Interactive Drama With Robots for Teaching Non-Technical Subjects

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Educational robotics has great potential as a learning tool at all levels, from kindergarten to the university. It provides rich opportunities for collaborative knowledge building and skills acquisition through the manipulation of and interaction with robots. Despite the remarkable progress in this field, the scope and impact of robot-based activities have primarily focused on the teaching of technical school subjects (i.e., computer science, mathematics, and physics). This work proposes to support the learning and teaching of non-technical school subjects through drama-based activities with multiple robots. This approach provides a multisensory learning environment where students can learn through representations or simulations of ideas, events, stories, phenomena, or processes using multiple robot actors. Based on the drama process used by teachers, we propose steps to create and perform plays with robot actors in an educational context and discuss different alternatives for its implementation. Finally, we discuss the challenges of creating plays with multiple robots for educational purposes.

Keywords: human-robot interaction, educational robotics, educational drama, drama with robots, robot theater

1. Introduction

Educational robotics is a term widely used to describe the use of robotics as a mediating tool in the learning and teaching process (Eguchi, 2013). It provides a multisensory environment that supports collective knowledge building through manipulation and interaction with educational robots. Additionally, activities with robots are an effective tool for fostering 21st century skills, such as creativity, problem-solving, communication, and collaboration (Eguchi, 2013; Mubin, Stevens, Shahid, Al Mahmud, & Dong, 2013). Despite the fact that robotics has shown great potential in the educational context, its impact and scope are mainly limited to areas related to robotics or technical subjects such as computer science, engineering, and mathematics (Benitti, 2012; Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). There are few studies that explore the use of robot-based activities to support the learning and teaching of other areas of knowledge, for example, biology, social sciences, peace education, education for sustainable development, and humanities. In this work, the term non-technical subject is used to refer to areas of knowledge that are not related to robotics. The main motivation for implementing educational robotics to support the learning and teaching of non-technical school subjects is to offer teachers a mediating tool that allows them to engage and motivate their students in the learning process through tangible and observable representations of the concepts and phenomena they are teaching (Kee, 2011).

In this paper, we propose educational drama as a strategy to integrate educational robots into non-technical school subjects. Educational drama is a well-established learning strategy that can support achievement across the entire curriculum. Within this environment, students develop a variety of skills, including communication, problem-solving, creative thinking, teamwork, and personal, social, and emotional development (Baldwin, 2009). Integration of educational drama and educational robotics provides a multisensory environment where students can learn through representations or simulations of real or imaginary events, stories, phenomena, or processes using multi-robot systems. The main difference between educational drama and theater lies in the fact that theater is focused on
producing an artistic product for an audience. In the case of educational drama, the product is not necessarily the outcome. Drama activities are mainly focused on the collaborative process of creating and performing theatrical plays (Motos, 1993; Van de Water, McAvoy, & Hunt, 2015). Consequentially, we use the word drama instead of theater in order to clarify that drama activities are more interested in the process rather than the final product.

The purpose of this paper is to analyze the potential of drama-based activities with multiple robot actors to support the learning and teaching of non-technical school subjects. We present the process to create and perform a drama with robots for educational purposes. This process was adapted from a typical drama process in education. We also discuss the different options to implement a play with robots and its challenges. In the context of this work, the term play is related to dramaturgy.

The paper is structured as follows: Section 2 shows a brief introduction of robots in education and discusses the use of robotics activities in non-technical school subjects. Section 3 details the use of drama as an educational tool. After that, the proposal of drama with robots is described in section 4. Next, section 5 describes related works in drama and theater with robot actors. In section 6, we describe the process to create and perform plays with robots in an educational context. Section 7 presents the challenges of implementing a drama with robot actors. Finally, section 8 shows conclusions and further steps.

2. Robots in Education

The aim of educational robotics is to support collective knowledge building, foster the acquisition of skills, and enhance the students’ learning experience by manipulating and interacting with robots (Alimisis, 2013; Benitti, 2012; Eguchi, 2013; Lennex & Nettleton, 2014; Mubin et al., 2013). Robots offer a concrete and tangible way to understand complex and abstract concepts and phenomena (Spector, Merrill, Elen, & Bishop, 2008). Within this environment, students are able to understand the connection between theory and practice. Robot-based activities provide instant feedback that leads students to inquire for themselves and figure out how to solve the problems they are facing with the robots. Other special features that educational robotics provides are the ability to attract and maintain the attention and interest of students in the learning experience (Eguchi, 2013).

The main theories that support the use of robots as a mediating tool are social constructivism and constructionism (Mubin et al., 2013). Jean Piaget was one of the pioneers of constructivist theory. He argued that knowledge cannot be built through the description of another person’s experience and emphasized that knowledge construction emerges as a result of the individual’s interactions with the environment (Ackermann, 2001; Keengwe, 2015; Piaget, 1973). Other constructivists also emphasized the social nature of learning (Martin, 2012). Lev Vygotsky proposed the notion of sociocultural constructivism. According to him, learners construct knowledge through social interaction with others (i.e., peers, parents, robots). Vygotsky is also known for the concepts of the zone of proximal development (ZPD) and scaffolding (Keengwe, 2015; Vygotsky, 1978). ZPD describes the differences between what learners could achieve without any help and what they perform with guidance. Scaffolding refers to the assistance that adults and more competent peers provide during the learning process. In the case of educational robotics, a robot tutor or a peer robot could provide this assistance. Seymour Papert developed constructionism theory based upon Piaget’s work (Papert, 1991). For both constructivism and constructionism theories, knowledge can be built by manipulating artifacts such as robots. Papert adds that conceptual changes occur through a progressive internalization of actions, particularly through constructing shareable artifacts (Ackermann, 2001). A robot-based activity can provide constructivism and constructionism environments through the construction, programming, and interaction with robots. Analogous to these theories, there is a variety of student-centered pedagogies that support the usage of robots in education, such as active learning, collaborative learning, problem-based learning, inquiry-based learning, and learning by design (Mubin et al., 2013).

The use of robotics in education has shown great potential to assist in the learning and teaching process. However, review of the literature shows that most educational robotics activities were not integrated into classroom activities. They take place in after-school programs, such as robotics clubs, summer camp programs, and workshops (Alimisis, 2013; Benitti, 2012; Mubin et al., 2013). A disadvantage of using educational robotics in non-formal education is that it affects a small portion of the student population (Bravo & Forero, 2012). Therefore, it is necessary to propose new strategies that facilitate the integration of robot-based activities into the school curriculum. For example, this paper suggests the usage of drama-based activities with robot actors.
There are examples in the literature showing that teachers have been able to integrate robotics into formal education. According to Benitti (2012), 80% of studies on robots in education address fields linked to mathematics or physics. Several papers report experiences with teaching mathematics and physics topics, such as follows: coordinate system, angles, fractions and ratios, recognition of quantities, graph construction and interpretation, Newton’s laws of motion, work, energy, force, and friction, using robots (Benitti, 2012; Karim, Lemaignan, & Mondada, 2016). Other studies focus on the development of programming skills through robot-based activities (Benitti, 2012; Mason & Cooper, 2013; Pittí Patiño, Curto Diego, Moreno Rodilla, Rodríguez Conde, & Rodríguez-Aragón, 2014). According to the above, the impact and scope of educational robotics in formal education are mainly limited to technical areas. There is a lack of studies expanding the use of robotics in other areas of knowledge, such as the social sciences and humanities (i.e., philosophy, literature, religion, art, music, history, and language) (Benitti, 2012).

There are also studies that combine robot-based activities with music, visual arts, and performing arts, but they are focused on supporting STEM (Science, Technology, Engineering, and Math) education (Chung, Cartwright, & Chung, 2014; Chung, 2014; M. Jeon et al., 2016). Most studies that explore the use of educational robots for the teaching and learning of non-technical subjects focus mainly on foreign language learning (Kennedy, Baxter, Senft, & Belpaeme, 2016; Mubin et al., 2013). The literature also includes a few efforts to design robot-based activities that support the learning and teaching of history (Hamner & Cross, 2013), music (Han, Kim, & Kim, 2009), human anatomy (Hamner & Cross, 2013), biology (Cuperman & Verner, 2013), poetry (Hamner & Cross, 2013), road traffic safety education (Da Silva & De Magalhães Netto, 2011), and emotional intelligence (Leite et al., 2015).

This work proposes the use of drama-based activities with multiple robot actors as a strategy to integrate educational robotics in the learning and teaching of non-technical subjects. Drama allows an easy connection with various areas of knowledge, such as mathematics, biology, social sciences, and humanities. The high level of description of a theatrical script could facilitate the development of strategies to create plays with robots intuitively. In this work, the term intuitive indicates that students and teachers can create a play with robot actors without having programming skills or knowledge of the syntax of a programming language. In the following section, we will present a short introduction of educational drama. Then, we will discuss our proposal for educational drama with robots.

3. Educational Drama

Educational drama, also known as creative drama or drama education, is a teaching and learning medium for cognitive, social, and emotional development. Activities with drama are an active, interactive, and collaborative experience that stimulates motivation, creativity, curiosity, exploration, and experimentation. Within this multi-sensory learning environment, students can generate creative ideas, solve problems together, communicate their thoughts, ideas and feelings, gain new knowledge, and develop and apply their skills (Baldwin & Fleming, 2003; Baldwin, 2009; García, 2008; Gutiérrez, 2004; Motos, 1993; Navarro, 2006; Núñez & Navarro, 2009; Van de Water et al., 2015).

Drama-based learning provides opportunities to learn subjects across the whole curriculum (Baldwin, 2009; García, 2008). Students can learn a wide variety of topics through movement, imitation, and social interaction. Drama helps understanding of abstract concepts by representing them in a concrete form. Within the drama experience, students can learn about phenomena and process through simulation; for example, students can learn about the behaviors and characteristics of different animals. Drama activities, such as role-playing, create genuine contexts to explore and learn about famous people (i.e., Galileo, Newton, and Darwin), professional activities, important historical events, and cultural and social aspects. Besides, students can learn about human experiences, such as pain, disease, death, and the meaning of life. Students can also discover mathematics and economics through dramatic play. For example, through marketplace simulation, students can develop a basic understanding of how the interaction of buyers and sellers determines market prices (Motos, 1993; Núñez & Navarro, 2009). Drama activities are also an effective form of therapeutic intervention and a way to promote mental health and personal growth.

There are several strategies for implementing drama in education, such as role-playing, forum theater, storytelling, story drama, and puppetry (Roy, Baker, & Hamilton, 2015). Role-playing is a type of simulation where students perform a particular role in an imaginary situation (Motos, 1993). Forum theater is an interactive
experience that involves the audience directly, allowing them to suggest changes in the storyline during the live performance. Through forum theater, students can explore different endings and their possible consequences. This strategy provides rich opportunities to learn about peace education and emotional learning (Baldwin & Fleming, 2003; Paracha, Jehanzeb, & Yoshie, 2009; Roy et al., 2015). Stories are a great way to share experiences and build knowledge. Storytelling through drama allows us to tell a story adopting the role of a storyteller. Story drama involves students in making up their own stories and dramatizing them. Finally, puppetry is a form of drama where an inanimate object or a puppet is an actor of the play. Through the manipulation of a puppet, students can easily express their ideas and feelings (Monkey Baa, 2012).

The vast range of opportunities and possibilities offered by educational drama and its interdisciplinary nature make drama an excellent strategy to involve educational robotics in the whole school curriculum, especially in non-technical areas. The following sections discuss the potential of drama with robots, related work, the process of creating and performing a play with robot actors, and the challenges of implementing this approach in an educational context.

4. Drama With Robots

Our proposal is to support the learning and teaching of non-technical school subjects through interactive plays with robots. This approach combines the potential of educational drama, educational robotics, and human-robot interaction strategies in order to create a powerful learning tool (Fig. 1). Educational drama supports collaborative knowledge building, fosters the development of 21st century skills, and enhances the students’ learning experience. Educational robots offer a concrete and tangible way to understand abstract concepts and ideas with instant feedback. Additionally, human-robot interaction provides strategies to improve the learning experience. There are two types of plays with robots that can help to support the learning and teaching of non-technical school subjects, as follows:

- **Plays that dramatize a story**: The purpose of this type of play is to recreate events and situations in order to help students to develop an understanding of a situation or problem, and explore different alternatives and their possible consequences. For example, students can create plays with robot actors that dramatize a cautionary story about environmental conservation. Students can also explore and react to situations of conflict, injustice, and oppression through plays with robot actors in a safe environment. A significant benefit of this type of play is that it gives students the opportunity to express their ideas, thoughts, and emotions through action, dialogue, and nonverbal expressions through the robot actors.

- **Plays that simulate a phenomenon or process**: The aim of these plays is to create enriched simulations of phenomena and processes. This type of theatrical play takes advantage of motion, behaviors, and appearance of robots to learn through analogies or metaphors. Robots offer a concrete and tangible way to visualize phenomena and processes that cannot be observed or experienced directly. The purpose of this type of play is to help students’ understanding of phenomena or processes that are abstract or unfamiliar by comparing them with behaviors (functional analogy) and appearance (structural analogy) of robot actors. For example, students can make analogies between the social behavior of ants and cooperative behavior of multiple robots to find and transport objects. Additionally, a robot actor can interact with students to improve their learning process. For instance, a robot actor, which portrays an electron, can tell students what its functions are in the atomic model.
Drama with robots provides students and teachers rich opportunities to interact with robots. During drama activities, a robot can assume the roles of tool, peer, and tutor (Mubin et al., 2013). When a robot is a tool, students build a drama production using robots as actors of the play. In the role of peer, robot actors act together with a human actor. Finally, a robot can assume the role of tutor and it could encourage the student to perform a play. In the following section, we will present a literature review about drama with robots and robot theater.

5. Related work

Some authors have explored the idea of theatrical plays with robot actors for educational purposes. For example, Laamanen et al. (2015) used this strategy to allow a natural integration of technical and non-technical school subjects. The authors designed and implemented a modular platform for drama with robots. They concluded it is important to develop a dedicated set of hardware for drama activities with robots. With existing robotic platforms for building robots (i.e., Lego Mindstorm, Vex Robotics) it is difficult to create verbal and nonverbal behaviors to convey emotions and intentions. They also claimed that traditional programming does not support the interdisciplinary motivation behind drama with robot actors. Therefore, it is important to design non-conventional programming strategies to create a play with multiple robots. Another challenge in drama with robots is to implement low-cost strategies for detecting the robots' position on stage. Alford et al., (2013) proposed an animatronics workshop for students between 14 and 17 years old. The students participated in a collaborative project where they had to write a script, build a character, record voices, edit sounds, and program the robot's movements. In the workshop, the students built a mechanism for creating the characters’ nonverbal expressions (i.e., gestures, body movement). They used hand puppets to give a pleasing appearance to the robot actor according to the character’s characteristics. Nonverbal expressions and robot appearances help students create each character’s personality. In this proposal, the robot actors did not have the ability to perform the dialogues themselves and could not move on stage, limiting their expression ability. Finally, Jeon et al., (2016) developed an afterschool program called “Making Live Theatre with Multiple Robots as Actors” to promote STEAM (Science, Technology, Engineering, Art, and Math) education.

Most researchers in performance using robots are mainly focused on the entertainment field (theater with robots). Moreover, many researchers in social robotics using robot theater as a controlled environment for HRI.
research and a testing ground for social robots (Fernandez & Bonarini, 2014; Hoffman, 2011). Although there are few studies on performance using robot actors for education, studies in robot theater are an important starting point. Table 1 shows the main research topics in robot theater and related work.

Table 1. Related works in robot theater

<table>
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<th>Research topic</th>
<th>Related work</th>
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<tr>
<td>Autonomous robot actors</td>
<td>A software architecture to build a robotic actor called TheatreBot has been proposed by Fernandez and Bonarini (2014). This architecture allows a user to program a robot actor by giving it high-level information similar to a theatrical script. The robot actor interprets the script and enriches it by itself. Through emotional and social models, the robot can decide its emotional state and its intensity. Besides, the robot actor modulates and enriches its movements according to the emotional state. Anzalone (2010) proposed an architecture based on drama theory to improve the robots' performance in cooperative tasks with people. Each robot is a character with its own personality, personal background, and psychological characterization. Consequently, each robot actor can interact with people in a different way. An interesting point of the proposed architecture is that both the character and social relationships can change over time.</td>
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<td>Creation of believable characters</td>
<td>Hoffman et al. (2008) affirm that two key aspects of performance with robot actors are gaze-following interactions and animacy. Eye contact with human actors makes it seem as if the robot is listening to the human actors. Animacy ensures that the robot looks alive. A robot actor is never completely still, even when the actor is not on stage. Simmons et al. (2011) propose the use of dramatic structure to create believable robot characters that engage and attract people to interact with, and exhibit social behaviors toward, the robots. Authors present several approaches to creating believable robot characters such as having a rich backstory and dynamic storyline, using verbal and nonverbal social behaviors, and incorporating sociocultural context into the robot’s behaviors. Katevas et al. (2015) manipulated the robot’s patterns of gesture and gaze and examined their effects on the responses of an audience. They found that the audience responds more positively when the robot actor looks at them and negatively when it looks away.</td>
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<td>Expression of emotions and intentions in non-anthropomorphic robots</td>
<td>Angel and Bonarini (2014) explore how to convey emotions through the movement of non-bio-inspired robotic platforms. Hoffman et al. (2008) explore how the robot AUR (a robotic desk lamp) can express emotions and intentions through its arm movements and light color and intensity. This robot could not move on stage. Buhaiiciuc (2013) explores how non-anthropomorphic robots can express emotions and intentions through sounds and color patterns, such as love (red), calm (blue), and no emotion (white). Breazeal et al. (2003) explore how an anemone robot can express intentions and emotions through body motions, such as interest and fear. This robot could not move on stage.</td>
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<td>Expression of emotions and intentions in anthropomorphic robots</td>
<td>Zeglin et al. (2015) describe the play “Sure Thing” that involves a human actor and the robot HERB, a bimanual mobile manipulator. In this proposal, the authors investigated how the robot’s body movement and prosodic speech convey the robot’s intention.</td>
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### Creation of plays that involve human actors and robot actors on the same stage

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<td>Hoffman et al. (2008)</td>
<td>Present a robotic puppeteering system used in a play with one robot and two human actors on stage. This system allows an operator to control the robot AUR through software with pre-animated gestures and sequences but at the same time allows the robot to be both expressive and responsive. Hoffman affirms that people are sensitive to notions of action coordination, timing, and fluency of verbal and nonverbal behavior. Consequently, challenges in plays with robots that involve human actors are real-time responsiveness, human-robot coordination, and managing a shared common space and resources.</td>
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<tr>
<td>Murphy et al. (2011)</td>
<td>Present the play “A Midsummer Night’s Dream” by William Shakespeare that involves seven flying robot and human actors on the same stage. Authors show that the audience learned how to interpret the robot behaviors based on the actors’ reactions. This article highlights that the proximity of the robot actors implies a risk to the audience and human actors.</td>
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<tr>
<td>Buhaiciuc (2013)</td>
<td>Presents the robot opera “Tod Machover’s Death and the Powers.” It is a live performance where the drama of human characters is told in retrospect by a chorus of mobile robots designed to sing, move, and react.</td>
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<td>Lemaignan et al. (2012)</td>
<td>Detail a play with a human actor and the robot PR2. This robot interacts with the environment and human actor through 2D barcodes. A challenge in plays with robots that involve human actors is to share and co-exist in a common space.</td>
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### Interaction of robot actors with the audience

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<td>Breazeal et al. (2003)</td>
<td>Implemented an interactive theater, where an anemone robot interacts with the audience. The anemone robot follows the movements of the people. It can also get scared when someone comes too close.</td>
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<td>Knight et al. (2011)</td>
<td>Developed a stand-up comedy, where a NAO robot recites jokes to an audience. NAO could change the content and emphasis of its performance in function of the audience feedback. Through laughter, applause, and green/red cards, the robot could detect if the audience liked or disliked the joke topic. Then, the robot chooses the next joke from a database of jokes based on audience preference. The robot performs basic nonverbal movements to add some expressiveness to the joke.</td>
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### Improvisation

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<td>Rodriguez et al. (2015)</td>
<td>Present a project where a NAO robot is a Bertsolari, an artist in Basque society who is capable of improvising a song with rhyme and meter discourse (bertso). The robot can interact with a human presenter and with the objects on stage, such as a microphone and seats. In the live performance, the presenter gives NAO rhyming words, and the robot must compose the bertso using a database.</td>
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### Promoting the acceptance of social robots

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<td>Jochum et al. (2016)</td>
<td>Propose the use of theater as a strategy for studying interaction with care robots. The authors suggest that theatrical plays with robots can positively influence the audience toward accepting socially assisted robots during periods of hospitalization and rehabilitation.</td>
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### 6. The process of creating and performing plays with robot actors

The drama process in education usually has the following stages (Brown, 2014; Monkey Baa, 2012): (1) topic choosing; (2) generation of ideas about characters, places, objects in the play, etc.; (3) creation a storyboard; (4) character building and decisions designing; (5) script writing; (6) rehearsal process; (6) final performance; and (7) reflection. This process could be adapted for drama-based activities using robots (see Fig. 2). Creating a performance with robots may be divided in two moments: (1) making drama and (2) performing drama. These moments are analyzed below.
6.1 Making drama

The purpose of this first moment is to create a script and bring this script to performance using robot actors. Fig. 2 shows four stages for creating a performance with robots. Descriptions of each stage are detailed below.

6.1.1 Performance planning

This stage consists of the following steps: (1) choose a topic (2) select a drama strategy (i.e., role-playing, storytelling, story drama, Forum Theater, monologue, or pantomime) and generate ideas on how to create the play; (3) create a storyboard and specify when and where the play takes place, how many scenes will the play have, what will happen in each scene, and which characters will be present; (4) analyze physical, social, psychological, and moral qualities of the characters (i.e., super-objective, objective, motivation, obstacles, psychological traits, emotional state, personality, mood, appearance, poses characteristics, motion characteristics, way to express, social relations, backstory, ethical behavior, and moral belief); (5) make decisions about visual qualities (i.e. costumes and props) and physical and aural atmosphere (i.e., music, lighting, sound effects, and decoration) that will be used in the play. During this stage, students should know what kinds of robots are available, because the theatrical play might depend on the capabilities and features of the robot actors.

6.1.2 Character, prop, and set builder

The purpose of this stage is to customize the robot actors with the features of their characters and build the set and props. It is essential to have some robot actors available. Students and teachers can design and build their own robot
actors through robotic construction kits, such as LEGO Mindstorms (Laamanen et al., 2015), or from scratch (Alford et al., 2013). However, it implies that a user needs to have prior knowledge in robot construction. A disadvantage with existing robotic platforms for building robots (i.e., Lego Mindstorm, Vex Robotics) is the difficulty of creating verbal and nonverbal behaviors to convey emotions and intentions (Laamanen et al., 2015). Another option is the use of assembled robots. Prior work in drama with robots reports the use of NAO, Pleo, Zoomer, Romo, Robosapien, ROBOTIS-OP2, and Aisoy1 (escolaprojectebcn, 2015; M. Jeon et al., 2016).

In our research, we implemented drama-based activities with the Quemes robots, which are line-follower, wheeled mobile robots developed by the SIDRe research group at the Pontificia Universidad Javeriana (González, Páez, & Roldán, 2013). Students create the characters through hand puppets with the features they choose (see Fig. 3). These puppets are installed on the top of the Quemes Robots. The disadvantage of this first robot actor prototype is that it has low expressiveness. In consequence, SIDRe and SIRP research groups at the Pontificia Universidad Javeriana have been researching how to design a low-cost robot actor that can easily change its appearance and can express emotions and intentions through verbal and nonverbal cues. Fig. 4 shows a new prototype of a robot actor that was developed by students of Electronic Engineering and Computer Science as part of their undergraduate project (Avila, Bermeo, & Merchan, 2016).

![Figure 3. Building a robot actor with a mobile robot and hand puppets](image)

![Figure 4. Prototype of robot actor development by the students of SIRP research group](image)

The robot actors can be customized with the features of their characters through craft materials, stickers, Lego pieces, 3D printed pieces or hand puppets (see Fig. 5 (a) and (b)) (Alford et al., 2013). There are robots with a screen that allow users to change their appearance. For example, RoboMe by WowWee uses the screen of a mobile device to display a face and graphical user interface. The user can interact with the robot through a mobile app and customize the robot’s face features (see Fig. 5 (c)).
In this stage, students and teachers may also build the set and props. Mixed-reality technologies can bring an interesting option to build them. For example, a multi-touch table allows students to draw the elements in their story collaboratively. It could also be an interface to interact with robot actors (Mi, Krzywinski, Sugimoto, & Chen, 2010). It is also important to consider the size and shape of the scenery in relation with the robot actors being used.

6.1.3 Script creation

Once the performance planning stage is completed, the script is constructed. The script is a roadmap that outlines a play with robots using the following four parameters (Jochum, Schultz, Johnson, & Murphey, 2014):

- **Character description.** This parameter specifies who makes the action. It also describes the main characteristics of the character such as personality, mood, feature gestures, feature movements, way to express, social relations, and backstory (i.e., age, family).

- **Actions description.** It specifies what a character does or says in the play. For example, verbal and nonverbal expressions, interaction with stage props (i.e., pick up an object, push a button), and other body motions (i.e., dance, sit, stand, clap, look around).

- **Temporal duration.** It indicates when the action happens. This parameter defines mechanisms of coordination between actions. An action may have pre-conditions and post-conditions as a mechanism of coordination (Fernandez & Bonarini, 2014). For example, the actor robot executes an action when detects patterns on the stage (pre-conditions), and the actor robot will finish the action when it detects a particular place on the stage (post-conditions). There are cases where the current action should continue until the next action meets all its pre-conditions. When the next action meets its pre-conditions, it sends an order to end the current action. In this work, we called this situation ‘expropriation of actions.’

- **Blocking.** This parameter indicates where the action takes place. Blocking specifies the positioning and movement of the characters on the stage. A fundamental aspect of a play with robots is the requirement of knowing the position of the robot on the stage (Laamanen et al., 2015). In the educational context, an easy option to control the position and movements of robot actors is by making the robot actors follow a black line or a grid.

Scripting can be understood as the programming of the robot actors. A script may have two abstraction levels: (1) low-level description, which specifies every small action of the robot actor (procedural programming); (2) high-level description, which defines a general robot's behavior and its interaction with other agents (behavior programming). In order to support the learning and teaching of non-technical subjects, the script should allow the user to program the robot by giving it a high-level description of actions (Laamanen et al., 2015). There are three different options of script authorship:
- **User authoring**: Students and teachers create the script. They can create it from scratch with or without assistance. They can also edit and mix scripts: predefined scripts or scripts made by others users.

- **System authoring**: The robot actor or external software creates the script according to user specifications.

- **Collaborative authoring**: Students and teachers, together with an autonomous system (robot actor or external software) create the script. In this kind of authoring, the robot could assume the role of tutor, peer, or learner (Fridin, 2014; Lu, 2012; Mubin et al., 2013).

Students and teachers can create a script that presents a single situation or a script with multiple versions of the situation (interactive script). Through an interactive script, a robot actor has the opportunity to change the path of the story according to the feedback from the audience, other actors, or the environment. The possibility to choose different paths for continuing the story opens up powerful learning opportunities. For example, students can explore different alternative endings of the story and analyze the outcomes during the live performance.

The script does not necessarily need to provide explicit details of the play (i.e., nonverbal expressions). Autonomous robot actors can modulate, enrich, and even add new actions according to characters’ traits and the storyline (Fernandez & Bonarini, 2014). A partial script may also be created at this stage. The robot actor can improvise the other part of the script in the live performance, according to the rapport from the audience (Fernandez & Bonarini, 2014; Lu & Smart, 2011b).

The options for human-robot interaction in this stage could be the following:

- **Interaction through an interface**: students and teachers can create the script through the following options: (1) text- or graphic-based programming environment on a computer or mobile device (Laamanen et al., 2015); (2) manipulating 3D models of robot actors and the stage (Buhaiciuc, 2013; Hoffman et al., 2008); (3) manipulating tangible objects (tangible programming) that represent elements on stage, including robot actors; and (4) interacting with avatars of robot actors (i.e., in a virtual world).

- **Direct interaction with the robot**: Students and teachers can also create the script through interaction with the robot. For example, the robot actor can learn a specific script from examples given by students and teachers (learning by demonstration). The input information for learning from demonstration could be visual, tactile, haptic, natural language commands, sounds, or mixed (Rouanet, Oudeye, Danieau, & Filliat, 2013).

### 6.1.4 Script interpretation

Once the script has been created, the robot actor needs to know how to perform the high-level behaviors (i.e., gesture or posture) and how to enrich them. There are three levels of autonomy to script interpretation:

- **Manual interpretation**: Students or teachers program or teach the robot actor how to perform the behaviors and actions.

- **Automatic interpretation**: Autonomous robot actors or external software can understand the script description (Fernandez & Bonarini, 2014). An autonomous robot actor can also enrich the script description. For instance, if the script describes that the robot actor should walk to a chair but offers no details of how to walk, the robot actor can choose the way of walking according to the character’s personality traits and emotional state, without additional instructions.

- **Collaborative interpretation**: Students or teachers together with autonomous robot actors interpret and enrich the script (Lu, 2012). For example, a human could teach a robot how to perform an action. Then, the robot actor could modify it or add an additional action.

A challenge is to create robot behaviors that are human readable. A robot actor requires expressing human-readable behaviors, so the audience and human actors can understand its intentions and internal states (i.e., emotions and mental or physical states), predict what the robot will do next, and interact with the robot in an effective way (Knight, 2011). The body of a robot actor is its main tool to act. The tools that the robot has for conveying meaning are the following:
Nonverbal expressions: According to the psychologist Albert Mehrabian (1972), in human-human communication, 55% of the information is delivered by non-verbal expressions. Through non-verbal communication, such as facial expressions, gestures, posture and body alignment, and proxemics, a robot actor can illustrate, reinforce, or substitute a verbal message. It could also guide the way in which the verbal message should be interpreted, help start and finish the speech of a participant, and convey feelings, emotions, intentions, and desires (Fong, Nourbakhsh, & Dautenhahn, 2003). A robot actor can change direction, speed, acceleration, size, shape, and frequency of gestures in order to convey a different meaning (Cohen, Looije, & Neerincx, 2014; Knight, 2011).

Verbal expressions: Verbal expressions are also an essential element to convey meaning. A robot actor can express emotions through emotional content of speech, such as prosody, loudness, pitch, and voice quality (level, variation, range) (Breazeal, 2003b; Crumpton & Bethel, 2016; Sunardi, 2010; Zeglin et al., 2015).

Physical appearance and embodiment: People can create expectations of a robot’s behavior based on its appearance. When there are mismatches between a real behavior and an expected behavior, people have a feeling of unease (uncanny valley) (Mori, 1970). The clothing, accessories, and materials worn by characters can express their personality or status. The costumes also reflect the period and style of the play. The embodiment determines people’s attitudes toward the robot and the ways of interacting with the robot (Sunardi, 2010).

Sound and light patterns: A robot actor can also express intentions and emotions through the color and intensity of light (Bethel & Murphy, 2008; Hoffman, 2011). For example, a robot can be angry when the light around the eyes is red, or sad with dark blue eyes (Buhaiciuc, 2013; Cohen et al., 2014; Hoffman et al., 2008). However, there is currently no consensus on which colors express each emotion, because they are culturally dependent (Park, Moshkina, & Arkina, 2010). The music and sound effects are also communication tools used to convey meaning.

Another challenge in drama or theater with robots is the creation of believable characters, so the audience and human actors believe that the robot is truly intelligent, lifelike, and has actions that make sense (Mateas, 1999; Sunardi, 2010). The following elements help create a believable, life-like character:

Emotions: The robot actor should have the capacity to express emotions and respond to others’ emotions (Breazeal, 2003a; Hoffman, 2011; Mateas, 1999). The current emotional state of the robot actor and its intensity has an influence on how actions and behaviors will be performed by the robot (Fernandez & Bonarini, 2014; Gockley, Simmons, & Forlizzi, 2006). The effect of an emotional response is of short duration, and the robot actor returns to its "baseline" emotional state until a further emotional event occurs. Factors that affect the intensity and type of emotion include the following:

- **Character’s personality traits**: Personality has an influence in the way a character displays its emotions (Bruce, Knight, Listopad, Magerko, & Nourbakhsh, 2000).

- **Intensity of the current mood**: Emotions are scaled by the intensity of the current mood (Simmons et al., 2011).

- **Emotional contagion**: Such affective empathy allows the robot actor to display behaviors appropriate to the emotional state of other characters (i.e., human or robot actors) (Leite et al., 2013).

- **Social situation**: Emotional intensity level could be reduced in order to behave in a socially correct way (Fernandez & Bonarini, 2014).

- **Attitude**: Attitude also has an effect on emotion. The like or dislike toward a person or an object may serve as a stimulus for emotion generation (Moshkina, Park, Arkin, Lee, & Jung, 2011).
Personality: Personality is the set of psychological traits that makes a character unique. The personality has an influence on the characters’ behavior, from the way they move to the way they speak (Mateas, 1999). Robot actors must give life to the personalities described in a script by performing actions. A good actor conveys a consistent, compelling, and believable personality throughout the performance of a given role. A robot actor can create a personality through the use of the verbal and nonverbal expressions (Rousseau & Hayes-Roth, 1998).

Attitude: Attitude is an amalgamation of feelings (positive or negative) toward a person, object, animal, or place. Attitudes appear and change in response to particular stimuli, such as dislike toward an unfriendly person (Moshkina et al., 2011).

Mood: Events or any environmental stimuli could change character's mood (i.e., positive, neutral, or negative). This effect decays over time, returning the robot actor to its “baseline” mood (Gockley et al., 2006; Simmons et al., 2011). Factors that affect the intensity and type of mood include the following:

- Changes in the physiological state: Illnesses, pain, lack of sleep, fatigue, and hunger have an influence on the mood.
- Emotional state: Emotional events can modulate mood.
- Social exchanges: Negative or positive exchanges change the mood. For example, a positive social exchange with a character modulates a positive mood, while a negative one tends to reduce the positive mood (Simmons et al., 2011).
- Attitude: The robot’s attitude toward persons or things has an immediate effect on its mood.
- Backstory: Life history and personal events of a character have a strong influence on its mood (Anzalone et al., 2010).
- Ability to complete goals: Character's mood can change based on how well the character thinks it is doing at achieving its goal (i.e., scene objective, super-objective) (Bruce et al., 2000).

Empathy: Empathy has been conceptualized in two ways: as cognitive empathy and as affective empathy (Leite et al., 2013). Cognitive empathy, also known as perspective-taking, is to understand others’ feelings, thoughts, and situations (standing in another’s shoes). In contrast, affective empathy, also known as emotional contagion, has been defined as the ability to experience emotions or feelings that are being experimented by others. In a drama with robots, the affective empathy may allow robot actors express emotions in accordance with the emotional state of other characters. Through cognitive empathy, a robot actor can add new prosocial behaviors in its performance (Leite et al., 2013). For example, a robot actor can use empathic utterances like, “Congratulations!” or “Well done!” while another character shares good news. A robot actor can also change the storyline based on its empathic response. Factors that affect the intensity of empathic responses include:

- Attitude and relation: These factors also have an influence on the intensity of empathic responses. Characters tend to be more empathic toward family members and friends than toward strangers (Leite et al., 2013).
- Backstory: People have stronger empathic emotions and reactions when they have a common backstory (e.g., a person who lived through a similar experience) (Tapus & Mataric, 2008).

Evolution: Characters’ traits and their social relationships change over the time as a result of interactions with others (Mateas, 1999; Simmons et al., 2011). For example, a character's empathic responses could change its relationship with a person (e.g., turning a stranger into a friend).

Backstory: Backstory is the history of a character and holds details about the character, including its age, family, living situation, past employment, and so on (Simmons et al., 2011).
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- **Natural movements**: The movements of robot actors should look and feel natural (Fernandez & Bonarini, 2013). To achieve this, researchers in computer animation and robotics have used theories of performance in the art field, such as the Disney Animation Principles (DAP) and Laban Movement Analysis (LMA) (Sunardi, 2010). Techniques in puppetry field can also give us clues to create believable characters. The power of the puppet’s expression is not determined by how well it mimics human behavior but by the ability to abstract human motions and offer an artistic projection of those behaviors (Jochum et al., 2014).

- **Autonomic behaviors**: A robot actor should not be motionless, even if the robot does not have an active role. A motionless robot can give the feeling that the robot has no life. An actor always has an internal state that is shown through body expressions (Fernandez & Bonarini, 2013; Hoffman et al., 2008). Robots can use autonomic behaviors, little movements such as breathing, blinking, or fidgeting, in order to increase their believability. Perlin’s noise-generating method has been used to simulate these autonomic behaviors (Simmons et al., 2011; Sunardi, 2010).

- **Robot gaze**: Robot gaze helps to increase the character’s believability. Eye contact and head gaze give the impression that the robot is listening and paying attention to what people say or do (Andrist, Tan, Gleicher, & Mutlu, 2014; Hoffman et al., 2008; Huang & Mutlu, 2014; Srinivasan, Murphy, & Bethel, 2015).

- **Coherence between internal state and non-verbal expressions**: The robot actor should define what gesture, body pose or physical action best describes the internal state and its context (Hoffman, 2011; Simmons et al., 2011).

- **Coherence between verbal and nonverbal expressions**: People are sensitive to notions of action coordination, timing, and fluency of verbal and nonverbal behavior (Hoffman, 2011). Consequently, it is important that a robot actor show coherence between its verbal and nonverbal expressions.

- **Real-time responsiveness**: A robot actor needs to respond in real time to the particular actions and timing parameters of human actors or audiences (Hoffman, 2011).

### 6.1.5 Rehearsal process

In the final stage, students or teachers rehearse and refine their scenes prior to performing for the class. They may examine whether the robot adequately conveys intentions and emotions, and if it synchronizes nonverbal and verbal expressions. They may also check the correct movement of robot actors on the stage and ensure that all the robot actors and technical aspects (i.e., lights, sound, props) mesh together into a unified and consistent whole. This stage can be executed parallel to the stages of script creation and script interpretation. Once this process is done, the play with robots is now ready to perform for a live audience.

### 6.2 Performing drama

The play with robots is now ready to perform for an audience. The performance with robots could be non-interactive or interactive. On one hand, a non-interactive performance is when there are no changes in the storyline. On the other hand, the performance is interactive when the storyline can be changed during the live enactment based on feedback from the audience, human actor, environment, or other robot actors. A robot actor can obtain the feedback from the audience or a human actor by way of the following strategies:

- **Basic vision pattern detection**: The robot actor is able of identifying simple markers, such as QR codes (Lemaignan et al., 2012) and color marks (Knight et al., 2011).

- **Advanced pattern detection**: the robot can identify complex patterns. For example, gestures and body motions (Rodriguez et al., 2015).

- **Basic sound detection**: The robot actor has the capability of identifying simple sounds. For example, using laughter or applause audio (Knight et al., 2011).

- **Advanced sound detection**: The robot can recognize complex sounds such as conversations (Rodriguez et al., 2015).
User interface: The audience or human actor can communicate with the robot actor through an interface on a computer or mobile device (e.g., a touchscreen tablet graphical user interface) (Leite et al., 2015).

Multimodal: A multimodal interface combines multiple input modalities, such as natural speech, hand gestures, facial gestures, eye gaze, body language, or tactile input.

In this stage, students and teachers can assume the role of a passive audience or an active audience. They can also assume the role of human actors and act together with the robot actors (Lu, 2012; Zeglin et al., 2015). A human actor could be physically present at the play or a distance through a robotic avatar.

One challenge in a live performance with robot actors is the improvisation, which can be divided into two levels (Fernandez & Bonarini, 2014): The first level involves simple improvisations that allow the robot to react to unexpected events on stage, such as mistakes made by other actors, synchronization and coordination errors, and robot failures (i.e., the robot not responding, battery failure) (Hoffman, 2011; Jochum et al., 2016); the second level involves complex improvisations that enable a robot actor to participate in a performance with a partial script or without one (Knight et al., 2011; Rodriguez et al., 2015). Challenges of complex improvisations are that the robot actor should understand the context of the current situation and choose the most appropriate robot’s behavior (Lu & Smart, 2011b).

Finally, engaging students in reflection on the drama process is essential. It reinforces the learning undertaken in the collaborative process (Brown, 2014). The reflection activities include structured class discussions, presentations, and written journal reflection.

7. Challenges of creating a play with robots for educational purposes

The challenges identified in the literature for the implementation of drama-based activities with robots are detailed below:

- **Robot actors (hardware):** Designing of a dedicated set of hardware for drama activities with robots is necessary. With the existing robot construction kits (i.e., Lego Mindstorm, Vex Robotics), creating verbal and nonverbal behaviors that convey emotions and intentions is difficult. Additionally, existing pre-assembled robots (i.e., Aisoy1, Thymio, Dash & Dot, and NAO) cannot easily change their appearance according to the features of the character (Laamanen et al., 2015). Social and expressive robots have great potential in drama activities with robots. They can easily convey intentions, desires, and emotions through verbal and nonverbal behaviors. However, the literature review shows that there are few social programmable low-cost robots in the market.

- **Programming environments:** There are several visual or graphical programming environments that help students and teachers to build a robot program easily, such as NXT-G software, Microsoft Visual Programming Language, Scratch, and Ardublock. Nevertheless, these programs also require knowledge of procedural programming concepts, such as loops, conditions, and variables (De Cristoforis et al., 2013). There is a need to design strategies to create plays with robots without having any previous programming skills or robotics knowledge. This authoring environment should be intuitive and easy to learn. Additionally, it should provide all the tools to create a successful play with robot actors.

- **Robot positioning and navigation on the stage:** A fundamental aspect of developing a play with robots is the requirement of knowing the robot’s position on the stage (Laamanen et al., 2015). There are plays where robots do not move on the stage; however, it limits their ability of expression (Alford et al., 2013; Hoffman, 2011; Knight et al., 2011; Zeglin et al., 2015). Therefore, a challenge in drama with robots is to implement low-cost strategies for detecting the robots' stage position.

- **Scripts with a high-level description and partial scripts:** The script does not necessarily need to provide explicit details of the play (i.e., nonverbal expressions). Autonomous robot actors can modulate, enrich, and even add new actions according to the characters’ traits and the storyline (Fernandez & Bonarini, 2014). The challenge is to design a control architecture of robot actors that allows performing plays with a high-level description of the script or partial scripts.
Audience participation: There is a need to research the active role of an audience in a performance with robots (Knight et al., 2011; Leite et al., 2015). In an educational context, students can change the path of the play during the live performance to explore different alternatives and analyze the results of various events (Leite et al., 2015).

Interactive plays: The storyline can be changed during the live performance based on the feedback of the audience, human actor, environment, and other robot actors (Leite et al., 2015). Another challenge is to develop an intelligent adaptation mechanism of the storyline based on audience feedback (i.e., students’ learning progress and the audience’s choices in the storyline).

Plays with human actors: Humans can assume the role of human actors and act together with the robot actors. Challenges are the real-time responsiveness and human-robot coordination (Hoffman, 2011).

Believable robot actors: Another challenge is to create believable robot actors that display behaviors consistent with the personality traits, mood, and emotional state of the characters portrayed.

Multiple robot actors: As the stage is a shared space, robot actors require the use of methods for multi-robot path planning and motion coordination. The challenge is to manage the cooperation between robot actors in order to assign roles, synchronize actions, and avoid conflicts.

Control architecture of robot actors: The last challenge is to design a control architecture of robot actors that supports teaching and learning of school subjects through the intuitive creation and performance of interactive plays with robots.

8. Conclusion and future work

This work proposed a method for integrating educational robots into the teaching and learning of non-technical subjects through drama activities. Our proposal combines educational drama, human-robot interaction and educational robotics in order to support learning objectives in non-technical areas and enhance the student-learning experience. Through the creation of theatrical plays with robot actors, students can gain new knowledge, develop 21st-century skills, and communicate their feelings, thoughts, and desires with ease. Drama with robots facilitates the implementation of powerful educational strategies, such as storytelling, forum theater, role-playing, and simulation of phenomena (i.e., motions of bodies in the Solar System, Bohr model of the atom), processes (i.e., recycling), and behaviors (i.e., flocking behavior, fish schools).

We are currently designing a control architecture for robot actors that can support teaching and learning of non-technical school subjects for the intuitive creation and performance of interactive plays that recreate stories and simulate phenomena or processes. One requirement is that the architecture should allow users without any programming skills to create a theatrical script for a play with multiple robot actors. If students can create a play intuitively, they could focus on the analogy or metaphor construction instead of focusing on how to program the robot actors. Additionally, the use of multiple robot actors widens the range of school topics that can be developed through a drama-based activity. This leads us to the following design question: how to construct an authoring environment that allows non-programmers to create plays with multiple robots? In order to answer this question, we are exploring a script-authoring environment that allows the creation of scripts through intuitive robot programming strategies, such as visual programming and programming by demonstration. Some tasks that users should be able to do intuitively in this authoring environment includes: create list characters of the play, specify the features of each character, assign an actor to a character, create a sequence of beats to form scenes, specify the actions that the robot actors must perform in each beat (who, what, when, where), link scenes together to form scene sequences, and finally, rehearse a particular beat, scene, or the whole play with robots.

Another requirement of this architecture is the creation of two types of scripts: a non-interactive script and an interactive script. The interactivity can promote student engagement during the performance of the play and enhance learning experiences (Blasco-Arcas, Buil, Hernández-Ortega, & Sese, 2013). Additionally, through monitoring learners’ progress and achievement during the live performance of the play, teachers can adapt material to the learning needs of students (Shank, 2013). This requirement leads us to the following design questions: how to
construct an authoring environment that allows creating interactive and non-interactive scripts? And how to manage interactive scripts based on audience feedback? We are exploring different types of narrative structures for the interactive scripts, such as, foldback structure and linear structure with interactive challenges that must be successfully completed for the story to continue to the next state.

The architecture should also allow creating consistent and believable characters that help the audience to engage with the characters and their situations. It could help students to better understand the analogy with robots. Additionally, creating believable characters could help capture the students’ attention during the performance of the play with robots. Considering this design purpose, how might an authoring environment that allows creating believable characters be constructed? And how could a robot actor be controlled to produce nonverbal behaviors that are consistent with the personality traits and emotional state of the represented character? Our architecture should be able to enrich the actions of the robot actor according to the internal emotional state and defining personality traits of the character. Additionally, the script-authoring environment should facilitate the user to create believable characters. For example, some tasks that the user should be able to do in the authoring environment include: defining emotional states of the characters, specifying verbal and nonverbal behaviors, synchronizing verbal and nonverbal expressions, and synchronizing interactions between the characters.

Finally, we will validate the implemented architecture through user participation. We will verify whether this architecture meets the design requirements and user needs by measuring the following elements: level of usability (effectiveness, efficiency, learnability, error tolerance, and satisfaction) and learning outcomes. This research is expected to contribute to the knowledge on the drama with robots in an educational context through the design of architecture for the control of robot actors. An additional contribution is to provide programming strategies that allow non-programmer users to create theatrical plays with multiple robot actors. This programming environment can also become a tool to promote algorithmic thinking and logical reasoning. The desired impacts are to increase the use of robot-based activities in the learning of non-technical school subjects and promote innovation in the teaching-learning process.

References


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