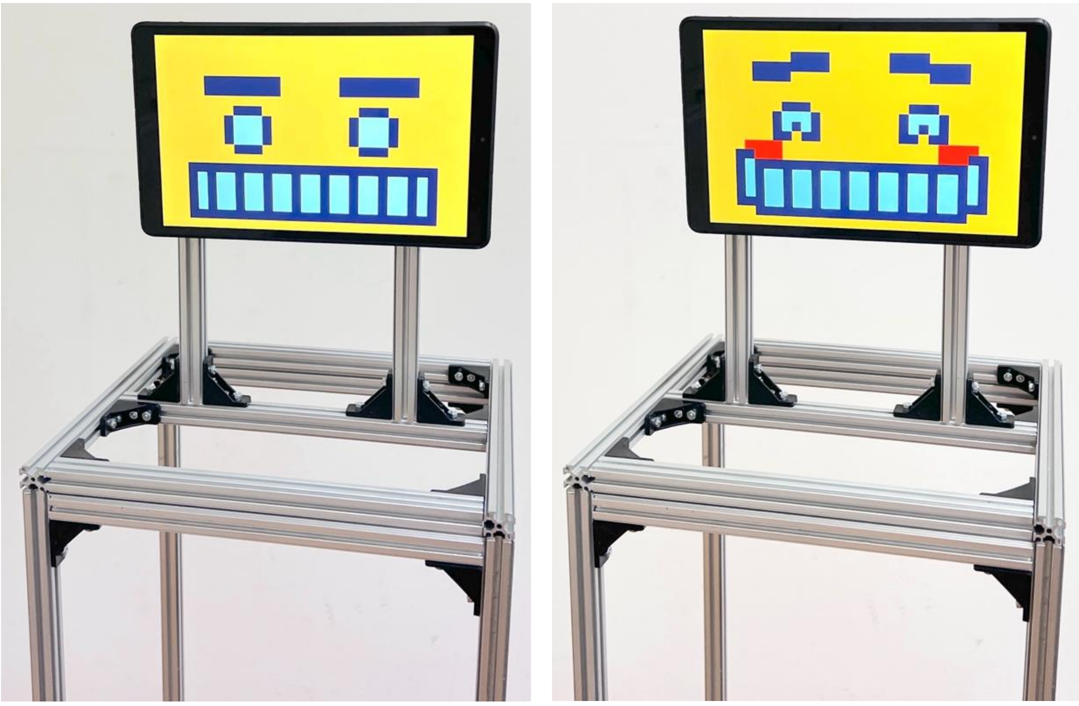


Figure 86. Examples of robotic facial expressions.

6. Robots, theater and school

6.1. What students think about performances with robot-actors

To find out what students think about the role of robots as actors in theater productions, a brief survey was conducted. The survey was completed by students who participated in creating plays with robots in Trbovlje (Slovenia, 8 students), Ivanić-Grad (Croatia, 5 students), and at the Summer Robotics Camp Petica, Ivanić-Grad (Croatia, 18 students), totaling 31 students. The results are shown in the Figure 87 and Figure 88.

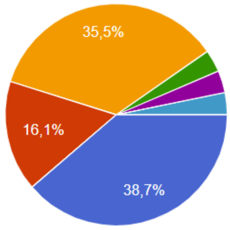


Figure 87. Diagram of students' responses to the question "Which type of robot would you most like to see in the theater": blue – humanoid, red – vehicle, yellow – animals, purple – transformers, green – no robots in theater, light blue – all.

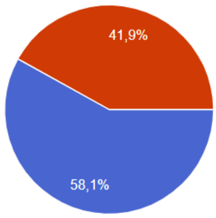


Figure 88. Diagram of students' responses to the question "Would you watch a play where the actors are only robots?": blue – yes, red – no.

Analysis of the responses to the question "What type of robot would you most like to see in a theater?" (Figure 87) suggests that there is a pronounced interest in humanoid robots, which are the most human-like in form and likely the first association with the term "robot". It is not surprising that the second preferred type of robot is in the form of an animal, given that this is closest to what children encounter on a daily basis. It is also interesting to note the presence of robots in media content, given the desire to see transformers in theater, which indicates the influence of technology through the film industry.

In the question "I would watch a play where the actors are only robots" (Figure 88), we can see that a slightly larger number of students are willing to give a chance to plays where only robots perform and would like to watch at least one such play. Interestingly, in the first question, almost all students (except one) listed at least one type of robot they would most like to see in theater, whereas in the second question, nearly half of the respondents answered that they would not like to watch only robots in plays. Given that the first question did not define whether humans would also perform alongside robots, and the second question has a clear definition, it could be concluded that plays where both humans and robots are actors are somewhat more interesting and something that students would prefer over just robots on stage.

6.2. What short children's theater stories with robots talk about

Students from Eugen Kvaternik Elementary School in Velika Gorica wrote 79 stories featuring robots as actors during their computer science classes. A total of 146 students participated in writing the stories, including 82 girls and 62 boys, aged between 9 and 15 years. Their stories were inspired by photographs and short descriptions of robots on Padlet. An analysis of these stories can reveal students' attitudes towards robots, how they perceive them, and how they integrate the concept of robots into the story.

The most commonly mentioned situation in the stories is friendship (situations where the robot has or lacks friends), followed by conflicts between robots and situations where the robot is the villain (Table 10). These themes reflect what today's youth are surrounded by. These situations are grouped into themes such as friendship, war, love, and others, and were analyzed by the gender of the students. As expected, themes of war and conflicts predominated among boys (45%), with love being almost unmentioned (3%). Surprisingly, girls also frequently described conflicts in their stories (35%). Most of the stories describe robots as positive characters (49% of boys and 69% of girls), but this attitude changes with the students' age. 93% of fifth graders consider robots positive, while only 60% of eighth graders share this view. Detailed analysis and conclusions are provided in [106].

Situation	Number of stories
The robot has at least one friend	53
Conflicts between robots	18
The robot is a villain	17
The robot has a family	15
The robot is in space	13
The robot flies	14
The robot fights against humans	12
The robot saves the world	8
The robot performs everyday human tasks	8
The robot travels through time	6
The robot engages in sports	4
The robot is in love	3
The robot is rusted from sadness	3
The robot explores the ocean depths	3
The robot loves music	2
People got bored of the robot after some time	2
Mentioning influential contemporary figures	2

Table 10. Number of occurrences of each situation in children's stories.

6.3. Examples of children's stories

Students of the Eugen Kvaternik Elementary School in Velika Gorica, under the mentorship of Dalia Kager, wrote numerous stories featuring robots as actors. Some of these stories were turned into scripts and realized on stage, which are presented in this manual. Below is a selection of stories from students of this school. Additionally, to encourage students from all over Croatia to think about robots on the theatrical stage, a competition "Theatrical Story with Robots" was organized in 2024 [109]. Award-winning stories are also provided below.

Example 1. Friendship
Authors: Jelena Kovačić i Lorena Katalenić
School: Ekonomska i birotehnička škola Bjelovar, Bjelovar
Mentor: Vesna Pavković-Dončević
1st prize in the "Theatrical Story with Robots" competition

Once there lived a robot named Yellow. He was special and yellow. He had the ability to change the color of his metal armor according to his feelings. Whenever he was happy, he would turn orange, and when he was sad, he would turn blue. Yellow was lonely. He wanted a friend with whom he could talk and hang out. While walking in a small park, he saw a little boy sitting on a bench crying. Yellow immediately ran to him. He asked why he was sad, and the boy replied that he had no friends because he was different from other children and felt unaccepted. "Today's children always have mobile phones in their hands and don't know how to play in the sand, swing, or slide," he replied. His parents couldn't afford a mobile phone because they were poor, but he wasn't mad at them. He knew how to have fun without a phone, he just wanted company to play with. Yellow decided to cheer up the boy. He danced, sang, and performed various tricks to make him laugh. He was happy and changed his color from yellow to orange. The boy found this amusing; he mimicked Yellow. In the evening, they were tired and decided to go home, planning to continue playing the next day. They spent a lot of time together and became best friends. Yellow taught the boy that with friends, every game becomes merrier, more challenging, filled with laughter... Friends make every moment of life unforgettable.

Example 2. Master Robert
Authors: Nikolina i Martina Bregar
School: Osnovna škola Žakanje, Žakanje
Mentor: Elvira Špelić Vidović
2nd prize in the "Theatrical Story with Robots" competition

Once upon a time, there was a robot named Robert who went to repair the Eiffel Tower because some parts had fallen off. The robot had to travel a long way to Paris. On the way, he lost his tools because his trunk was open. He had to go back and find the lost tools. He lost a hammer, pliers, a screwdriver, and screws. First, he went to the lake where he found the pliers and also saw screws near colorful frogs. Happily, he lit up in green, blue, and white colors. He diligently picked everything up and stored it in the trunk. While searching further near a farm, he found the hammer and saw a white horse grazing on the grass. Happily, he "blinked" in yellow color. He also stored the hammer in the trunk. It had gotten dark, so he had to turn on the lights because the path through the forest was getting darker. Among the tall pines, he found the pliers and stored them in the trunk. Happily, he lit up in green color. He lit up in red lights and played a cheerful tune and continued his journey to Paris, the city of love.

Example 3. The Pet
Author: Petra Srebrenović
School: Ekonomska i birotehnička škola Bjelovar, Bjelovar
Mentor: Vesna Pavković-Dončević
3rd prize in the "Theatrical Story with Robots" competition

For my birthday, I received a small robot as a gift. I was surprised by this gift; I didn't expect something like this, and my first thought was: "What do I need this for?" Then I began to study it. It could talk. I was surprised that its voice sounded similar to mine. Then I watched its movements. It followed me around all the time, as if it wanted to mimic me. When I told it to stop, it obeyed. It looked at me with robotic eyes as if it was a real person who understood me. I started giving it various commands. I told it to come, and it came close to me. Then I told it to follow me, and it obeyed again. I even tried talking to it. When I said, "Good day," it would say it too. Then I asked how it was, and it responded, "I'm fine." I realized it had the power to recognize the voice questioning it and to respond to questions. It was so well programmed that at times I thought it had something human about it. A bit creepy, right? At times it scared me when I accidentally said a word, and it repeated it. After some time, I got so used to it that days without it were unimaginable. It grew on me – like having a pet that is always with you, and you don't have to feed it, just charge its batteries.

Example 4. A Birthday Gift
Author: Mateja, 6th grade
School: Eugen Kvaternik Elementary School, Velika Gorica
Mentor: Dalia Kager

In the play, the characters include robot Jimu (Shapeshifter) and a girl named Lorena (shoulder-length brown hair, blue dress with small white flowers, white ballet flats), mom (32 years old, long blonde hair, red shirt, black jeans, and white sneakers), dad (35 years old, brown hair, blue short-sleeve shirt, black track pants, and black sneakers). At the front, at the beginning of the stage, there is a wooden fence, and behind it a small green lawn where Lorena is playing with a ball. While playing, she thought about what she wanted for her birthday. She decided to ask her mom and dad for a robot. The day arrived - Lorena's birthday.

MOM: Good morning Lorena, what would you like for your birthday?
LORENA: Morning, mom! For my birthday, I'd like a robot that can change shapes.
DAD, MOM: (in unison): Sure! (Mom and dad leave Lorena with her grandmother and go to the store)
MOM: Hey, should we buy this robot named Jimu?
DAD: Why not, just make sure it can transform into various shapes.
MOM: It says it can transform into various shapes.
DAD: Alright, then it's a yes. (Mom and dad return to pick up Lorena to give her the gift).
LORENA: Wow! It's so pretty! I'll call it Shapeshifter. (The robot began to transform into various shapes, and Lorena was happy. Every day she played with it.)
LORENA: Shapeshifter, you are my best friend, even though you're a robot!

Example 5. Saving Robocity
Author: Daniel, 5th grade
School: Eugen Kvaternik Elementary School, Velika Gorica
Mentor: Dalia Kager
Robots: Lego Spike Prime

Robot Mike lives in Robocity with his friend Scotti. Robot Mike would be the savior of Robocity. His friend Scotti would help him. Aliens wanted to destroy the city, and robots Mike and Scotti would create an all-powerful sword. Any alien it touched would turn to gold dust. They would later share this gold and no one in the world would be poor anymore.

Example 6. Mice Don't Belong in Toilets
Author: Josip, 6th grade
School: Eugen Kvaternik Elementary School, Velika Gorica
Mentor: Dalia Kager
Main character: Billy
Robot: Code & Go Robot Mouse Activity Set
Setting: Billy's room

Once upon a time, there was a little boy named Billy. Billy loved playing a video game called OSU! He played it every day. One day when he got home from school... of course, he went to play OSU! on his computer. So, he turned on the computer and opened OSU! Billy said, "Oh man! I can't wait to spend my life and time on this game!" Anyway, this time instead of playing some easy songs, he decided... to play the hardest songs! And of course, he was bad at them and lost several times. But Billy had a master plan! He decided to buy a hacker mouse from eBay for only $1! Billy didn't think anything suspicious and bought the mouse. Two days later - the mouse arrives! He immediately unpacked it, went to his computer, and plugged it in. His computer started acting weird when he plugged in the mouse, but he didn't think much about it and opened OSU! Once in the game, he tried to play the hardest song and to his surprise... He was even worse at it! It only took him a minute to realize that... he had been tricked! He became so angry and frustrated that he went to his bathroom and threw his mouse into the toilet as hard as he could and flushed it. A moment of silence. The toilet started making clicking sounds and... EXPLODED!!!

From that day on, Billy learned never to try to cheat in games and not to order things from eBay that cost $1 and sound too good to be true.

THE END!

Example 7. The Best Friend Robot
Authors: Kiara, Roman, and Dario, 8th grade

School: Eugen Kvaternik Elementary School, Velika Gorica
Mentor: Dalia Kager
Main character: robot Isaiah (MeccaNoid) and girl Maria
Supporting characters: Elijah (Alpha 1 Pro) and Moses (Aelos 1S / Aelos 1 Pro)

The action begins when little girl Maria is insulted and beaten at school. Because of this, her mother ordered a robot Isaiah via Facebook to be her friend and protect her. When he arrived, Maria liked Isaiah, so they became best friends. One day when they went to school together, Maria's classmates mocked her because her only friend was Isaiah. When Isaiah heard this, he called more of his robot friends - Elijah and Moses. The next day, Elijah and Moses came with Isaiah and Maria. Isaiah was happy because Maria was happy - because she finally had friends.

Thus, Isaiah became Maria's best friend.

Example 8. Robocleaner
Authors: Valentina and Brigita, 8th grade
School: Eugen Kvaternik Elementary School, Velika Gorica
Mentor: Dalia Kager
Robot: Lego Spike Essentials

Robocleaner helped with all household chores, but suddenly he gave up. It saddened him that he always had to work alone and no one wanted to help him. Sometimes he wanted to take time for himself, but he could not because he was busy with all the household chores. One day Robocleaner just stopped working and rusted from sadness and depression.

6.4. What teachers and educators think about robots

To assess the attitudes of teachers and educators towards robots, a survey was conducted using the Negative Attitude Toward Robots Scale (NARS) [107]. The aim of the research was to explore resistance to robotics among Croatian teachers using negative attitudes towards robots, as their views can directly influence students and their perceptions (limited physical exposure to technology, but also an impact on their perception). The questionnaire is shown in Table 11 and consists of 11 positively and 3 negatively worded items grouped into three sub-scales:

- Sub-scale 1 (S1): Negative attitude towards interaction situations with robots.
- Sub-scale 2 (S2): Negative attitude towards the social impact of robots.
- Sub-scale 3 (S3): Negative attitude towards emotions in interaction with robots.

The study involved 62 participants, teachers of various levels of formal education (from kindergartens, elementary and secondary schools to universities), as well as educators from associations and other informal forms of education. Participants voluntarily attended the lecture "Robots in Theater" or workshops on programming Arduino microcontrollers, but completed the questionnaire before the activities themselves. The results of the responses to individual questionnaire items are shown in Figure 89.

The first sub-scale of the questionnaire relates to attitudes towards human interaction with robots and from the given results it can be concluded that the respondents are not worried or afraid when it comes to some interaction with robots such as using robots at work, standing in front of robots, operating a robot in front of others, or talking to a robot, and also the word robot is not insignificant to them. However, the attitude is completely different when it comes to decision-making by robots or artificial intelligence, they believe that it would not be good at all.

Looking at the items of the second sub-scale, which relate to the social impact of robots, we can see that a larger number of respondents have a negative attitude when it comes to causing discomfort in the presence of robots and the fear that something bad would happen if robots were alive and if we depended too much on them. However, two items provoke a different opinion from respondents, which is that most of them believe that robots cannot have a bad influence on children and that robots will not dominate society in the future.

The last sub-scale consists of positively worded items. According to the results, it is visible that respondents would not feel comfortable if robots had emotions, nor could they talk or befriend them then. Thus, negative attitudes towards emotions in interaction with robots are more pronounced.

The general result of the conducted research showed that teachers who use robots in teaching have less negative attitudes towards all sub-scales of the questionnaire. Differences are most pronounced in the female sample, which shows more negative attitudes than the male sample. A more detailed analysis is given in the paper [108].

NARS item	Questionnaire item	Sub-scale
1	I would feel uneasy if robots really had emotions.	S2
2	Something bad might happen if robots developed into living beings.	S2
3*	I would feel relaxed talking with robots.	S3
4	I would feel uneasy if I was given a job where I had to use robots.	S1
5*	If robots had emotions, I would be able to make friends with them.	S3
6*	I feel comforted being with robots that have emotions.	S3
7	The word “robot” means nothing to me.	S1
8	I would feel nervous operating a robot in front of other people.	S1
9	I would hate the idea that robots or artificial intelligences were making judgments about things.	S1
10	I would feel very nervous just standing in front of a robot.	S1
11	I feel that if I depend on robots too much, something bad might happen.	S2
12	I would feel paranoid talking with a robot.	S1
13	I am concerned that robots would be a had influence on children.	S2
14	I feel that in the future society will be dominated by robots.	S2

Table 11. Items of negative attitudes towards robots scale. * marks reverse items

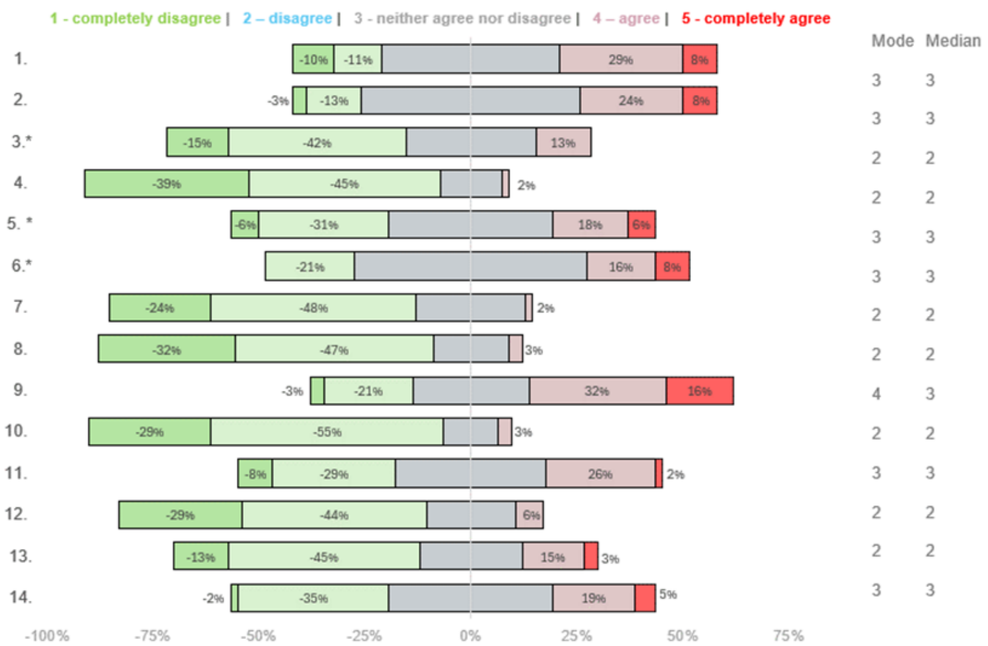


Figure 89. Frequency of responses to individual questions.

6.5. Connection of the steps in creating a play with 21st century skills

The skills needed for successful living in the modern digital age are called 21st-century skills. They can be divided into three groups of skills: learning skills, literacy skills, and life skills (Figure 90). There are other types of divisions, but the essence remains similar.

Learning skills (often called the "Four Cs" in English, referring to the first letters of their names) include mental processes necessary for adapting to future work environments. Learning skills are:

- Critical thinking, which involves analyzing available information, facts, evidence, observations, and arguments to make an informed conclusion and decision. It helps us recognize ambiguity, and we learn to question, interpret, justify, and think [111]
- Creativity describes thinking outside the box, enabling viewing problems from a different perspective, leading to innovations [110]
- Collaboration involves working with others, learning to achieve compromises, and jointly searching for the best solution to a problem. It often includes a willingness to sacrifice part of one's ideas and accept others' solutions [110]
- Communication encompasses talking with others, teaching how to effectively convey ideas between different types of people to eliminate potential misunderstandings [110]

Literacy skills (often called IMT in English) include recognizing and critically analyzing facts, primarily related to data on the Internet. Literacy skills are:

- Information literacy, which covers understanding facts, data, statistics, and numbers. It assesses the need for information, its location, evaluation, storage, retrieval, and use to solve problems [112]
- Media literacy, which involves understanding the methods of information publication. It includes the ability to access, analyze, comprehend, evaluate, and create communication in various forms, i.e., the nature, techniques, and impacts of media messages [112]
- Technology literacy, which involves understanding the devices and machines used, such as computers, mobile devices, and others. Through this literacy, students learn which devices are used for performing which tasks and thereby remove the possible fear of using technology [110]

Life skills are often referred to as FLIPS skills in English and include personal and professional qualities of each individual. Life skills are:

- Flexibility, which encompasses deviating from plans as necessary to adapt to changes. Students must learn that their ideas are not always the best, how to recognize and admit they were wrong, when and how to change, and how to respond to change [110]
- Leadership is the skill of motivating a team to achieve a set goal. For those who are not currently team leaders, this skill helps understand the decisions made by the leader. In this way, an individual develops their skills to be ready to lead when the position arises [110]
- Initiative teaches how to start projects independently. It is the willingness to step forward with an idea and take the risk of realizing that idea. It teaches students how to set goals, plan to achieve those goals, and implement their plans [113]
- Productivity teaches how to remain efficient under pressure, how to complete the assigned work within the allotted time, i.e., how to do more in less time. By learning this skill, students discover their best working methods while respecting other people's approaches [110]
- Social skills help in meeting and networking with others for mutual benefit. These skills include learning etiquette, politeness, manners, and small talk [110]

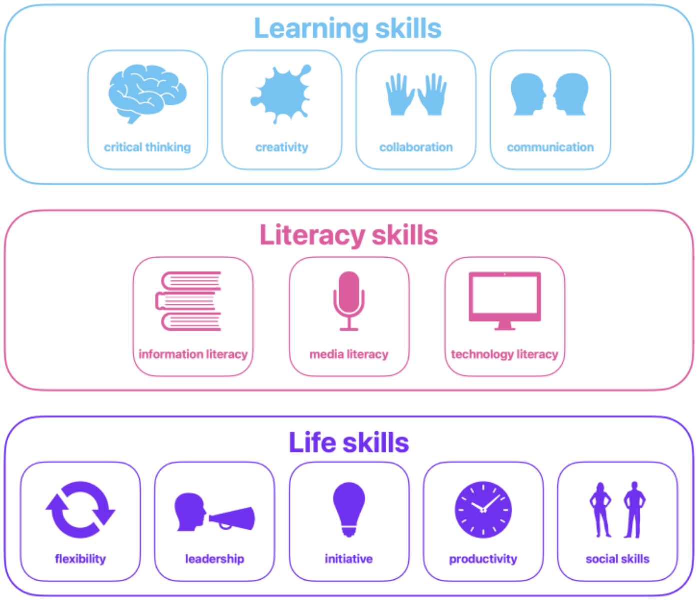


Figure 90. 21st century skills.

Working on a theater play with robot-actors develops all the above-mentioned skills, some on a larger scale, some on a smaller scale (Figure 91). On the basis of a questionnaire conducted among 20 teachers and educators, after listening to the lecture "Robots in the theater" created on the basis of this manual (January 2024), the results were obtained as to what skills the students will develop when creating a theatrical performance with robots. All respondents agree that making a play with robots develops creativity (100%), 90% of them agree that it develops communication, cooperation and initiative, and 85% critical thinking. They are followed by technological literacy (75%), media literacy (70%), information literacy (65%), flexibility and social skills (60%). The skills that are least developed are leadership and productivity, for which 45% of respondents agree that they are still developed when creating a play.

In the research conducted after the lecture "Is there place for robots in theater?" (April 2024), based on this manual, 27 participants evaluated each step of creating a play for which skill it develops (Table 12, Table 13, Table 14). It was shown that each step of the play affects the development of multiple skills, with nearly all steps influencing the development of creativity and collaboration. The development of critical thinking is particularly influenced by the steps of choosing robots and assessing the quality of the performance. Communication skills are most developed in creating the movement diagrams for robots, synchronizing robots and actors, and in the actual performance before an audience. The most prevalent literacy skill is media literacy, present in almost all steps of creating a play, except in direct work with robots where the development of technology literacy dominates. Information literacy is most developed in the stages of getting ideas and choosing robots. Life skills are the least represented, yet still, getting an idea for a play develops initiative and leadership, writing scripts develops productivity and initiative, making props, scenery, lighting, and sound develops productivity, and acting rehearsals and synchronization of actors and robots develop social skills. This analysis shows how working on theater productions with robots greatly contributes to both new knowledge and the overall development of 21st-century skills.

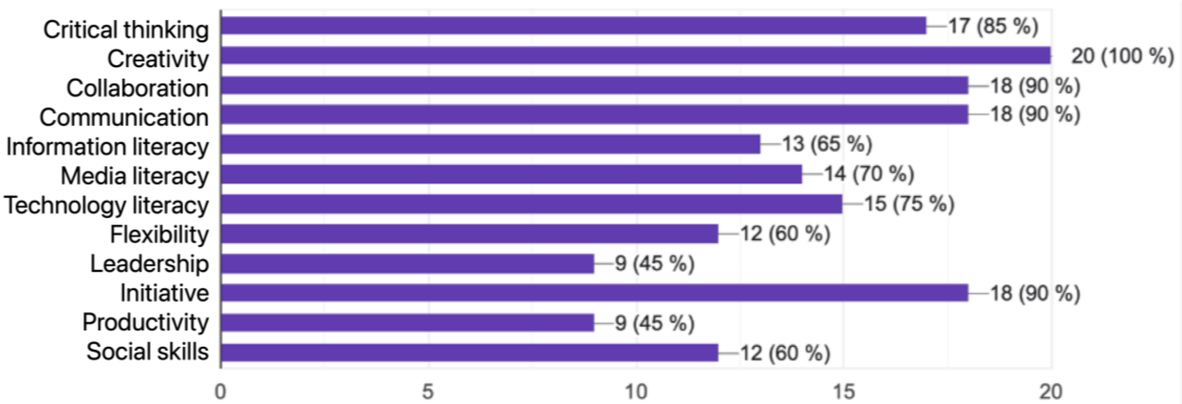


Figure 91. 21st century skills developed by working on a theater play with robots.

Steps in creating a theater production	Critical thinking	Creativity	Collaboration	Communi-cation
Get an idea	10	22	17	17
Design and write the story	12	23	17	14
Select robots	19	11	17	16
Write the script	12	23	17	15
Sketch the robot movement diagram	16	15	19	20
Build the robot-actors	15	22	18	14
Create costumes	11	23	18	16
Make props	8	22	18	14
Create scenery, lighting, and sound	9	21	20	14
Program the robot-actors	14	20	19	14
Conduct acting rehearsals	10	16	22	16
Synchronize actors and robot-actors	10	18	17	18
Perform the play	6	15	19	18
Assess quality	16	13	17	14

Table 12. Connection of learning skills and steps in creating a play.

Steps in creating a theater production	Information literacy	Media literacy	Technology literacy
Get an idea	18	20	10
Design and write the story	14	19	8
Select robots	15	6	17
Write the script	10	21	5
Sketch the robot movement diagram	13	8	18
Build the robot-actors	12	13	16
Create costumes	7	14	11
Make props	10	16	13
Create scenery, lighting, and sound	7	18	15
Program the robot-actors	13	8	17
Conduct acting rehearsals	8	19	9
Synchronize actors and robot-actors	11	18	12
Perform the play	11	20	10
Assess quality	11	16	11

Table 13. Connection of literacy skills and steps in creating a play.

Steps in creating a theater production	Flexibility	Leader-ship	Initiative	Product-ivity	Social skills
Get an idea	13	14	19	13	13
Design and write the story	11	12	14	14	11
Select robots	13	9	10	15	11
Write the script	8	7	16	16	8
Sketch the robot movement diagram	6	9	15	17	7
Build the robot-actors	12	12	12	14	8
Create costumes	10	11	11	14	8
Make props	14	11	11	16	8
Create scenery, lighting, and sound	13	10	11	16	11
Program the robot-actors	8	12	15	14	11
Conduct acting rehearsals	10	11	12	12	14
Synchronize actors and robot-actors	11	16	12	9	14
Perform the play	12	12	13	15	12
Assess quality	6	13	11	12	9

Table 14. Connection of life skills and steps in creating a play.

* Best result for each step of the play is marked in red, best result for each skill is marked in blue.

6.6. Connection of the steps in creating a play with robots to the curriculum

Each step in creating a play with robots is closely related to the learning outcomes in vocational high schools in Croatia and Slovenia and the selection of subjects in elementary schools (Table 15) [114][115].

Stage Play Creation Steps	Croatia	Slovenia
1. Planning the Play		
1.1. Obtain an Idea	High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text. High School, Croatian Language A.3.1. The student delivers instructive and argumentative texts in accordance with their purpose and the desired effect on the recipient.	
1.1.1. Choose Context	High School, Croatian Language A.3.1. The student delivers instructive and argumentative texts in accordance with their purpose and the desired effect on the recipient.	
1.1.2. Study Available Robots	Elementary School, Information Technology A.1.1. After the first year of studying Information Technology in the domain of information and digital technology, the student recognizes digital technology and communicates with familiar individuals with the help of a teacher in a safe digital environment.	High School, Computer Science Technician - Introduction to Computer Science module: The student applies various techniques to identify the problems of clients.
1.1.3. Conduct a Brainstorming Session	High School, Croatian Language A.3.1. The student delivers instructive and argumentative texts in accordance with their purpose and the desired effect on the recipient.	High School, Computer Science Technician - Computer Products and Services module: The student designs an innovative solution to solve a given complex

	High School, Croatian Language A.3.2. The student listens to instructive and argumentative texts of various functional styles and forms in accordance with a certain purpose. High School, Croatian Language A.4.1. The student discusses in accordance with the purpose and the desired effect on the recipient.	problem in a group using the "design thinking" method.
1.2. Conceive and Write the Story	High School, Croatian Language A.1.4. The student writes descriptive and narrative discourse texts, achieving the characteristics of functional styles in accordance with the purpose and desired effect on the recipient. High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text.	High School, Media Technician - Expressing with Image and Sound (EIS) module: The student will be able to prepare the elements of the synopsis design for AV production.AV produkcije.
1.2.1. Conceive the Story	High School, Croatian Language B.4.4. The student creatively expresses themselves according to their own interest, inspired by the text.	
1.2.2. Develop Characters from the Story	High School, Croatian Language B.4.4. The student creatively expresses themselves according to their own interest, inspired by the text.	
1.2.3. Determine the Atmosphere of the Story (decide on costumes, props, physical (lighting, decorations) and sound atmosphere)		High School, Media Technician - Expressing with Image and Sound (EIS) module: The student knows the dramaturgical elements of scenic, makeup, and costume design. The student uses different light sources according to the object of the painting and the space in which it is located; The student selects sound for different media.
1.3. Select Robots	Elementary School, Information Technology C.2.1. After the second year of studying Information Technology in the domain of digital literacy and communication, the student chooses a device and program for simple school tasks based on the teacher's advice.	High School, Media Technician - Multimedia Production module: The student learns about traditional and modern devices for interaction. The student selects and uses appropriate software. High School, Computer Science Technician - Introduction to Computer Science module: The student gathers and uses the most appropriate digital technology for communication, The student advises others on the use of digital technologies for communication.
2. Script Creation		

2.1. Write the Script	High School, Croatian Language A.1.4. The student writes descriptive and narrative discourse texts, achieving the characteristics of functional styles in accordance with the purpose and desired effect on the recipient. High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text.	High School, Media Technician - Expressing with Image and Sound (EIS) module: The student creates a synopsis and script for an AV message.
2.1.1. Describe Characters	High School, Croatian Language A.1.4. The student writes descriptive and narrative discourse texts, achieving the characteristics of functional styles in accordance with the purpose and desired effect on the recipient. High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text.	
2.1.2. Describe Actions	High School, Croatian Language A.1.4. The student writes descriptive and narrative discourse texts, achieving the characteristics of functional styles in accordance with the purpose and desired effect on the recipient. High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text.	High School, Media Technician - Expressing with Image and Sound (EIS) module: The student draws on the floor plan the camera setups and the movement of actors and camera.
2.1.3. Determine Duration	High School, Croatian Language A.1.4. The student writes descriptive and narrative discourse texts, achieving the characteristics of functional styles in accordance with the purpose and desired effect on the recipient. High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text.	High School, Media Technician - Expressing with Image and Sound (EIS) module: The student draws on the floor plan the camera setups and the movement of actors and camera.
2.1.4. Describe Positions	High School, Croatian Language A.1.4. The student writes descriptive and narrative discourse texts, achieving the characteristics of functional styles in accordance with the purpose and desired effect on the recipient. High School, Croatian Language B.1.4. The student creatively expresses themselves according to their own interest, inspired by the text.	
2.2. Sketch the Movement Diagram for Robots	High School, Croatian Language A.2.4. The student writes expository texts, achieving the characteristics of functional styles in accordance with the purpose of the text and the desired effect on the recipient.	High School, Media Technician - Expressing with Image and Sound (EIS) module: The student draws on the floor plan the camera setups and the movement of actors and camera.

	High School, Croatian Language A.3.4. The student writes instructive and argumentative texts, achieving the characteristics of functional styles in accordance with the purpose of the text and the desired effect on the recipient. High School, Logic A.2. The student diagrams sentences expressed in ordinary language in various ways and translates the diagrams back into ordinary language.	
3. Preparation		
3.1. Build Robot Actors		High School, Mechatronics Technician - Robotics module: The student builds a simple mobile robot with wheels and controls it, possibly also regulates and guides it to perform a specific task.
3.2. Synchronize Actors and Robot Actors		High School, Clothing Manufacturer - Tailoring module - Women's Clothing: The student considers the wishes of clients and can advise them, The student draws fashion sketches, The student cuts the fabric for the clothing, The student creates custom-made clothing.
3.3. Synchronize Actors and Robot Actors		
3.4. Synchronize Actors and Robot Actors	Elementary School, Information Technology C.5.4. After the fifth year of studying Information Technology in the domain of digital literacy and communication, the student uses multimedia programs to realize more complex ideas in a communicative or collaborative environment.	High School, Media Technician - Filming and Editing module: The student knows how to choose appropriate lighting; The student records suitable sound for the image.
4. Synchronize Actors and Robot Actors		
		High School, Computer Science Technician - Introduction to Computer Science module: The student creates a "minimum viable product" of the project and presents it to the target client.
4.1. Synchronize Actors and Robot Actors	Elementary School, Information Technology A.2.1. After the second year of studying Information Technology in the domain of information and digital technology, the student explains the role of software in computer usage. Elementary School, Information Technology B.2.1. After the second year of studying Information	High School, Computer Science Technician - Introduction to Computer Science module: The student creates a test plan and test cases for the implemented solution, The student tests the implemented solution according to the test plan, The student fixes bugs in the implemented solution.

	Technology in the domain of computational thinking and programming, the student analyzes a sequence of instructions that perform a simple task, correcting the order if necessary. Elementary School, Information Technology B.4.2. After the fourth year of studying Information Technology in the domain of computational thinking and programming, the student solves more complex logical tasks with or without a computer. Elementary School, Information Technology C.4.1. After the fourth year of studying Information Technology in the domain of digital literacy and communication, the student selects an appropriate program for a given task, recommends it to others, and explores the possibilities of similar programs. Elementary School, Information Technology C.4.2. After the fourth year of studying Information Technology in the domain of digital literacy and communication, the student designs a plan for creating a digital work, produces it, and evaluates the work. Elementary School, Information Technology B.5.2. After the fifth year of studying Information Technology in the domain of computational thinking and programming, the student creates an algorithm to solve a simple task, verifies its correctness, and identifies and corrects errors.	High School, Computer Science Technician - Application Programming module: The student writes applications in a selected tool for developing window applications.
4.2. Synchronize Actors and Robot Actors		High School, Computer Science Technician - Introduction to Computer Science module: The student monitors and leads group project work according to the selected agile methodology.
4.3. Synchronize Actors and Robot Actors	Elementary School, Information Technology A.3.2. After the third year of studying Information Technology in the domain of information and digital technology, the student explains and analyzes simple hardware/software issues and difficulties that may occur during their use.	High School, Computer Science Technician - Introduction to Computer Science module: The student chooses solutions to complex problems that involve changing, refining, improving, and integrating new content and information into existing knowledge.

		High School, Computer Science Technician - Application Programming module: Deals with events (triggered by the mouse, keyboard, or clock). High School, Mechatronics Technician - Robotics module: The student knows how to determine the coordinate system of the robot, The student knows how to use logical functions, The student knows how to use timing functions, The student knows how to use the input and output units of the robot controller.
5. Performance		
5.1. Perform the Play		High School, Mechatronics Technician - Robotics module: The student knows how to use the input and output units of the robot controller.
5.2. Evaluate Quality	Elementary School, Croatian Language B.1.1. The student expresses their observations, thoughts, and feelings after listening to/reading a literary text and connects them with their own experience. Elementary School, Information Technology C.4.2. After the fourth year of studying Information Technology in the domain of digital literacy and communication, the student designs a plan for creating a digital work, produces it, and evaluates the work.	

Table 15. Learning outcomes in schools in Croatia and Slovenia and their connection with the steps of creating a theater play with robots.

7. Educational robots

The market offers a wide variety of educational robots for different age groups, with various appearances, shapes, and levels of complexity. Table 16 provides some of these, with links to assembly and programming, which are not necessarily the official links of the manufacturers themselves.

Robot	Robot assembly	Robot programming
Lego Mindstorms	- https://makecode.mindstorms.com/tutorials - https://www.lego.com/cdn/cs/set/assets/bltbef4d6ce0f40363c/LMSUser_Guide_LEGO_MINDSTORMS_EV3_11_Tablet_ENUS.pdf - Discover LEGO MINDSTORMS EV3 (video)	- https://www.lego.com/en-gb/themes/mindstorms/learntoprogram - https://ev3lessons.com/en/ - LEGO MINDSTORMS Robot Inventor Guide: How to Program Your Sensors (video) - https://makecode.mindstorms.com/examples - https://ev3-help-online.api.education.lego.com/Education/en-gb/page.html?Path=editor%2FCreatingPrograms.html - https://education.lego.com/en-us/lessons/ev3-tutorials/
Lego Spike Prime	- https://spike.legoeducation.com/prime/models/ - https://education.lego.com/en-us/teacher-resources/lego-education-spike-prime/ - https://education.lego.com/en-us/product-resources/spike-prime/downloads/building-instructions/	- https://spike.legoeducation.com/prime/unit-plans/ - https://spike.legoeducation.com/prime/help/lls-help-python - SPIKE Prime Tutorials (video playlist) - https://education.lego.com/en-au/lessons/prime-competition-ready/my-code-our-program/ - https://www.cmu.edu/roboticsacademy/roboticscurriculum/Lego%20Curriculum/lego_spike_prime_resources.html
Lego Spike Essentials	- https://spike.legoeducation.com/essential/models/ - https://education.lego.com/en-us/teacher-resources/lego-education-spike-essential/start-here/lego-education-spike-essential-start-here-play-student/ - https://education.lego.com/en-us/product-resources/45345-spike-essential-resource-page/downloads/building-instructions/	- https://spike.legoeducation.com/essential/unit-plans/ - https://education.lego.com/en-us/lessons/?products=SPIKE%E2%84%A2+Essential - https://www.robotsgottalents.com/spike-essential-zone - https://spike.legoeducation.com/essential/help/lls-help-python
Fischer-technik	- https://www.fischertechnik.de/en/service/information-and-updates/downloads - FischerTechnik Lessons (video tutorials - assembling and programming)	- https://www.fischertechnik.de/-/media/fischertechnik/fite/service/elearning/spielen/earlycoding/begleitmaterial-early_coding.pdf - https://cfw.ftcommunity.de/ftcommunity-TXT/de/programming/brickly/ - https://cfw.ftcommunity.de/ftcommunity-TXT/en/programming/python/
Cubelets	- https://modrobotics.com/cubelets-getting-started-guide/	- https://modrobotics.com/cubelets-blockly-tutorials/

	- https://learn71.ca/wp-content/uploads/2018/08/Cubelets-Overall-Overview.pdf - https://modrobotics.com/cubelets-robot-ideas/	- https://modrobotics.com/cubeletschat/introduce-programming-with-block-based-coding/ - Create and Saving Programs with Cubelets Blockly (video)
mBot	- https://support.makeblock.com/hc/en-us/articles/12822859943959-A-Beginner-s-Guide-to-mBot - How to Assemble mBot Step by Step (video)	- https://makeblockeducation.sharepoint.com/:b:/s/makeblockeducationassets/ERHScuMdS31BktUMQ1wTu7wBiSlcswQyohRqSbHZj3PCug?e=rzYv35 - Setting up your MBot and transferring simple programmes (video) - https://learning.kidzcancode.com/course/introduction-to-robotics-using-makeblock-mbot/ - https://forum.makeblock.com/t/sample-code-for-mbots/3348/2 - https://ccr.fresnounified.org/wp-content/uploads/mBlock-Using-the-Sensors-Programs.pdf
Thymio	- Introduction au robot Thymio (video)	- Thymio Basic Tutorial (video) - https://www.thymio.org/teaching_resource/ - https://assets.kogan.com/files/usermanuals/thymio-vpl-tutorial-en.pdf
Codey-Rocky	- https://support.makeblock.com/hc/en-us/articles/12990942477847-A-Beginner-s-Guide-to-Codey-Rocky	- http://cdnlab.makeblock.com/Codey-Rocky-Coding-Guide_EN.pdf - https://learning.kidzcancode.com/course/introduction-to-robotics-using-makeblock-codey-rockey/ - https://support.makeblock.com/hc/en-us/sections/360001829193-Codey-Rocky
STEMI	- https://old.stemi.education/lesson/694939 - UNBOXING & LETS PLAY! - HEXAPOD Robot - The Six Legged Robotic STEM Kit by STEMI (video) - Stemi Hexapod (Assembly & first steps) - video - https://www.e-skole.hr/upute-za-koristenje-opreme/stemi-hexapod/	- https://old.stemi.education/lesson/639436 - https://old.stemi.education/lesson/919243 - https://github.com/stemi-education/stemi-hexapod
DJI Robomaster	- How to Assemble RoboMaster S1 Video - https://dl.djicdn.com/downloads/robomaster-s1/20200324/RoboMaster_S1_User_Manual_v1.8_EN.pdf - https://dl.djicdn.com/downloads/robomaster-s1/20191030/RoboMaster_S1_Quick_Start_Guide_v1.4_EN.pdf	- https://www.dji.com/hr/robomaster-s1/programming-guide - https://terra-1-g.djicdn.com/851d20f7b9f64838a34cd02351370894/RM%20EP%20CORE/Scratch%20Programming%20Guide_RoboMaster%20EP%20Core.pdf
EMoRo	- https://hrobos.hr/wp-content/uploads/2012/06/E-MORO_Upute.pdf	- https://www.emoro.eu/
REV	- https://www.revrobotics.com/content/docs/ClassBot-Guide.pdf	- https://docs.revrobotics.com/duo-control/programming/hello-robot-introduction-to-programming - Moving Forward and Backward - Blocks

	- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/basic-bot-guide-rev.pdf	- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/blocks-programming-guide.pdf
Jimu	- https://www.manualslib.com/manual/1337164/Ubtech-Jimu.html - Building Your JIMU Robot | JIMU ROBOT by UBTECH Robotics	- Programming Movements | JIMU ROBOT by UBTECH Robotics - Blockly Coding | JIMU ROBOT by UBTECH Robotics
Sphero Bolt **Sphero Mini**	- https://support.sphero.com/en-US/articles/bolt-72242 - Tutorial: Sphero Bolt Setup (video) - Sphero Mini (video playlist) - Sphero BOLT (video playlist)	- https://edu.sphero.com/cwists/preview/52597x - https://edu.sphero.com/programs/ - https://www.hackster.io/sphero/projects
Alpha 1 Pro	- https://assets-new.ubtrobot.com/Alpha%201%E7%B3%BB%E5%88%97APP%E8%BD%AF%E4%BB%B6%E4%BD%BF%E7%94%A8%E8%AF%B4%E6%98%8E%E4%B9%A6%EF%BC%88%E8%8B%B1%E6%96%87%EF%BC%89.pdf?download - Alpha1 Pro Unboxing	- https://assets-new.ubtrobot.com/downloads/Alpha%201S%20Operation%20user%20manual%20for%20PC.pdf?download
Aelos 1 **Aelos 1 Pro**	- https://www.lejurobot.com/wp-content/themes/LejuWP/download/Aelos%201Edu.pdf	- https://www.lejurobot.com/wp-content/themes/LejuWP/download/Aelos%201S%20Robot%20User%20Manual%20.pdf - https://www.lejurobot.com/wp-content/themes/LejuWP/download/Aelos%201Pro.pdf
MeccaNoid	- https://spinmastersupport.helpshift.com/hc/en/7-meccano/faq/362-instructions/?s=sonic-plane - Meccano | How To Build (video tutorials playlist)	- https://www.youtube.com/playlist?list=PLd9flvrHyYheqkODcSuZB-mPRkMyrIPzu - http://intl.meccano.com/meccanoid-programming - https://www.techagekids.com/2016/10/meccanoid-behavior-builder-robot-coding.html - https://spinmaster.helpshift.com/hc/en/6-meccanoid/section/12-programming/?p=web
Gladius Mini S	- https://www.chasing.com/en/service-support/gladius-mini-s.html	- Mobile App setup manual
Tello	- https://dl-cdn.ryzerobotics.com/downloads/Tello/Tello%20User%20Manual%20v1.4.pdf	- https://tello.oneoffcoder.com/index.html - https://scratch3-tello.app/
Airblock MakeBlock	- http://cdnlab.makeblock.com/Airblock-V1.0_STD_EN_User%20Manual_D1.4.6_7.40.4602_Print.pdf	- http://download.makeblock.com/Airblock%20Coding%20Examples%20with%20Makeblock%20APP.docx - http://download.makeblock.com/AirblockAPP-EN.pdf - Airblock video tutorials
Parrot Mambo	- https://www.parrot.com/en/support/documentation/mambo-range	- https://www.tynker.com/courses/stunt-pilot-drone - Sample Block Code to Fly Parrot Mambo - Program Parrot Mini Drone with Tynker App 2017 - Connect, Take Off, Land
CoDrone	- https://learn.robolink.com/lesson/0-1-introduction-to-codrone-edu-2/	- How to use Blockly for CoDrone Pro/Lite - https://www.eduporium.com/blog/eduporium-experiment-codrone-edu/

	- https://www.manualslib.com/manual/2985669/Robolink-Codrone-Mini.html	- https://learn.robolink.com/product/codrone-edu/
Smart Lumies	- https://smartlumies.com/pages/faq-setup	- https://smartlumies.com/pages/faq-coding
Botley® 2.0 the Coding Robot Activity Set 8	- https://www.manualslib.com/manual/1533331/Learning-Resources-Botley.html#product-botley	- https://www.learningresources.com/amfile/file/download/file/2249/product/5891/ - https://markhampubliclibrary.ca/wp-content/uploads/sites/74/2023/03/Botley-Instructions.pdf
Matatalab	- Matatalab Coding set videos - https://matatalab.com/en/product-support	- https://matatalab.com/en/wiki/product-wiki/coding-set - https://www.lekolar.no/globalassets/inriver/resources/141727.pdf - https://matatalab.com/en/self-guided-course
Cubetto	- https://www.primotoys.com/cubetto-user-manual/	- Programming (video tutorials)
Code & Go Robot Mouse Activity Set	- Code & Go™ Robot Mouse Activity Set	- https://www.learningresources.com/amfile/file/download/file/889/product/340/
Blue-bot	- https://asset.pitsco.com/sharedimages/resources/bluebot-userguide.pdf	- https://www.terrapinlogo.com/downloads/file/Getting%20Started%20with%20Blue-Bot%20App.pdf - https://youtu.be/T6SyP7Imygs?si=vF3LvMSboBhvNFxY - https://www.digitaltechnologieshub.edu.au/teach-and-assess/classroom-resources/lesson-ideas/blue-bot-challenges/
mTiny	- https://education.makeblock.com/help/mtiny-start/ - https://educatec.ch/media/pdf/21/41/d7/mTiny-Edu_Global_V2-3.pdf - mTiny Discover Kit for Education (video tutorials)	- https://support.makeblock.com/hc/en-us/articles/1500009717862-Use-Coding-Cards-to-Play-with-mTiny - mTiny Discover Kit - Coding
Coding & Robotics KOSMOS	- Introduction to Coding & Robotics - robot Sammy (video) - https://www.thamesandkosmos.com/manuals/full/567012_Kids-First-Coding&Robotics-Manual.pdf	- https://www.thamesandkosmos.com/manuals/full/567012_Kids-First-Coding&Robotics-Manual.pdf
Coko	- Coko - how to	- Coko - how to
Code&Go Mouse Mania Bord Game	- Code&Go Mouse Mania Bord Game - how to play and program it	- Code&Go Mouse Mania Bord Game - how to play and program it
ESP32	- https://randomnerdtutorials.com/getting-started-with-esp32/ - How to Setup and Program ESP32 Microcontroller using Arduino IDE	- A beginner's guide to ESP32 | Hardware & coding basics + Wi-Fi server demo - ESP32 Projects - The 10 Best ESP32 Robotics Projects
Arduino	- Getting started with Arduino	- Built-in program examples - Arduino Robotics Projects
VIDI X	- https://vidi-x.org/ - What is VIDI X	- VIDI X programming manual - VIDI Lab

Raspberry Pi	- https://www.raspberrypi.com/ - https://opensource.com/resources/raspberry-pi - Raspberry Pi Explained in 100 Seconds	- https://projects.raspberrypi.org/en/projects/raspberry-pi-getting-started - Getting Started with Your Raspberry Pi (video) - Raspberry Pi Robotics Projects (1) - Raspberry Pi Robotics Projects (2)
Micro:bit V1 **Micro:bit V2**	- https://microbit.org/get-started/user-guide/introduction/ - Introduction to the BBC micro:bit (video)	- https://microbit.org/code/ - https://makecode.microbit.org/projects/toys - https://microbit.org/projects/make-it-code-it/ - https://makecode.microbit.org/projects/

Table 16. Educational robots and links to examples of their assembly and programming.

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