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Case Report

Using Robots with Storytelling and Drama Activities in Science Education

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Abstract: Storytelling and drama are well-known teaching tools that can be used throughout the curriculum for the active participation of students in their own learning process. The introduction of robots in storytelling and drama activities provides students with a meaningful, multisensory, hands-on learning experience. This paper explores the potential and challenges of using storytelling and drama activities with robot actors in science teaching. We present the lessons learned from two experiences of storytelling and drama activities with robots in science education. Observations revealed that this approach facilitates the development of science concepts, creates a rich context to foster skills in students, creates a positive classroom environment, and improves the students' attention and motivation. Finally, it was identified that there is a need to design low-cost expressive actor robots that are easily customizable. Additionally, the need to develop multi-robot programming interfaces that facilitate the creation of scripts for robots and their programming is also shown.

Keywords: educational robotics; robotic storytelling; robotic drama; science education

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1. Introduction

Storytelling and drama are powerful teaching tools to promote cognitive, social, and emotional development in students. Both provide students with great opportunities to explore, discuss, and express their thoughts, ideas, and emotions. These strategies facilitate collective knowledge building and help students bring abstract concepts into concrete experiences. In addition, they are valuable tools to foster critical thinking, problem-solving skills, decision-making, negotiation, collaboration, and literacy skills [1–3]. Activities of drama and storytelling can be used in many school subject areas, including science. For example, in the geography class, students can explore the cultural and social features of the population in different regions or countries. In history class, historical characters or events can be easily explored through developing and acting out the story. Regarding personal and social education, these strategies also offer powerful opportunities to share your opinions and emotions and explain your points of view. Science education can also be enriched with storytelling and drama activities. Using narratives and movement, students can represent physical phenomena such as planetary movement, electrical circuits, the action of molecules, etc. They can also show representations of theories, scientific results, and discuss moral and ethical dilemmas. These strategies are also an effective form of therapeutic intervention. They can provide a safe environment in which children can express themselves freely [4].

Activities of storytelling and drama have taken a new dimension with the incorporation of educational robots. Using robots to represent the story in a storytelling and drama activity provides students with a multi-sensory experience and an enjoyable learning environment. In the case of science education, the use of robots may increase interest and motivation towards learning scientific concepts. In addition, the tangibility, movements, and appearance of robots can help students understand complex and abstract concepts. This paper explores the integration of storytelling and drama with robots into science teaching as a strategy for enhancing the learning of scientific concepts and fostering skills such as inquiry. This approach combines the potential of educational robotics with the benefits of educational drama and storytelling. Two experiences of storytelling and dramatizations are presented and analyzed. We discuss the educational methodology, features of robot actors, programming environment, and implications for future work. The results show the need to design expressive low-cost robots that are easily customizable. Additionally, the need to develop multi-robot programming interfaces that facilitate the creation of scripts for robots and their programming is demonstrated. This paper is structured as follows. We begin with an introduction to educational robotics. Then, the approach of integrating robots into storytelling and drama activities and the background are detailed. Subsequently, we report on two experiences of storytelling and drama with robots. Finally, the discussion and conclusions are presented.

2. Educational Robotics

The use of robots in education has shown great potential to enhance students learning experiences [5–7]. Robots can be used as smart, tangible, and mobile learning objects that facilitate the understanding of complex and abstract concepts and phenomena [8,9]. The activities with educational robots also foster the development of technical and soft skills [10]. In addition, robot-based activities attract and motivate students and enhance their learning process [11–13].

There are three main theories that support the use of robots as learning objects that enhance the teaching and learning processes: constructivism, constructionism, and socio-cultural constructivism. Piaget's constructivist theory argued that knowledge emerges as a result of the individual's interactions with the environment [14]. Papert's theory of constructionism is a natural extension of constructivism and emphasizes hands-on activity [15]. Vygotsky's theory of sociocultural constructivism argued that learning takes place first on the social plane [16]. Robot-based activities generate constructivist and constructionist learning environments that allow students to learn through direct manipulation and interaction with robotic artifacts. Robot actions can provide students with immediate feedback on their work and enable them to detect misconceptions [17,18]. In addition, learning activities with robots can provide environments that promote collaborative team working, cooperation, and communication.

Usually, educational robots are used as a tool, in which students carry out tasks of designing, building, and/or programming of robots. There are several robotic construction kits available on the market that allow students to quickly and easily build and program robots, such as the Lego Mindstorms, VEX Robotics, and Makeblocks kits. Additionally, there are preassembled programable robots such as Dash & Dot, Darwin-Mini, Thymio, NAO robots that are ready to be programmed. In recent years, 3D printers have become a powerful tool to build robot prototypes. The introduction of social robots in education has created new learning opportunities. Now, students can also learn by interacting with social robots that can assume the role of a tutor, partner, or learner in a learning activity [19–21]. Tutor robots are used to create learning experiences in which the robot should guide and monitor the student's learning process. In a learning activity with a peer robot, students and robots collaborate to accomplish a learning task. When a robot assumes the role of a learner, the student becomes the teacher of this robot. In the literature review, we will present some examples of these roles of robots in storytelling and drama activities.

Educational robotics has proven to be a valuable tool in science education [22,23]. Robot-based activities can improve students' attitudes towards science education and can be an effective tool to promote STEM or STEAM education [24–28]. Educational robotics also helps to promote science equality. Studies show that educational robots contribute to reducing the gender gap in science, reduce the belief in gender stereotypes, and increase positive attitudes about science learning [24]. Activities with educational robots can contribute to the development of scientific inquiry skills such as observation, hypothesis formulation, testing of these hypotheses by conducting experiments, analyzing data, and drawing conclusions [23].

Analogies are powerful tools for learning through robots. Students can learn through analogies between bioinspired robotic models and biological systems or natural phenomena [29–31]. Students can use robotics to create tangible models of biological systems and understand the subject more deeply. For example, students can build and program a robot snake prototype and analyze in detail its appearance, structure, movement, and functionality [31]. In this process, students must have a deep understanding of biological systems to create their robotic model. They also have the opportunity to explore the similarities and differences between their robotic model and the biological system. The limitations of robotic tools also create rich opportunities to promote creativity, problem-solving, and analog reasoning skills.

3. Storytelling and Drama Activities Using Robots

The benefits of storytelling and drama could increase with the inclusion of robots in the presentation of the story, particularly in science education. The storytelling and drama activities with robots provide students with a multi-sensory experience and become active, engaging, tangible, and remarkable learning activities [32–34]. In the context of a story, students can create simulations or demonstrations of events, facts, and phenomena using robots. For example, in science education, students can create a story about a science topic and use multiple robots to act out this story. Drama and storytelling with robots broaden the scope of typical robotics activities in science education. Now the robot-based activities are not only focused on the student building a bio-inspired robotic model but also the student being able to explore the behavior of a complete system or model using multiple robotic actors in the context of a story. The use of multiple robotic actors increases the potential of robotics in science education because there are several scientific concepts that are difficult to explain with a single robot, such as food chain, ecosystems, planetary movement, among others.

There are several ways to introduce robots into a storytelling or drama activity depending on the role that the robot assumes in the learning process. For example, a first option may be to design learning activities in which students program robots to be storytellers or actors for the representation of stories. Students can build their own robots using a commercial robotics kit or from scratch. They can also use preassembled robots ready to be programmed. The representation of the story could involve only robotic actors or the collaboration of human and robotic actors. A second option is to present students with an already created story. Here, the students assume the role of the audience and do not intervene in the process of creating the story. In these activities, the audience can play a passive or active role in the story performance. For example, in the active role, they could change the storyline or interact with the robot actors. A third option is to design learning activities in which students have to interact with social robots that assume the role of tutor, peer, or learner in the context of a storytelling or drama activity. In this paper, we focus on the first option where students have an active role in the creation process.

We believe activities of storytelling and drama with robots are a powerful tool in science education. Through these activities, students can make representations or simulations of phenomena using robots. The tangibility and behaviors of the robots help students to develop mental representations of abstract and complex concepts and make meaningful connections. Moreover, this approach fosters the development of key skills such as communication, collaboration, inquiry, and problem-solving. An advantage of the drama and storytelling activities with robots is that they help the student to have a deep understanding of the content presented through a story. If they understand the story, they can program each action of the robot actors. In traditional storytelling and drama activities, students generally focus on their character and are unaware of what is happening to the other characters in the story. However, in a robot activity, students must have an understanding of the actions that all robot actors must do. Another benefit of including robots in the presentation of stories is that it could increase interest and motivation towards learning scientific concepts. The use of robots also creates a context to easily integrate engineering design into the learning activity. Finally, it is important to note that the achievement of learning outcomes is not guaranteed solely by the introduction of robots in learning activities [11,13]. It is essential to develop a student-centered learning methodology that favors the achievement of learning outcomes through robotic storytelling and theatrical activities.

4. Background

The literature review shows that there are several works exploring the integration of programmable robots in drama and storytelling activities. For example, Bravo et al. [32] presented a drama activity with robot actors to introduce the topic of conflict resolution to elementary children. In this activity, students created the story from scratch and turned it into a script. Students record the dialogues of the story and program the robot actors through an intuitive script-authoring environment. They also customized the robots with the features of the characters and decorated the stage. Szecsei [35] described a project that uses robot theater to promote STEM education to underrepresented students. In this project, students write scripts and program NAO and Cozmo robots to perform theatrical plays that explore human values. Their performances often involve human actors and use the speech recognition capability to synchronize actions between robots and human actors. Stork [36] used robots and digital storytelling to foster communication, collaboration, critical thinking, and creativity skills. In the proposed activity, students used Sphero Bot robots to design and build an interactive story. The result of this study shows that robotic storytelling provides an authentic context for applying design thinking and developing 21st-century skills. The paper of Ko and collaborators [25] presented how to promote STEAM education through robot-theater programs. In this program, high school and college students learned robot programming to control the behaviors of robot actors. While elementary school students used a remote control to control their robot actors. Barnes et al. [37,38] implemented an afterschool program called Child-Robot Theater to promote STEM education for socio-economically underprivileged students. This program uses robots such as Pleo Reborn, Robosapien, Nao, Darwin, Romo, Zoomer, and BB-8 robots to make a living theater. The learned lessons include choosing a familiar story rather than creating one from scratch and implementing a modularized robot-theater program with short-term goals in order to maintain the motivation of young children. Angel-Fernandez et al. [33] presented a robotic storytelling activity to introduce basic programming and foster creativity in children. The first part of the activity focused on exposing children to the Thymio robot and introducing basic concepts of robotics and programming. The second part of the activity focused on storytelling. Students create their own story and implement the story with the robots.

We also find works in which students play the role of the audience. Ruffin et al. [39] implemented a storytelling activity with the NAO robot to improve the story and literacy-based retention rates of elementary students. The authors used the voice variability, motions, and LED lights of the robot to increase the retention of story elements. Therefore, and collaborators [40] explored a robot-based play-drama intervention to enhance narrative skills and gestural communication in preschoolers with an autism spectrum disorder. In the first part of the intervention, students watched the performance of NAO robots. In the second part, children interacted with the socially assistive robots during roleplays in order to improve their narrative skills. Other works invite the audience to have an active role in the live performance. For example, the work of Lytridis [41] explored the use of a robot actor that starts a conversation with children who are selected from the audience. The purpose of the theatrical play is to engage children in identifying and describing emotions.

Regarding the interaction with social robots, some works explore the use of learner robots in a storytelling and drama activity. Verhoeven et al. [42] developed a robotic storytelling activity for learning a second language. In the activity, the robot forgot some words and asked the children to help them remember them. Children must remind the robot of the word to keep him happy. Other papers explore the use of tutor robots. For example, Soute and Nijmeijer [43] developed a robotic storytelling application to promote literacy skills in young children. In this application, the child must correctly organize some cards with images of different events in a story. Then, they have to show the cards to an owl robot who will narrate the fragment of the story corresponding to that card. However, the robot will only read the card if it is in the correct order. If the child makes a mistake in the order of a card, the robot helps him to pick the correct card. The work presented by Kory-Westlund and Breazeal [44] includes a robotic storytelling activity in which a robot tells a story to children. In certain parts of the story, the robot asks children a dialogic reading comprehension question about the events of the story. After the robot finishes telling the story, it asks the children to retell the story. There are other authors who use robots that assume the role of companions of children. For example, Kory and Breazeal [45] developed a social robot that interacts with children as partners in a storytelling game. During this game, children learn new vocabulary and improve storytelling skills. Leite and colleagues [34] developed a storytelling-based activity to help children expand their emotional vocabulary and strengthen their emotional intelligence skills. In this activity, a pair of social robot actors perform a story and at specific points in the story, the children are asked to choose which decision the character should make. This allows students to analyze how this decision could change the course of history. Wu et al. [46] explored collaborative storytelling activities with human and robotic actors. The authors compared an activity in which the NAO humanoid robot tells and represents a story with an activity in which the NAO robot tells the story and the human acts it out. The results show that the audience prefers the plays in which there is a collaboration between humans and robots.

This literature review shows that most of the papers focus on improving literacy skills in students. Few articles explore this type of activity in science education, so there are great research opportunities in this field. Some of the research needs identified are: (1) to explore the benefits and challenges of storytelling and drama activities with robots in science learning; (2) to establish an educational methodology for the implementation of this approach; (3) to identify the characteristics robot actors should have for science education (4) to define the functionalities that the programming environment should have to facilitate the creation of representations of stories with robots.

5. Methods

We carried out two experiences with school students where they co-created a dramatization with robots of a story related to science learning. In the first experience, students were invited to explore water pollution and its social and environmental implications. In the second experience, students learned about Thomas Alva Edison and the incandescent light bulb. The purpose of these experiences was to identify an educational methodology to implement storytelling and drama activities using robots and the challenges of implementing this approach in science education. These experiences are detailed below:

5.1. Experience 1—Social-Environmental Conflicts

Given that the literature review did not find an educational methodology to implement storytelling and drama activities with robots, the objective of this experience was to develop the first version of this educational methodology. For this reason, a small sample of students was chosen for the development of this activity. Below we present details of this experiment.

5.1.1. Type, Duration, and Location of the Study

This experiment was carried out in a school setting after school hours (field study). We created a robotics club with the help of a technology teacher and sixth graders were invited to join this club (within-subject design experiment). The motivation for the students was that the generated product would be presented on the school science day as their science project. The pilot activity lasted six weeks with weekly sessions of two hours (short study).

5.1.2. Participants

This experience was developed with a group of 8 students from 11 to 13 years old (50% girls and 50% boys) and a technology teacher. The participants had no programming experience or robotics knowledge.

5.1.3. Story

The learning objective was to learn about water contamination and its social and environmental implications. Therefore, students co-created a dramatization with robots of a socio–environmental conflict related to water contamination. To guide the storytelling process, the students were told what the goals of each scene were. They were also informed about the characters on the stage and the place where the events occurred (see Table 1). From this information, students created their own stories with the teacher's guidance.

Table 1. Student's guide for creating a story about socio–environmental conflicts.

Scene	Objective	Characters	Scenario
Scene 1	Margaret discovers that the water in her house is contaminated because her Pepa cow gets sick when she consumes water from the river.	Margaret and Pepa cow	Margaret's farm
Scene 2	Margaret and her neighbor Charlie decide to go report the contamination of the river to the mayor of the town Mr. Smith.	Margaret and Charlie	Charlie's house
Scene 3	Margaret and her neighbor Charlie tell Mr. Smith about the problem of contamination in the water caused by the textile factory of the town.	Margaret, Charlie, and Mr. Smith.	Mayor's office
Scene 4	Margaret and Charlie organize a protest to shut down the factory. However, after talking with the owner of the company, Olivia, they realize that this factory is the livelihood of many families. Olivia realizes that she must do something to avoid polluting the river.	Margaret, Charlie, and Olivia	Textile factory
Scene 5	A meeting is organized where an agreement is reached that respects the interests of both parties.	Margaret, Mr. Smith, and Olivia	Mayor's office

5.1.4. Robots and Materials

The students used mobile line follower robots. They used craft materials to give the robots the appearance of the character to be played (see Figure 1). Since the robots used are line following, the students created a mat with black lines drawn so that the robots could move to different locations on the stage. Additionally, a mobile application was developed to teleoperate the movements of robots on stage. Through this mobile application, the students can send the robot commands to move forward, turn right or turn left. As the robots did not have the ability to reproduce audio, the students had to say the dialogues of the story during the teleoperation.

5.1.5. Design and Procedure

The experience began with an inquiry process in which students investigated water pollution and its social and environmental implications. The students were then given a case of socio–environmental conflict and the purpose of the scenes of the robotic play. From this, the students created the story for each scene. Once the story is created, the students proceed to create a script where they must specify what actions the characters perform, where the action will take place, and some indications that enrich the interpretation of the action (e.g., emotions and verbal and non-verbal expressions). We used paper cards with characters' actions to facilitate the script creation process (see Figure 2). Subsequently, the students built the scenery for the play. In addition, the robot actors were personalized with the physical features of the characters they portray. Next, the students teleoperated the robots according to this created script and rehearsed the entire play several times. Finally, the created robotic play by the students was presented on science day.

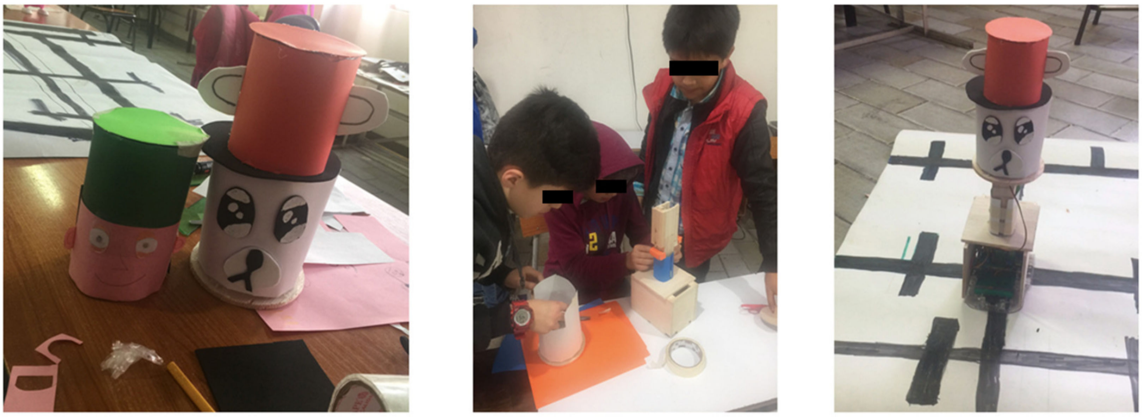

Figure 1. Robot actors used in the first experiment.

Figure 2. Script creation using a cards of characters actions.

5.1.6. Findings

The applied educational methodology consisted of six steps: inquiry activity, storytelling process, script creation, customization of robot actors and scenery, rehearsals using robots, and final performance or the robotic play. This methodology allowed students to co-create the dramatization of the story using robots in a satisfying way.

Dividing the story into scenes from the beginning makes it easier for students to create the script for the robot actors. Giving students the objective, characters, and where actions occur in each scene greatly facilitates the process of creating the story and helps guide students to the desired learning objective. However, the storytelling process took a long time for the students and they needed constant accompaniment from the teacher.

Many of the students had no prior knowledge of the structure of a script. In the first experience, some paper cards were created so that the students could easily identify which actions the characters were doing, for example, talking, looking towards a character, moving towards a place on the stage. However, the students saw all the actions sequentially and it was difficult for them to express the actions that other characters were doing in parallel. This shows the need to explore strategies that facilitate the development of scripts for students and where they can explicitly define all the actions that robot actors must perform.

This experience showed us the importance of having software that facilitates the control of the robot actors. This software should allow controlling of robot actors' actions such as movements on the stage and verbal and non-verbal expressions. The difficulty of synchronizing the actions of the robots through the individual teleoperation of each robot actor was also evidenced. Therefore, the software should also allow the synchronization of robot actor actions. The students stated that the robots were not expressive and could not adequately interpret all the actions that they imagined of the character. This shows that the use of expressive robots is essential for students to be able to correctly represent a story using robots. For example, robots must be able to express emotions and must be able to play audio files. Finally, it was observed that the students really enjoyed the process of creating the representation of the story with robots. The process of customizing the robots and creating the scenery was fun for the students.

5.2. Experience 2—Thomas Alva Edison and the Incandescent Light Bulb

With the lessons learned from the first experience, we developed a second experience in another school during class hours and with a different teacher. For this activity, we already had better planning of each session, expressive and easily customizable robots, and an interface for better teleoperation of the robots. Next, we present the details of this second experience.

5.2.1. Type, Duration, and Location of the Study

The second experiment was carried out in a school setting during school hours (field study). The students were part of two classes taught by the teacher who participated in the experiment (within-subject design experiment). The activity was carried out during the class schedule of the technology education subject. The pilot activity lasted two months with weekly sessions of two hours (short study).

5.2.2. Participants

The experiment was developed with two sixth-grade classes and a total of 53 students. One class had 26 students, of which 18 are boys and 8 girls. The other class had 27 students of which 15 were boys and 12 girls. The ages of the students were between 11 and 13 years old. The lessons were carried out equally in both classes. The technology teacher participated in the experiment. Students and the teacher had no programming experience or robotics knowledge. We also had the help of two final-year students of the technology education program who supported the teacher in the development of the sessions and in conducting field observations. These teacher assistants worked together with the technology teacher in the planning of each of the sessions following the methodology that was obtained from the first experience. It is important to clarify that these assistants had not had previous experience with the approach of storytelling and robotic drama or in educational robotic activities. They were trained in the use of robots and software.

5.2.3. Story

Students had to create a dramatization with robots of a story about American inventor Thomas Alva Edison and the incandescent light bulb. In order to facilitate the students' work, the story was divided into three scenes, and each scene was divided into three parts. The first scene shows the need: candles do not light much, have a short duration, and can cause fires. The second scene shows the observation: Edison realized that a filament glows when an electric current flow through it. Finally, scene 3 shows the solution: Edison invented the incandescent light bulb. Table 2 shows an example of the story of scene 1 given to students.

Table 2. Story of Scene 1 of Thomas Alva Edison and the incandescent light bulb.

Scene 1	Story	Characters	Scenario
Part 1	Edison was sitting in the living room reading a book, but it began to get dark, and he could no longer read well. In the kitchen was his wife Mary, she tells her son William to go to the garage and bring Edison the candle that is next to the tools.		
Part 2	Mary lights the candle and goes into the living room and tells Edison to use this candle to read. Edison thanks Mary and she is happy. Mary goes to the kitchen to make dinner with her son and Edison stays reading. But soon after the candle goes out and Edison could not continue reading.	Edison, Mary, and William	Edison's house. Places: kitchen, living room, and garage
Part 3	Edison goes to the workshop to find another candle but there were no more candles in the house. Edison gets sad and goes to the kitchen. When he gets to the kitchen, he tells Marty and William that he would like to invent something that can last longer than a candle, that can light more and that does not start a fire.		

5.2.4. Robots and Materials

Each team of students used three mobile line follower robots to represent a scene of the story (see Figure 3). In total, we had nine robots for the whole class. To improve the expressiveness of these actor robots, a screen with RGB LEDs was included. Through this screen different emotional faces (e.g., happy, sad, angry, calm, and neutral faces) were projected. Previously, a process of design and validation of emotional faces was carried out with another group of children. In addition, a Bluetooth speaker was also added to the robot actors for playing the audio files.

Figure 3. Actor robots used in the second experiment. These robots had a screen to enhance the emotional expressiveness of the robots. They also had a speaker for audio playback.

We developed a better web application to teleoperate the robots (see Figure 4). However, students still must synchronize the actions of the characters. We had three computers to control each robot actor. The interface had different buttons to control the movements of the robot on the stage (e.g., move forward, turn right and turn left) and to choose the emotional face of the robot. It also had buttons organized by scenes with the different audios that the robot was going to reproduce.

Figure 4. Interface for robot control. (**Left**): web application to teleoperate the robots. (**Right**): students using the interface to teleoperate the robot actor.

5.2.5. Design and Procedure

The technology teacher together and one of the teacher assistants were responsible for directing the activities with the students. The other teacher assistant was responsible for conducting field observations. As there were two classes, the teacher assistants changed roles. That is, in one of the classes the teacher assistant accompanied the technology teacher and in the other class, he carried out the fieldwork observations.

Each class was divided into three teams of students and each team divided into three groups. Each team was assigned a scene and each group a part of that scene. In this way, the whole class co-created a theater play with robots in a collaborative way. Additionally, each group was given three robot actors to represent the scene. Once the groups were formed, the students carried out an inquiry process about Thomas Alva Edison and the incandescent light bulb. Subsequently, each group converted their story fragment into a script following the format shown in Figure 5. This format was designed so that students could easily input the actions that the characters did simultaneously. The students recorded with their voices the dialogues that the robot actors had to say. Additionally, they customized the robot actors and the stage using craft materials. Then, each team rehearsed the entire scene and made improvements to the script. They used the designed interface to teleoperate the robot's actions. The activity finished with the presentation of the play with robots by the whole class and with a reflection activity.

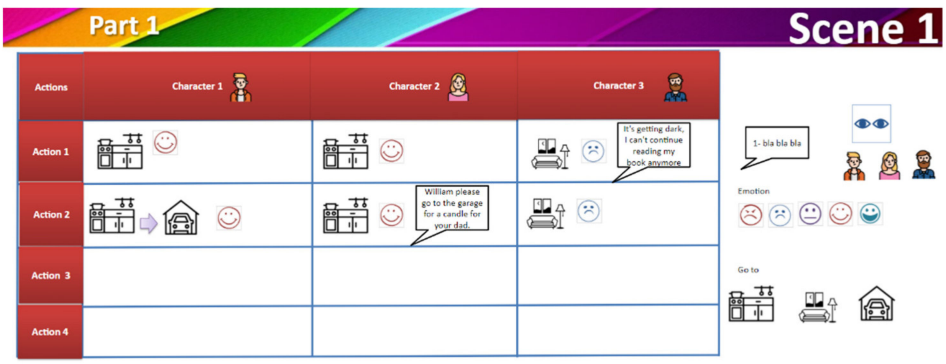

Figure 5. Format to create the script.

During each of the sessions, one of the teacher assistants evaluated the session and took notes of important facts. The teacher assistant had to fill out a form in each session where he evaluated the achievement of the objectives of the session, motivation, collaborative work, communication, and skills for the development of the proposed activities of each student group. In addition, at the end of the experience, questions were asked to the technology teacher and the teacher assistants about the overall experience.

As can be seen, our evaluation focused on the technology, teacher and teacher assistants. In an upcoming experiment, we will focus on rigorously validating this experience from the student's perspective.

5.2.6. Findings

The educational methodology used allowed the students to perform the representation of the story using robots. Dividing the story from the beginning into three scenes and in turn dividing each scene into three parts allowed the whole class to collaboratively create the story representation using robots. Unlike the first experience, this time the students were given more details about the events of the scene. This allowed reduction in the time for the development of the storytelling process and more time to inquire about Thomas Alva Edison and the incandescent light bulb. Although the students did not create the story, they could enrich it at the robot script creation stage.

In this second experience, the students were asked to record the dialogues that the characters said. Then, during the teleoperation, the students activated the corresponding audio. This activity attracted a lot of the students' attention because they had to make a coherent voice with the character and their inner state. However, noise from the classroom made the recording process difficult for some students.

The use of more expressive robots improved the representation of the story. In addition, the students were able to gain a better understanding of the story because they had to put themselves in the place of the character to understand how they felt and correctly program the emotion in the robot actor. It was observed in both experiences that the students really enjoyed dressing up the characters and constructing the scenery.

It was evidenced that it is required to have more robots for the whole class. Each team had three robots to act out the scene, but some conflicts arose within the teams as various groups of the team needed to use the robots to rehearse and improve their scene fragment. To solve this, maximum times were defined for the tests with the robots.

Although in this experience there was software that allowed the robot actors to teleoperate better, errors were frequent in the synchronization of the actions of the robots by the students. It was also difficult for them to be able to control all the actions of the robots (e.g., movements, emotions, and audio files) simultaneously. To facilitate the development of these activities, software is required that allows the creation of characters and assigns them to a robotic platform, the programming, and synchronization of the actions of each character, and the control of the execution of the play (e.g., starting, pausing or stopping the play's execution). Due to most science education teachers having no training in programming or robotics, this software should be intuitive. The need to know how to program robots can become a barrier to the adoption of this strategy.

In the first experience, we observed difficulties in defining parallel actions between the characters. Therefore, in the second experience, a format was designed with a table where the students had to put what actions all the characters perform at a certain point in time. This tool helped the students a lot in the construction of the script and they were motivated to give all the characters some action. This approach can be used as inspiration for the design of robot actor control software.

In the first experience, the students created their own robot mat using markers and cardboard. However, this mat was easily wrinkled and dirty. In the second experience, the students were given a resistant and washable mat that already had images of the places of the stage printed on it. It was decided to make a mat with black lines in the shape of a grid that simulated the streets and avenues of a city. However, so that this mat is more generic and can be used in other plays, it is recommended to leave the places marked and that the students put an image or 3D model of the stage place on top.

Finally, the results of the evaluation of the global experience by the technology teacher and two teacher assistants are summarized in Table 3 (where 1 is the lowest score and 5 is the highest value). The main difficulty identified is that a lot of work time was required during the classes for the achievement of all the planned activities. In general, teachers have time limitations for the development of the content of the subject. It is important to clarify that students were not left with work outside of class in order to observe the students' work.

Table 3. Results of the evaluation of the global experience by the teachers.

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>The activities for each session were following the learning objectives.</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Using robots promotes the acquisition of new concepts in your class.</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>The experience of interacting with robots promotes an appropriate learning environment.</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Children's interest in the use of robots is maintained throughout the work sessions.</td><td></td><td></td><td></td><td colspan="2">X</td></tr>
<tr><td>The proposed activities promote creative thinking and additionally, the solutions developed by the students are relatively simple to implement.</td><td></td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>Role of the teacher proposed in the educational experience to generate conditions for analogical thinking and the fluency of students during the development of activities.</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Implementation times of the activities were appropriate according to what was initially planned.</td><td></td><td></td><td colspan="2">X</td><td></td></tr>
<tr><td>School technology activities presented were appropriate for the development of the content under the constructivist principles of learning.</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>Accompanying activities were assertive for the development of the activities and practices of the tenured teacher.</td><td></td><td></td><td></td><td></td><td>X</td></tr>
</table>

6. Discussion and Conclusions

We have divided this section into three categories: educational methodology, robot actors and software for programming robots.

6.1. Educational Methodology

Figure 6 shows our educational methodology to implement storytelling and drama activities with robots. Not all the stages must necessarily be carried out. For example, in the second experience presented, the storytelling process was omitted because the students were given a general description of the events of the scene. However, students enriched this story during the script creation stage. According to the time available for the development of the activity and learning objectives, stages such as the storytelling process and the personalization of actors and robotic scenarios can be reduced or omitted. Another possibility is to develop some stages in parallel. For example, while some students program the robots, others can personalize the robot actors and decorate the stage.

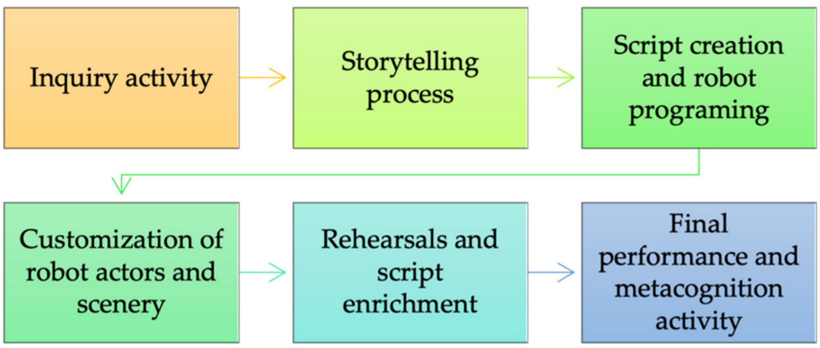

Figure 6. Educational methodology to implement storytelling and drama activities with robots.

Observations in these experiences revealed that storytelling and drama activities facilitate the teacher's development of scientific concepts with their students. In addition, the use of robots created a positive classroom environment, improving students' attention and motivation. In future work, we consider it important to carry out a rigorous validation of the achievement of the learning objectives and validate this approach from the point of view of the students.

Our proposed methodology is focused on activities where robot actors are programmed to represent stories. However, it is also interesting to explore the methodology for activities involving programmable actor robots and humans or activities with social robots that can take the role of tutor, peer, and learner.

Finally, a frequent topic of discussion is why to use robots and not just simulators or digital storytelling software. Studies have shown that the manipulation of tangible and concrete objects such as robots favors the development of thought [15,47–49]. The behaviors of robots allow students to develop mental representations of abstract ideas and facilitate the connection between theory and real-life situations. Now, the introduction of social robots capable of making interventions according to the learning needs of students in storytelling and drama activities opens up great learning opportunities that a digital tool may not be able to provide [50]. Future research may focus on making a rigorous study on the benefits of using storytelling and drama activities with robots compared to other approaches such as digital storytelling.

6.2. Robot Actors

These experiences showed that it is essential to have actor robots that are expressive and can be easily customizable with the features of the character they are portraying. Non-verbal and verbal expressions are crucial to conveying to the audience how the characters feel and what their intentions are. However, most robot building kits do not allow you to build expressive robots. In recent years, trend has been seen for expressive preassembled robots but many of them are not easily programmable.

Unlike a typical educational robotics activity, drama and storytelling activities require more robots because stories often have multiple characters. However, most of the commercial kits are mono-robot. Thus, schools would need to purchase various kits to implement this approach in the classroom. This can be a limitation because many schools do not have a large budget to purchase these tools. It requires the development of low-cost robotic kits that facilitate the creation of expressive actor robots for storytelling and drama activities with robots. In our experiences, the number of characters per scene was limited to a maximum of three characters. However, there was a need for each group of students to have their own robots to rehearse their parts of the stories or establish rules for using this shared resource.

We also found that the outer structure of the robots should allow students to easily customize the robots. In our experiments, we created a case where students could easily glue their craft supplies. However, we consider that new alternatives should be explored that allow easy customization of the actor robots.

Finally, the problem of locating the robots on the stage is easily solved with line follower robots. However, if other types of robots are used, it is necessary to explore low-cost solutions that facilitate the navigation of the robots on the stage.

6.3. Robot Programming Environment

In our review, we did not identify commercial software that facilitates the creation of dramatizations with robot actors. The teleoperation of robot actors is an alternative for the development of narration and dramatization activities with robots; however, it is more susceptible to errors in the activation of robot actions and synchronization problems between robotic actors. The use of an interface that allows the easy creation and execution of representations of stories with robots would greatly facilitate the development of a storytelling and drama activity with robots.

Based on the literature review, experiences with storytelling and drama activities with robots, and teachers' perceptions, the following functionalities of a programming environment interface were identified:

- Program the actor robots: the interface should allow the programming of the robot actors according to the script of the play. Actions, motions on the stage, verbal and nonverbal expressions, emotions of robot actors are defined through the interface. In addition, it should allow users to edit and add new robot actions easily. Our experiences show the importance of the interface including the possibility of recording or uploading the audio files of the script dialogs. Given the context of storytelling and drama, it is recommended that the programming is done through a script format or storytelling format since this contains all the indications for an actor.
- Support the programming of the behaviors of several robot actors simultaneously: most of the commercial robot programming software allows the programming of one robot only. Storytelling and drama activities require a programming environment that supports multiple robots. It is important that the interface allows synchronization of the actions between robot actors easily. In addition, the interface should allow programming of simultaneous actions. For example, two robots moving at the same time to a point on the stage. It should also motivate users to always attribute some action to the robot actors and not leave them still on stage as if they were lifeless.
- Provide an intuitive programming strategy: several of the target teachers and students are non-programming. Therefore, it is essential to provide them with an intuitive programming strategy that allows programming of robot actors without the need for advanced programming knowledge. Given the context of storytelling and drama, it is recommended that programming be done with high-level commands (e.g., make a happy face, go to the park, raise arms) rather than the motor and sensor-level instructions (e.g., move motor right forward, rotate servomotor 90 degrees).
- Control of the story performance: through the interface, the user should have the possibility to control the execution of the script. For example, the user should be able to start, pause or stop the play performance.
- Create interactive stories: the interactivity of the students during the performance of the play can enhance their learning experience and promote student engagement. Therefore, it would be interesting if the interface had the functionality to create scripts with multiple storylines. Based on the feedback obtained from the audience, the storyline can be changed. This would allow students to explore the consequences of taking one action or another. For example, they can explore what happens if they dump garbage in a river or decide not to dump it.
- Support human actors: another interesting feature of an interface for storytelling and drama is supporting representations of stories with robots and human actors. One of the main challenges is how to synchronize the actions between robots and students using the typical educational robots.

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