J Sci Educ Technol (2017) 26:561–581
DOI 10.1007/s10956-017-9698-9

Learning Robotics in a Science Museum Theatre Play: Investigation of Learning Outcomes, Contexts and Experiences

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Published online: 16 August 2017

Abstract Theatre is often introduced into science museums to enhance visitor experience. While learning in museums exhibitions received considerable research attention, learning from museum theatre has not. The goal of this exploratory study was to investigate the potential educational role of a science museum theatre play. The study aimed to investigate (1) cognitive learning outcomes of the play, (2) how these outcomes interact with different viewing contexts and (3) experiential learning outcomes through the theatrical experience. The play 'Robot and I', addressing principles in robotics, was commissioned by a science museum. Data consisted of 391 questionnaires and interviews with 47 children and 20 parents. Findings indicate that explicit but not implicit learning goals were decoded successfully. There was little synergy between learning outcomes of the play and an exhibition on robotics, demonstrating the effect of two different physical contexts. Interview data revealed that prior knowledge, experience and interest played a major role in children's understanding of the play. Analysis of the theatrical experience showed that despite strong identification with the child protagonist, children often doubted the protagonist's knowledge jeopardizing integration of scientific content. The study extends the empirical knowledge and theoretical thinking on museum theatre to better support claims of its virtues and respond to their criticism.

Keywords Museum theatre · Science theatre · Informal education · Contextual model

Electronic supplementary material The online version of this article (doi:10.1007/s10956-017-9698-9) contains supplementary material, which is available to authorized users.

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Introduction

Informal science learning can occur in a multitude of environments and in a variety of formats (NRC 2009; Tal and Dierking 2014). One environment that has been studied fairly extensively is the science museum and research indicates that it can provide young audiences with a diversity of learning outcomes (NRC 2009).

Within museums in general and science museums in particular, theatre, drama and role play are often introduced to liven up exhibits, attract visitors to specific exhibitions and help mediate difficult content (Hughes et al. 2007). This genre has been gaining considerable impetus in the last two decades (Jackson and Kidd 2008) as is reflected by the foundation of the International Museum Theatre Alliance (IMTAL) in 1990, a non-profit professional association for museum theatre practitioners and supporters (IMTAL n.d.).

Despite the wide use of theatre within museums, and despite the many claims that museum theatre can be a powerful educational tool, very little research supports such claims and rebuts their criticisms of not being sufficiently educational by educators and sufficiently artistic by artists (Baum and Hughes 2001; Hughes 2010; Hughes et al. 2007). In the context of these criticisms, our goal is to investigate whether a theatre play can be an effective science learning environment and to explore the kinds of learning outcomes such an informal setting can afford.

'Museum theatre' is broadly defined as 'the use of theatre and theatrical techniques as a means of mediating knowledge and understanding in the context of museum education' (Jackson and Rees Leahy 2005, p. 304). The label of museum theatre has been applied to describe a wide range of activities within a museum including scripted or improvised performances by paid professional actors, costumed characters played by amateur volunteers and science demonstrations to name just a few (Bridal 2004). A more discerning approach defines museum theatre as a piece that tells a story and that engages the imagination, thus transporting the audience to a different time and place and in which the script and the actors become agents of emotional transport (Dornfest in Bridal 2004). Choosing the more discerning approach allows investigating the main characteristics that set museum theatre apart from other activities within the museum (such as exhibitions, science demonstrations, workshops). Thus, in this study, we explore the characteristics of learning science in a distinct informal learning environment that is characterized by fictional narrative, imagination and transportation to a different time and place.

Contemporary learning theories in informal learning environments have highlighted the multifaceted nature of learning outcomes they may afford (Bamberger and Tal 2008; Brody et al. 2007; Rennie and Johnston 2004). Furthermore, learning outcomes may be seen as either a product (based on conceptual change theory) or as a process (based on socio-cultural theory). Since this study is exploratory by nature, we tried to capture a wide array of learning outcomes to understand the potential role of science theatre in the museum. We thus view learning outcomes as both a product and a process.

Our first goal was to demonstrate cognitive outcomes of watching a science museum theatre play. We follow Allen's approach of first constraining learning to the learning goals of the museum in order 'to put the museum in a stronger position to make claims about its efficacy as a learning institution' (Allen 2002, p. 262).

The second goal of the study was to situate the theatrical experience within the overall museum visit and identify interactions with other elements of the visit. To investigate this, we turn to the contextual model which posits that learning is situated within a series of contexts (Falk and Dierking 2000, 2012).

The third goal of the study was to focus on the learner's experience of the play (process). To this end, we turn to a model of the theatrical experience developed by Eversmann (2004, and later refined by Boerner et al. 2010) which allows capturing the process of meaning making and interactions with a theatre play.

We studied a play about robotics that ran alongside an exhibition on the same theme in a science museum, which was attended by school classes and families. This allowed us to investigate an array of learning outcomes, various visiting contexts and the potential role of science theatre in the overall experience.

Specifically, we asked the following:

1) What are the cognitive learning outcomes of an educational science play on robotics as compared with the learning goals intended by the playwrights?
2) How do these cognitive learning outcomes of watching an educational science play on robotics interact with different viewing contexts?
3) How do the viewers experience the theatrical event?

In the following section, we first outline what is already known about learning in museum theatre. We then appropriate two theoretical frameworks from related fields that will guide our search for learning outcomes that go beyond those found in the existing literature.

Literature Survey

Research on Museum Theatre

Early research reports on museum theatre were in essence internal evaluations. Bicknell and Fisher (1994) found that interactions of first-person interpreters (historical characters) in museum galleries can draw in learners and enlighten in some cases, yet cause distancing and embarrassment in others (by putting visitors in the limelight without their will or arousing a feeling of distrust and being out of control). Baum and Hughes (2001) report on a meta-analysis of 10 years of evaluations of plays in a science museum. The analysis found cognitive knowledge gains among viewers of all plays evaluated, as well as viewers' positive attitudes towards the learning process.

In the past decade, research endeavours on museum theatre were based on more elaborate theoretical frameworks and went beyond simple evaluations of audience cognitive gains. Hughes (2010) studied how the audience makes meaning of museum theatre plays in history and science museums. Data were collected using pre- and post-show surveys, observations and group interviews. Data analysis was informed by transactional theory from the field of literary studies which suggests that when reading a book or watching the play audience have an active role in interpretation. The study highlighted the centrality of empathy in the aesthetic response to the theatre piece and the importance of spectator-actor interaction in the engagement of spectators with the theatre.

Another notable endeavour is a research project conducted by Jackson and his team on performances in history and heritage museums (Jackson and Kidd 2008). While no 'one size fits all' (p.134) recipe can be given, the authors do come to some general findings and recommendations for practitioners. The team suggest that 'when well designed and sufficiently integrated into the museum experience as a whole, theatre can offer a significant enhancement to the learning by children' (Jackson and Rees Leahy 2005, p. 1). Their study investigated the museum site, the audience, the content and the performance. Data were collected using interviews, observations and surveys and learning was seen as a constructivist process. Some of the general findings are that performances often have a positive value, they may have a long impact on the visitor and that recall is often aided by artefacts. The researchers also highlight the importance of the framing of the event (i.e. what happens before and after the performance and how the visitor is engaged within the performance).

In a previous study, we investigated a museum play on evolution (Peleg and Baram-Tsabari 2016). We used performance and spectator analyses from the field of theatre studies to link between producers' intended aims, the written script and the learning outcomes. Explicit and cognitive aims were decoded as intended by the viewers. The evidence was weak for decoding of implicit and affective aims. The producers were concerned that there was a conflict between the didactic and aesthetic elements, although this conflict was not apparent in the script.

Walker et al. (2013) investigated how a science theatre show on HIV-AIDS can affect behavioural intentions. Data were collected using specially devised surveys on HIV-related intentions as well as items on self-reported enjoyment and learning. The study found that watching the play strengthened already positive intentions. Claims of interest, enjoyment and learning predicted changes in intention as did prior knowledge.

In recent years several studies reported on school children learning science from educational science plays in school settings (outside of museums). Wieringa et al. (2011) studied 15–17-year-old students' and experts' reactions on a play presenting socio-scientific issues on food technology. The researchers found that the use of caricature to portray scientists may have hampered the possibilities to reach the audience and that a discussion held after the play was considered crucial and was appreciated by the viewers.

Carpineti et al. (2011) report on four theatre plays based on physics demonstrations. Empirical studies of audience acceptance of two of the plays is reported. One show, for primary school children, showed that the goals set for the play were successfully achieved, namely articulated memories of the play, positive engagement of the children, enthusiasm and formation of an idea about what scientists do. In the second show, for secondary school children, the authors claim that the goals were only partly achieved and suggest that the show be accompanied by teaching materials for teachers and classes. Finally, Lanza et al. (2013) investigated the use of theatre to increase knowledge on earthquakes and risk preparedness, with preliminary results suggesting that theatre can act as an agent for behavioural change.

In a study on children's learning of basic chemistry from an educational science play (Peleg and Baram-Tsabari 2011), questionnaires and interview data showed that children's conceptual knowledge increased as a result of the play. Children's general attitudes towards science did not change, but the play widened their view of what learning science can be. Theatrical elements important to children's recollection of the play were the narrative, props, stage effects and the characters. In the children's memory, science was intertwined with the theatrical elements. Nonetheless, children could distinguish well between scientific facts and the fictive narrative.

All these studies indicate that science theatre can have cognitive learning outcomes. The learning processes and affective learning outcomes of viewers of the play were not well presented in these studies.

One thing that becomes obvious from reviewing the literature on museum theatre is the lack of robust theoretical frameworks. Most studies lacked them or relied on ones from faraway fields. Since 'theory is essential to keep such an enterprise from spinning off into a mere collection of unrelated investigations' (Schauble et al. 1997, p. 3), it is one of the intentions of this paper to develop a theoretical framework suitable for the study of science museum theatre. In order to develop such a framework, we turn to research on informal learning environments. While most theories were developed based on museum learning, we believe they can well inform learning in museum theatre with appropriate adaptations.

Theoretical Framework

Theories of Learning in Informal Learning Environments

In informal learning environments such as museum, zoos and aquaria, what constitutes learning is not straightforward. While these environments may contribute to conceptual knowledge, they do not only aim at improving subject matter knowledge, but rather have wider goals such as changing attitudes, increasing motivation and other affective aims (NRC 2009; Schauble et al. 1997).

Drawing on research on formal learning environments, early studies in out-of-school venues mainly focused on cognitive knowledge acquisition (Rennie et al. 2003; Rennie and Johnston 2004). In these studies learning was seen as a product of the visit. They were based on conceptual change theory looking at change in children's achievement or knowledge usually by means of pre- and post-visit instruments (Bamberger and Tal 2008; Rennie et al. 2003).

Later research on museums and other informal learning environments not only looked at what visitors learn but also at how they learn it (Bamberger and Tal 2008; Rennie and Johnston 2004). Such studies were based on socio-cultural theory and emphasized the way people learned independently of the content (Bamberger and Tal 2008). Studies focusing on process would characterize the forms and functions of visitors' activities that take place in the museum (Schauble et al. 1997) and thus need tools beyond simple questionnaires such as open or structured interviews, think-aloud techniques and audio and video recordings (Rennie et al. 2003).

The museum visit experience is highly personal and idiosyncratic (Falk and Dierking 2012; Falk and Storksdieck 2005; Rennie and Johnston 2004). It depends not only on visitors' prior knowledge, experience and motivation but also on the visitor's choice of engaging with others, with exhibits and on her/his unique experience in the museum. With the idiosyncratic nature in mind and considering learning as both a process and a product, the learning outcomes from a museum visit are multiple and multifaceted and can be of a cognitive, affective, behavioural or social nature (Bamberger and Tal 2008; Brody et al. 2007; Rennie and Johnston 2004).

In this study, we first concentrate on the cognitive outcomes of watching a science museum theatre play. We follow Allen's approach of first constraining learning to the learning goals of the museum in order 'to put the museum in a stronger position to make claims about its efficacy as a learning institution' (Allen 2002, p. 262) an approach also followed by Bamberger and Tal (2008).

In order to enrich our understanding of the outcomes of the play, we also examine learning as a process. Most contemporary systems of capturing the visitors' learning processes were constructed with museum visits in mind. Many rely upon a moment-to-moment or micro-analysis of interactions and conversations in museums (Ash 2003; Rahm 2004). Due to the configuration and dynamics of the theatre play in which the audience is expected to keep quiet, these methods are not suitable for investigation during the play. Focusing on the process of learning from a socio-cultural theory point of view implies looking at what forms visitors' activities as well as their process of meaning making (Schauble et al. 1997). To this end, we turn to a model of the theatrical experience developed by Eversmann (Eversmann 2004, and later refined by Boerner et al. 2010) which allows capturing the process of meaning making and interactions with a theatre play. Using this approach, we collect data *from* visitors and *through* their interpretation, thus allowing the learner's voice to be heard as recommended by several scholars (Bamberger and Tal 2008; Rennie and Johnston 2004). Further details of the approach will be described below.

Watching a museum theatre piece takes place within a wider context of the museum visit. In order to place the learning outcomes (both cognitive and of the theatrical experience) in this wider context, we turn to the contextual model of learning (Falk and Dierking 2000, 2012). The model, which draws on constructivist, cognitive and socio-cultural theories of learning, acknowledges the complex nature of learning in informal environments and suggests that learning is not an abstract experience that can be isolated. Rather, all learning is situated within a series of contexts (Falk and Dierking 2000, 2012): a personal context, a socio-cultural context and a physical context.

Investigating Theatre Through the Contextual Model

The contextual model is most often applied to environments which offer free choice for the learner. Theatre studies are increasingly unveiling the active, free choice nature of the spectator instead of that of the passive spectator as an 'empty vessel' waiting to be filled (Balme 2008; Bennett 1997). The similarity to free choice environments persists, with increasing evidence on the contextual nature of the theatrical viewing experience (TSP 2012). We believe that the contextual model is suitable to studying theatre play with appropriate adaptation as described below and summarized in Table 1.

The Physical Context The physical context refers to the physical aspects of the learning environment. In a museum, this includes its large-scale properties (such as space, lighting and climate) as well as exhibits and objects within the museum (Falk and Storksdieck 2005). Within the theatre context, this might include the performance space (stage design), the theatre building or the position of the theatre building/auditorium within a wider layout (the city, the museum). Yet theatre scholars have not investigated the viewers' experience of these contexts (Balme 2008).

The Socio-cultural Context The socio-cultural context is based on the premise that learning is often socially mediated, especially in informal learning environments (Falk and Dierking 2012; Schauble et al. 1997). This context includes the influence of social interactions within such environments and the postulated effects of the cultural value placed on free choice learning environments (Falk and Storksdieck 2005). Within theatre research, facilitation of performances by friends, family or teachers is crucial in inducting young people into live theatre (TSP 2012).

Socio-cultural interactions in museums are normally investigated by following and recording groups within the museum (e.g. Ash 2003; Rahm 2004). Such dialogic interactions are common and are an important part of the meaning-making process (Ash 2003). Due to the conventions of theatre these interactions are rare during the performance. Whether such conversations happen after visiting the theatre, and their potential importance, are beyond the scope of this study.

The Personal Context The personal context contains the personal history that an individual brings with him/her to

Table 1 The most influential factors in museum learning according to the contextual model (Falk and Dierking 2012; Falk and Storksdieck 2005) and how they might be expressed in a science museum exhibition and theatre play

	Exhibition	Play
Personal context		
1. Visit motivation and expectations	Expectation of a museum visit that will take place in an exhibition hall with (interactive) exhibits	Expectation of a theatrical experience that will takes place in an auditorium, with a fictitious narrative and with actors
2. Prior knowledge	Child's prior knowledge on the scientific topic of the exhibition	Child's prior knowledge on the scientific topic of the play. Theatrical literacy
3. Prior experiences	Past experiences visiting museums	Past experiences watching plays. Theatrical literacy
4. Prior interests	Interest in the topic of the exhibition	Interest in the topic of the play
5. Choice and control	Depends on the circumstances. Freedom may include choice of topic, space, order, time and interactions	Choice of what to focus on in the play and how to interpret it. Limited choice of space and no choice of time
Socio-cultural context		
6. Within-group social mediation	Interactions with parents and other children during the visit	Interactions with other audience members (children and adults) before, during and after the performance. During the performance interaction is not necessarily verbal (for example laughter)
7. Mediation by others outside the immediate social group	Mediation by museum guides	Mediation by the actors and other museum staff
Physical context		
8. Advance organizers	Introductory signs to the exhibition, flyers	Flyers, announcements by guides prior to the play
9. Orientation to the physical space	Exhibition map, prior orientation at the information desk	Little orientation is needed and can be provided by on-site museum guides
10. Architecture and large-scale environment	Museum/exhibition hall	The auditorium. The scenery
11. Design and exposure to exhibits and programs	Design of the exhibits	Design of the play: costumes, scenery, choice of characters, narrative
12. Subsequent reinforcing events and experiences outside the museum	Depends on what follows the visit	Depends on what follows the play

the learning situation, including visit motivation and expectations, prior knowledge, prior experiences, prior interests and choice and control (Falk and Storksdieck 2005). We expect the effect of these factors on expected learning outcomes to be similar between museum exhibitions and museum theatre. The factor that might show the most difference is that of choice and control.

Prior knowledge and experience in the theatre context should not only include knowledge about the subject matter but also knowledge and experience of viewing and interpreting plays, a term referred to as dramatic literacy, theatre literacy or theatre confidence (TSP 2012; Wright and Garcia 1992). These can influence viewers' experience and interpretation of the play (Niemi 1988; Reason 2006).

The Theatrical Experience

In order to understand the learning outcomes relating to the process of learning in the theatre play, we turn to the model of the theatrical experience.

'At least one spectator is needed to make a [theatre] performance' (Grotowski 1968, p. 32 in Bennett 1997). While this is an obvious statement, theatre studies have virtually ignored the real audience and mainly discussed ideal or hypothetical viewers (Balme 2008; Boerner et al. 2010). This bias is probably due to traditional focus of theatre studies on the aesthetic object and a lack of knowledge of appropriate research tools.

Eversmann's model of the theatrical experience (Eversmann 2004) is a recent breakthrough in theorizing the spectator's experience. The model is based on Csikszentmihalyi and Robinson's (1990) model of the aesthetic experience and on theatre professionals' memory of 'flow' experiences in the theatre. The model consists of four dimensions: a perceptual dimension, a cognitive dimension, an emotional dimension and a communicative dimension. The model was verified for the non-flow experience of the 'average' (non-professional) theatre-goer (Boerner et al. 2010).

The Perceptual Dimension This dimension deals with 'perception *per se*—i.e. without interpreting or attaching meaning to the experience' (Eversmann 2004, p. 151) such as spontaneous physical reactions or a kinetic response to the stimuli on stage ('feeling' the dancer's movements).

The Cognitive Dimension This dimension 'covers the spectator's intellectual dealing with the performance' (Boerner et al. 2010, p. 174) and is influenced by general and theatre-specific knowledge and expectations. Eversmann suggested that unlike the perceptual dimension 'much of the cognitive effort made by the spectator occurs after the performance, when there is time to think over what has been seen, to come to terms with it and to relate the show to the individual's own life' (p.153). This dimension has four subdivisions:

(1) Understanding the meaning of the performance. (2) Intellectual stimulation—the performance as a source of inspiration. (3) Recognition of oneself or of familiar circumstances. This recognition is triggered by a situation a character is in or the psychology of a character. (4) Recognition with or alienation from a character. In this form of recognition the spectator tries to actively imagine himself/herself in the fictional situation and what he/she would do in the same situation as the character on stage.

A concern in children's educational science theatre is whether children can differentiate between those parts of the play which are fictitious (the narrative) and the scientific facts and phenomena. The play would fail its aim if children were to dismiss scientific information as being fictive together with the story.

When learning facts from a fictional, text two types of behaviour have been described in the literature (Marsh et al. 2003). *Integration* or *incorporation* involves linking facts to pre-existing world knowledge. These facts are then remembered without retaining links to their fictional source and thus are seen as part of existing world knowledge (these facts are 'true'). Educational uses of fictional narratives, such as in theatre plays, aim for integration in the hope that facts will be assimilated into the child's general knowledge. In *compartmentalization*, these facts retain the link to their fictional source and are thus separate from the reader's world knowledge (these facts are 'fictional'). Integration is encouraged by telling readers that a narrative is 'real' as opposed to fictional (Potts et al. 1989 in Barriga et al. 2010), while compartmentalization may occur for a number of reasons such as a belief that the fictional source was not credible (Marsh et al. 2003).

The Emotional Dimension The emotional dimension includes spectators' affective reactions to the performance: emotions connected with the fictional content of the performance (e.g. empathy with the characters) and emotions connected with going to the theatre itself (e.g. excitement about the theatrical event).

The Communicative Dimension The communicative dimension is concerned with the interaction between the spectator and the performance. On a primary level communication in the theatre occurs between the individual spectator and the individual actor. On a second level the individual also indirectly communicates with the director or the playwright. Thirdly, communication also occurs between individuals in the audience to create a feeling of collectivity or communality.

Synthesizing the Frameworks

As a child enters the museum auditorium to watch the play, she does so in an array of contexts: she might be visiting with her family or in the context of a school field trip; she might have already seen some exhibitions or have gone to the auditorium immediately upon entering the museum (because the play is about to start); she may know a lot about the subject matter of the play prior to watching it, or have little knowledge of the subject matter. Upon entering the auditorium, the lights go down and the play begins. The child undergoes some kind of (learning) experience watching the play. She might be amused, moved, bored, drawn into the play; she might empathize with the protagonists, or feel that they are in no way related to her life. She might pick up on a lot of conceptual knowledge or have learnt no conceptual terms whatsoever. Maybe it was a new experience for her and she learned about what it is like going to the theatre.

We use the two frameworks to complement each other. The contextual model, appropriated from science learning in informal settings, serves us as a characterization of the entry point to the theatre, portraying how the learner relates to the environment. The model of the theatrical experience, borrowed from theatre studies, is used to characterize the experience in retrospect and focuses on the artistic aspects of the environment. Together they allow for a multifaceted and rich examination of the experience.

Methods

The first goal of this study was to characterize the cognitive learning outcomes of a science museum's play on robotics as defined by the playwrights. The second goal was to contextualize these cognitive learning outcomes and find how different viewing contexts affect them. The third goal was to characterize the theatrical experience as a further learning outcome.

Research Approach and Procedures

Data were collected using questionnaires and semi-structured interviews. To investigate the effect of different contexts on the learning outcomes, data were collected from two groups of children: (1) visitors who came to the museum in the context of a family visit (family group) and (2) students who came to the museum in the context of a school field trip to watch the play (school group). Other data concerning the visiting context (such as demographics and visitation to an exhibition on robotics) were collected in items built into the questionnaire.

In the family group, it was challenging to administer both pre- and post-questionnaires due to the difficulty of locating the same visitors before and after the play and young visitors' limited patience in filling in questionnaires. We therefore choose a two group post-only quasi-experimental design often used in the evaluation of informal learning environments (Allen 2008; Campbell 2008): the experimental group consisted of children who were asked to fill in questionnaires immediately after watching the play and the comparison group consisted of children who visited the museum and did not watch the play. The samples were corrected to allow for similar demographics of the groups.

In the school group administrating both a pre- and a post-play questionnaire was more straightforward and was done by visiting the school a week before and a week after the play (Table 2). In this context, it was difficult to form a comparison group because the school insisted all children watched the play at the given date. The school group consisted of six classes of students grades 2 to 3 who saw one of two performances on the same day. The performances took place about a month after the summer holiday. Since the school is a private, fee-paying school, most children came from an above-average socioeconomic background.

The second goal of the study was to contextualize the cognitive learning outcomes by investigating the effects of different contexts. In order to investigate different physical contexts, we exploited an exhibition on the topic of robotics which was a main attraction in the museum at the time of study. To investigate the interaction of visiting the exhibition on the cognitive learning outcomes of watching the play, the family group was further divided into children who already visited the exhibition and those who did not. This information was gathered in the questionnaire. A 2 × 2 factorial design resulted, allowing assignment into one of the four condition groups (see Table 3). To investigate personal contexts, demographic data were gathered in the questionnaires (gender, age, school grade).

In-depth semi-structured interviews were conducted in order to enrich the data on the cognitive learning outcomes as well as achieving the third goal of the study, namely to deepen understanding of learners' learning process by investigating viewers' theatrical experience. For the family group, we found it difficult to conduct interviews in the museum (since they were eager to continue their visit) and we also wanted to know the long-term effect of the experience; thus, we conducted phone interviews some 3 months after the visit. Parents were also interviewed by phone to enrich the interview data by learning more about the motivation for attending the theatre and to get parents' perspective of the child's viewing experience. The school group was interviewed face to face on the school campus.

Below, we provide details of the settings, data collection, research tools and analysis.

The Play

'Robot and I' was commissioned by a major science museum in Israel to accompany an exhibition on robotics. The museum staff wanted a play to cater for the 5–9 age group. A team of two (one is a co-author of this paper) was contracted to write and produce the play. After an initial research, the two co-writers met with the museum's educational staff and the general aims and messages of the play were decided upon. Initial ideas were based on existing teaching materials on robotics (e.g. NASA n.d.; Razor Robotics n.d.; SPARK n.d.). The four educational goals were finalized with the museum educational staff (personal communication, April 1, 2010):

A - Each robot needs to have a motor, sensors and a computer. In essence a robot is a machine that senses the world using sensors, processes the sensed information using a computer and moves using a motor in response (SPARK n.d.).

B - Robots can help humans in a multitude of ways. Robots can entertain people, perform surgery, assemble cars in factories, explore places where humans cannot go, etc. (NASA n.d.; Razor Robotics n.d.; SPARK n.d.).

C - Children can be inventive and design things, including simple robots.

D - Robots are not human—they need not look like people (e.g. the Roomba vacuum cleaning robot) and they cannot replace human love. Often children (and adults) think of robots as the humanoid image presented in movies with a face, arms and legs (SPARK n.d.). To challenge this conception, the museum staff requested that there be no real robots or humanoid looking robots on stage. The museum's educational staff also wanted to

Table 2 Design of the study for the family group and the school group

	Pre-questionnaire	Play	Post-questionnaire
Families: experimental group		X	X
Families: comparison group			X
School group	X	X	X

Table 3 Breakdown of the family group questionnaires ($n = 239$)

	Has been to the exhibition (visitors)	Has not been to the exhibition (non-visitors)
Has seen the play (viewer)	139 double exposure—visitors and viewers	35 viewers only
Has not seen the play (non-viewer)	43 visitors only	22 comparison group

emphasize that despite all the many advantages of robots, unlike humans, they do not have emotions.

The play was a one-actor show presented daily during the summer school holiday (the play was presented by either an actor or an actress on different days). Visitors could see the play at no additional charge.

The protagonist Yaeli, an imaginative young girl (or the boy Ori in the actor's version), who is woken up by her baby brother's screaming. Disgruntled with mom spending too much time with the baby, the girl decides to builds lots of little 'robots' from everyday materials. These little 'robots' will help mom out so she has more time to spend with Yaeli. Designing the robot, Yaeli learns that robots need sensors, a motor and a brain-like computer.

In the second part of the play, Yaeli sees a news report about a volcano erupting. She immediately transforms herself into an all-powerful robot that saves a village from the eruption, thus learning of different ways robots can help people. The play ends with Yaeli getting injured on the shin. After getting a comfort kiss from mom, she realizes that while robots can do many things, they cannot replace mom's love and affection. A full synopsis is available in the supplementary materials.

The Exhibition

'Robot-zoo' is a travelling exhibition that shows larger-than-life-size animal-like robots (Evergreen Exhibitions, n.d.). Cutaways in the robot sides reveal the machinery and gadgets that operate the robot. The exhibition was on display in the science museum for several months and received major publicity (more details in the supplementary materials).

Research Tools

Questionnaires The questionnaire was developed to examine respondents' knowledge and attitudes towards robotics. Since we limited the content knowledge to that intended by the museum/writers (following Allen 2002), the knowledge items aimed at the four intended learning goals of the play. A brainstorming session yielded 35 initial items. Following an expert validity session with five experts in science and robotics education the questionnaire was revised. The first piloting of the questionnaire occurred in the form of one-on-one or group interviews with children visiting the museum in which one of the researchers presented the questionnaire items orally. This was especially useful in discovering issues of clarity and intelligibility. Questions that were misunderstood or were too difficult were changed and the subsequent version was administered as a written questionnaire. In the second pilot study 52 questionnaires were collected from viewers and non-viewers of the play. This second pilot allowed to perform an initial quantitative data analysis on the questionnaire. Based on data analysis the questionnaire was revised and administered again. In a third pilot study, 28 viewer and non-viewer questionnaires were collected and final changes were made to the questionnaire (data from the pilot studies are not included in the findings). The main changes made to the questionnaire were as follows:

- Improving the graphic layout to make the questionnaire more friendly and less threatening to the responders.
- Language was simplified or clarified as found necessary. Some questions were too open and young children found them difficult to reply to. These questions were narrowed to scaffold the answer (e.g. the general question 'What is a robot?' was changed to 'What do you think are the most important components of all robots?' and 'Why do you think robots are a special kind of machine?').
- The number of items was severely reduced by eliminating items which elicited similar responses ('How do robots help people?' and 'Is it important to build robots?' received similar responses and thus only the former was kept) or by uniting several questions into one 'yes or no' question to reduce graphic space and time of response (e.g. the questions 'Are there robots that love people?' and 'Give an example of a robot' were replaced by 'yes or no' items to whether different kinds of robots exist).
- Items which seemed too basic for the children yielding no useful data were removed.

- Items relating to science studies were removed since very young children do not always learn science in school and do not have sufficient experience of learning science.
- A 'comments for parent' section was removed as no parents responded to it in the piloting.

It was decided that the questionnaire be no longer than 3 A4 pages for the non-viewers and 4 A4 pages for viewers. The final questionnaire consisted of (the full translated version of the questionnaire is available in the supplementary materials):

1. *Introduction*—A short introduction for the parents explaining the purpose of the questionnaire and asking them to help their children read it, but not to answer for them. This was followed by a short introduction for the children explaining the purpose of the study.
2. *Demographics*—Children were asked to specify their gender, age and what school grade they were about to begin after the summer holiday. They were also asked to specify whether they had seen the 'Robot and I' play and whether they visited the 'Robot-zoo' exhibition.
3. *Knowledge about robots*—Five items relating to the four intended learning goals: one closed item consisting of nine yes/no questions and four open items (Table 5, column 2).
4. *Attitudes towards robots and theatre plays*—Two Likert-type items were used with smiley faces to help children express their feelings towards each item (Hopkins 1985 in Conner 1991).
5. *Opinions and attitudes towards* '*Robot and I*' (*for viewers only*)—Six open and two closed items asking for the viewer's experience of the play.

All the texts in the questionnaire were written with diacritical marks (that stand for vowels in Hebrew), a system frequently used in the low grades of elementary schools. The questionnaires for the school groups were essentially the same, but the introduction to the parents was omitted and the one for the children was replaced with one appropriate for the school context.

Interviews In the beginning of the family questionnaire parents were asked to give their consent for a subsequent telephone interview. Some 80% of parents gave their contact details on the questionnaire. Families who watched the play were contacted about 3 months after they saw the play (M = 100 days, SD = 7 days) with the original intention of probing children's long-term memory of the play and the theatre experience. First the interviewer asked to talk to the parent (or grandparent) who accompanied the child to the play. The parent was asked whether it was convenient to hold the phone interview at the current time and whether they give permission to record the conversation.

Phone conversations were attempted on weekdays in the afternoon between the time children returned from schools until dinnertime. In many cases it was not possible to interview the child at the first instance and a repeated call was necessary. In several cases the adult agreed to be interviewed but asked that the child would not be. In cases where there was no answer, another attempt or two were conducted before the phone number was abandoned. The multitude of limitations (limited time frame, families' busy schedule and some parents' reluctance) led to a big dropout rate from the original 80%.

In cases where an interview was achieved, we found that most children cooperated well with the interviewers. Children were interviewed individually. When more than one child was at home, the interview took place with all children who were willing. For technical reasons it was not possible to interview these children together (recording voice over speakerphone results in poor quality), but they usually heard their siblings responses. We also interviewed parents to enrich our data, particularly to learn more about the motivation for attending the theatre and to get the parents' perspective of the child's viewing experience.

Interviews were semi-structured. Children were asked of their recollection of the play, understanding of the play and the science content and of their theatrical experience. Parents were asked about their opinion of the play, their reasons for attending the performance and their child's subsequent mentions of the play (interview questions are detailed in the supplementary materials). Interviews with parents lasted 5–15 min and those with the children 7–15 min.

Children in the school group were interviewed on the school premises (usually an empty classroom or in the hall) in dyads. A previous study (Peleg and Baram-Tsabari 2011) found that this is the most effective group size. In individual interviews, children were intimidated, and in groups of three and more, the conversation often drifted off topic. We are aware that this causes a methodological limitation when comparing to the family group. However, in the family group interviews there was always a person present at home (parents and siblings) who would often interact with the interviewees in a similar way to the interactions in the school interviews. Interview questions were in essence the same as those presented to the family group. Interviews lasted 20–30 min. Interviews were meant to take place 3 months after the play as with the family group, however, due to school constraints they took place 3–4 weeks after the play (M = 31 days, SD = 3.7 days) presenting another methodological limitation.

Sample

Family Group In total, 433 questionnaires were collected. In order to have comparable viewer and non-viewer groups only children about to start first to fourth grades were included in the analysis. This yielded a sample of 239 questionnaires (Table 3). The final sample consisted of approximately equal numbers of children about to start each grade level (1st grade $n = 60$, 2nd $n = 68$, 3rd $n = 52$, 4th $n = 59$) of which 148 were boys and 91 were girls. Overall 20 adults and 15 children were interviewed by telephone. In 11 cases, it was possible to interview both the child/children and the adult and who accompanied them.

School Group About a week before the performance, 85 pre-performance questionnaires were collected, and 89 post-performance questionnaires were collected a week after the performance. To allow for pairing without jeopardizing anonymity, students were asked to write a number read out by the teacher. This resulted in 76 paired questionnaires (2nd grade $n = 36$; 3rd grade $n = 40$; boys $n = 31$; girls $n = 45$). Teachers were asked to select verbal students of all levels of achievement for interviews. The students' level of achievement was not revealed to the interviewer. In total, 16 interviews were conducted with 32 children in the school group.

Data Analysis

Questionnaires Analysis of the open questionnaire items is demonstrated in Table 4. Items were analysed using an emerging theme approach. Initial categories were suggested by a team of researchers who were exposed to the data for the first time and later refined to fit the data. In one item (B), we sought the answers that were provided by the play. Item E in which respondents are asked what they would most want to know about robots elicited responses in the form of a question. This allowed us to categorize each response according to its epistemological level (following Peleg and Baram-Tsabari 2013).

An external researcher coded 20% of the responses to each open-ended question in order to obtain a measure of inter-rater reliability. Cohen's Kappa values were 0.90 to 0.99 suggesting excellent reliability, except for one item (item E, Table 4) which showed good reliability (Kappa = 0.65; benchmark values according to Altman 1991 in Gwet 2012).

Analysis of ordinal data was conducted using Mann-Whitney or Kruskal-Wallis tests as appropriate. Analysis of nominal data was conducted using a chi-square test.

Table 4 Questionnaire open-ended items and their analysis

	Item	Details of analysis
A	What do you think are the most important components of a robot?	Categorization into brain/computer, sensors, motor, hands/feet, face, other.
B	How do you think robots help people?	Categorization: 1) Types of help ('they entertain', 'they make life easier', 'they save lives', etc.). 2) Field of help ('in the household', 'in industry', 'in medicine', etc.). 3) Type of answer: hedonic ('they entertain people') or utilitarian ('they save lives') according to Diefenbach and Hassenzahl (2011).
C	Robots are a special kind of machine, why do you think robots are special?	Categorization: similarities ('robots are special because they talk') or differences ('because robots know many things we don't know') related to humans.
D	What would you most want to know about robots?	Each question was given an epistemological level (Peleg and Baram-Tsabari 2013): recognition (What does the robot have in its stomach?), understanding (How are robots made? How do they move?) and control (Will robots be able to build a time machine that we will show us what future robots will look like? Do robots feel pain like I do?).
E	What can children invent?	Categorization: 1) Emerging theme analysis which yielded six categories (games, imaginary machines, robots, ambiguous, children can invent anything, other). 2) Level of detail of response: general response ('a robot'), a response with little detail ('a robot lizard'), a response explaining the function of the invention ('a robot that mows your lawn') and a very detailed response ('a robot that can cut wood using specialized laser eyes').

Interviews Since we applied an existing theory to the context of museum theatre, we mostly adopted a top-down approach for analysis of the interviews with a priori codes arising from the theoretical framework and from the research questions (Gibson and Brown 2009). A coding tree was constructed with three main nodes relating to the contextual model, cognitive learning outcomes and the theatrical event (details of the coding book and coding tree are available in the supplementary materials).

To test for reliability, after the analysis of some 15 interviews by one researcher, the second researcher was trained by explaining the code tree and analysing one interview together. The second researcher was then asked to code a list of 60 statements from several interviews. The main sources of disagreement were located and codes were refined by reexamining the literature and by consultation with external researchers. After these corrections a list of 228 statements (corresponding to 20% of all quotations) was coded by an external researcher. Due to the large quantity of codes the inter-rater reliability for coding interview statements using the coding tree was calculated using Krippendorf's alpha macro for SPSS (Hayes and Krippendorff 2007). The resulting α value of 0.84 can be regarded as an excellent agreement (Krippendorff 2004).

Findings

The findings are presented according to the three goals of the study: (1) We describe the cognitive learning outcomes of the play. (2) We then focus on the viewing contexts through the theoretical framework of the contextual model. (3) Finally, we conclude with our findings of the theatrical experience through the lens of Eversmann's model.

Cognitive Learning Outcomes of the Play

In order to 'to put the museum in a stronger position to make claims about its efficacy as a learning institution' (Allen 2002, p. 262), we first investigate the cognitive learning outcomes as defined by the four learning goals set by the writers as described in the methods section.

A - **Every robot needs to have a motor, sensors and a 'brain'/computer**. When asked what the most important components of the robot are, just over half of the playgoers[1] mentioned at least one of these components, compared to only about a quarter of the non-viewers (Table 5, section A). Non-viewers mentioned each component at about the same rate of 10%. Viewers mentioned 'brain' and 'motor' the most (34 and 32%, respectively) and sensors the least (22%), probably since they were less familiar with the word. In the longer term, several weeks after the show, only two of the 47 children interviewed mentioned all three components, one mentioned two components and 6 mentioned one component only, namely the brain.

B - **Robots can help humans in a multitude of ways.** In the play, the protagonist imagines he/she becomes a robot that saves a cat from a cave and enters a volcano to save a village from destruction. This was done to show that robots can be beneficial in a multitude of ways. Viewers did not pick up this message, as evident from three closed items (Table 5, section B). Interview questions asking whether there are robots that can enter volcanoes or enter caves received a wide range of responses from 'robots do not exist' to 'yes, there are even robots that go to space'. However, most responses were negative, and in the affirmative ones, this information was apparently gleaned from other sources than the play. The children appeared to consider the story as unreal and thus dismissed the information intended to be encoded in it. This will be further addressed in the section on the personal context section (and in Table 7).

C - **Children can be inventive and design things.** One of the main reasons the protagonist in the play was chosen to be a child was to inspire children to use their imagination, be inventive and design objects (even though the robots built on stage were not functional). Two questions aimed to identify the effect of this goal (Table 5, section C), but no significant difference was found between the viewers and non-viewers.

In the interviews, children generally expressed positive feelings towards the protagonist's building of robots, but many were sceptical as to his/her success. Many thought that only engineers can build robots, that the robots the protagonist built were look-alikes and that the design process was flawed. Some children, however, expressed feelings of appreciation towards the protagonist for trying and some went on to say that they themselves had built such contraptions or wanted to try building inventions like those in the plot.

D - **Robots are not human—they need not look like people and they can't replace human love.** In three closed items, respondents were asked whether there are robots that help prepare homework, need to sleep and love people (Table 5, section D). The items elicited similar response patterns except for the item relating to love, in which non-viewers gave

[1] For the purpose of the overall cognitive learning outcomes, we merged the school and family groups. The school group's pre-play questionnaires were considered as non-viewers and the post-play questionnaires were considered as viewers (playgoers). To check the validity of this merge we compared the family's non-viewer questionnaires and the school pre-play questionnaire and found that they did not differ significantly.

Table 5 Intended learning goals and actual learning outcomes for (a) the entire sample and (b) the two physical contexts

			(a) Entire sample (school and family groups)			(b) Investigating the physical context					
						Family sample					
Intended Learning Goal	Item	Analysis	Non-Viewers (n=197)	Viewers (n=219)	Sig.	**Non-Viewers (n=112)**	**Viewers (n=130)**	Sig.	**Non-Visitors (n=57)**	**Visitors (n=184)**	Sig.
A - Each robot needs to have a motor, sensors and a 'brain'/computer	**What do you think are the most important components of a robot?**	Number of components mentioned that appear in the play	(n=197)	(n=219)		(n=112)	(n=130)		(n=57)	(n=184)	
		0	75%	48%	***[a] ††[c]	63%	31%	***[a] ††[c]	53%	43%	n.s.[a]
		1	22%	26%		31%	28%		30%	30%	
		2	3%	16%		5%	24%		11%	17%	
		3	1%	10%		1%	17%		7%	10%	
		Breakdown into the individual components	% (number)	% (number)		% (number)	% (number)		% (number)	% (number)	
		"a brain/thinking unit"	11% (20)	34% (72)	***[b] †[d]	13% (14)	43% (53)	***[b] ††[d]	22% (12)	31% (55)	n.s.[b]
		"sensors"	10% (19)	22% (49)	***[b] ††[d]	17% (19)	36% (47)	***[b] †[d]	21% (12)	29% (54)	n.s.[b]
		"motor"	10% (19)	33% (72)	***[b] †[d]	15% (17)	50% (65)	***[b] ††[d]	30% (17)	35% (65)	n.s.[b]
B - Robots can help humans in a multitude of ways	**Are there robots that ..**	Percentage of positive answers	% (number)	% (number)		% (number)	% (number)		% (number)	% (number)	
	can go into volcanoes?		23% (44)	30% (65)	n.s.[b]	24% (27)	22% (28)	n.s.[b]	34% (19)	20% (36)	*[b] †[d]
	can go places humans can't?		77% (149)	75% (159)	n.s.[b]	81% (91)	74% (94)	n.s.[b]	73% (41)	79% (144)	n.s.[b]
	look like snakes?		33% (63)	35% (75)	n.s.[b]	46% (51)	45% (57)	n.s.[b]	34% (19)	49% (89)	*[b] †[d]
	prepare food?		36% (71)	34% (72)	n.s.[b]	33% (37)	28% (36)	n.s.[b]	27% (15)	32% (58)	n.s.[b]
	can vacuum?		70% (136)	73% (155)	n.s.[b]	83% (93)	76% (97)	n.s.[b]	73% (41)	81% (148)	n.s.[b]
C - Children can be inventive and design things	**What things can children invent?**	Level of detail	(n=102)	(n=116)		(n=69)	(n=73)		(n=33)	(n=109)	
		short idea	53%	60%	n.s.[a]	39%	47%	n.s.[a]	46%	42%	n.s.[a]
		an idea with a description	28%	30%		32%	40%		36%	36%	
		an idea with an explanation	15%	10%		22%	14%		15%	18%	
		A full detailed explanation	4.9%	0%		7%	0%		3%	4%	
	Do you think it is easy or difficult to build a robot		(n=183)	(n=196)		(n=108)	(n=117)				
		very easy	6%	5%	n.s.[a]	4%	0%	n.s.[a]	4%	1%	n.s.[a]
		quite easy	8%	10%		7%	9%		2%	9%	
		quite difficult	28%	32%		32%	42%		44%	35%	
		very difficult	59%	53%		58%	50%		50%	55%	
D - Robots are not human	**Are there robots that ..**	Percentage of positive answers	% (number)	% (number)		% (number)	% (number)		% (number)	% (number)	
	help do homework?		20% (40)	22% (47)	n.s.[b]	13% (17)	17% (19)	n.s.[b]	11% (6)	17% (30)	n.s.[b]
	love people?		65% (125)	48% (102)	***[b] †[d]	64% (72)	41% (53)	***[b] †[d]	38% (21)	56% (103)	*[b] †[d]
	need to sleep?		26% (50)	24% (51)	n.s.[b]	25% (28)	8% (10)	***[b] †[d]	14% (8)	17% (30)	n.s.[b]
	Why are robots special machines	% of the respondents comparing robots to people who..	(n=56)	(n=58)		(n=41)	(n=42)		(n=17)	(n=66)	
		highlighted similarities	70%	55%	n.s.[a]	73%	62%	n.s.[b]	47%	73%	*[b] †[d]
		highlighted differences	30%	45%		27%	38%		53%	27%	

Table 5 (continued)

Other learning outcomes	What would you most like to know about robots?	Epistemological level of answer	(n=129)	(n=133)		(n=92)	(n=98)		(n=41)	(n=149)	
		recognition	33%	24%	n.s.[a]	30%	26%	n.s. [a]	42%	24%	* [a] †[c]
		understanding	65%	75%		67%	74%		59%	74%	
		control	2%	1%		2%	1%		0%	2%	

For the purposes of joining the school and family group to form the entire sample, the school group, the pre-play questionnaires were considered as non-viewers and the post-play questionnaires were considered as viewers. Since each question had a slightly different sample size (no response to the question on some questionnaires or irrelevant answers), the absolute number of responses is given for each item. Cells shaded in grey indicate a significant difference of at least $p < 0.05$. †—small effect size (*r* or *V* are 0.10 to 0.29), ††—medium effect size (*r* or *V* are 0.3 to 0.49), †††—large effect size (*r* or *V* are larger than 0.5). Benchmark values suggested by Field (2012) and the NSSE (2008)

n.s. not significant $*p < 0.05$, $**p < 0.01$, $***p < 0.001$

[a] Calculated by a Mann-Whitney for independent samples

[b] Calculated using a chi-square test

[c] Effect size calculated by $r = Z\sqrt{N}$

[d] Effect size was calculated using Cramer's *V*

significantly higher rates of positive responses (i.e. there are robots that can love—a wrong answer) than viewers. The following conversation between two 3rd grade boys from the interview data exemplifies the two points of view:

Student A: 'Of course robots love people, because people invented them'.

Student B: 'No! They don't have feelings!'

Another open item asked why robots are a special kind of machine. About a quarter of responders compared robots to humans. These answers were divided into two categories: those that highlighted similarities between humans and robots ('because robots can talk', 'because robots are humans made of steel') and those that highlighted differences between humans and robots ('because robots don't eat or drink', 'because robots can do things we can't'). Viewers gave more responses highlighting differences (45%) than non-viewers (30%). However, this result was not statistically significant. Asking children the same question in the interviews often led to a lively discussion in the school group where children were interviewed pairwise. This discussion revealed some of their preconceptions. Many claimed robots were different from machines since they have human traits, such as talking, walking and thinking. Other discussions revolved around robots moving whereas machines do not and that robots do not exist whereas machines do.

Table 6 Response pattern to three questionnaire items showing an interaction between the two physical factors—watching the play and visiting the exhibition

	Factor 1—watching the play	Viewers (n = 174)		Non-viewers (n = 65)		Statistical significance	Effect size Cramer's V[a]
Item	Factor 2—visiting the exhibition	Visitors (n = 139)	Non-visitors (n = 35)	Visitors (n = 43)	Non-visitors (n = 22)		
A	Are there robots that love people?[b] Percentage of positive replies	43%	33%	72%	41%	***	0.303 (medium)
B	Are there robots that need to sleep?[b] Percentage of positive replies	9%	4%	25%	24%	**	0.236 (small)
C	How do robots help people?[c] Percentage of respondents who provided an answer of 'by making life easier'[d]	26%	11%	15%	7%	*	0.185 (small)

$*p < 0.05$, $**p < 0.01$, $***p < 0.001$

[a] Benchmark values according to Field (2012)

[b] A yes or no question. Significance was calculated using a χ^2 test

[c] Open question. Significance in the reply pattern was calculated using a χ^2 test and indicates a significant difference in the number of respondents providing the answer detailed in the table

[d] Other categories of responses were 'by replacing humans', 'by doing dangerous jobs' or 'by doing things humans can't do'. Response pattern to these categories showed no significant difference between the four condition groups

It is no wonder that the children found it difficult to build a mental image of what a robot is, since robots stretch the traditional boundaries between the animate and the inanimate (Bernstein and Crowley 2008; Friedman et al. 2003; Melson et al. 2009). However, the item concerning love of people was explicitly mentioned in the play and was indeed taken up by some viewers.

In the interview, children were asked whether robots always looked like people. In ten of 31 interviews children mentioned one or more human features that they believed all robots have (such as arms, a head, a face). In seven interviews, children claimed that robots need not look like humans and that they knew this from a source other than the play (a parent's workplace, an afterschool activity on robots, etc.).

The Viewing Context

A more complex picture of the learning outcomes developed upon a breakdown of the sample into their viewing contexts based on the contextual model. This allows a glimpse of how arriving in the theatre in different contexts can affect the learning experience of viewers.

Physical Context Two aspects of the physical context affected the learning outcomes of visitors: interactions between the play and the concurrent robot-zoo exhibition and the appearance of different actors in the play. This section is based on data collected from the family group, since only families visiting the museum were exposed to these two different contexts.

Interactions between the play and the exhibition To test for interactions between the play and the exhibition the four condition groups were compared (Table 3). A very weak synergy was found in the learning outcomes between the play and the exhibition. One category of replies to an item asking how robots help people was 'by making their lives easier' (Table 6, item C). The rate of this answer was the lowest for the comparison group (non-viewers and non-visitors). It increased upon participating in one activity (the play or the exhibition) and peaked for children who participated in both. No such synergy was found for other categories (such as 'by doing things humans can't do').

With regard to anthropomorphic views of robots, a conflict appeared between the play and the exhibition. In an item asking whether robots that love people exist (Table 6, item A), the rate of affirmative responses (i.e. the incorrect response) was the highest for exhibition visitors and the lowest for viewers of the play. The rate for the naïve audience (comparison group) and for children who participated in both activities was about equal and intermediate to that of the viewers and the visitors. A similar response pattern was seen in an item asking whether robots that need to sleep exist (Table 6, item B). Apparently the exhibition fostered anthropomorphic views whereas the play discouraged them. This is supported by another item in which children were asked why robots are a special kind of machine, with exhibition visitors providing more anthropomorphic responses (robots look like humans) than non-visitors (Table 5, item D).

Several learning outcomes were specific to either viewers or visitors, with no interaction between the two factors. One such item asked the respondents to name the most important components in a robot. This was one of the explicit messages in the play, and it indeed carried over to the viewers with components mentioned in the play cited significantly more often among viewers than among non-viewers (Table 6, item A).

Despite the above evidence that the play and the exhibition had little synergistic effects on learning outcomes, in most interviews parents claimed that watching the play blended well into the museum experience and that it provided diversity to the museum experience. Parents felt that the play served as a good place to summarize and digest what was seen and learned in the exhibition and that it provided a moment of calm from the turmoil of the museum, while still being part of the learning environment.

Appearance of different actors in the play Since two actors (female and male) performed alternatively, we were able to assess whether a different actor (albeit the same script) might affect learning outcomes. No differences in most learning outcomes or level of enjoyment was found. One item stood out - there were significantly more responses mentioning 'brain' (as the control centre of the robot) as the most important components of a robot for the plays by the actor than those by the actress (55 and 35%, respectively, $p < 0.05$). Observations revealed that the two wrote the word 'brain' differently: the actor used the typical spelling while the actress wrote what she thought was the one used in school. In interviews several children said the actress made a spelling mistake. This minute visual difference seemed to affect the outcomes, while other differences in the acting styles seemed to have lesser effects.

Personal Context In the family group enjoyment of plays seemed to decrease with age (75% of the 1st graders claimed to like plays very much compared with only 44% of 4th graders; $p < 0.01$). Older children also provided significantly more answers relating to industry and security when asked how robots can help humans and to a greater extent wanted to know how robots are made. In the family group, girls more than boys, reported that they like watching plays in general (98 and 75%, respectively; $p < 0.001$) and that they enjoyed 'Robot and I' in particular (87% of girls enjoyed it very much compared with 69% of the boys; $p < 0.05$). Apart from this no other gender-related differences were found in the questionnaire items regarding knowledge, attitudes or interest. Also, no interaction between the gender of the performing actor and the gender of the viewer was found (boys who watched a performance with the actor and girls who watched a performance with the actress).

Falk and Storksdieck (2005) noted five influential factors to assess personal context: (1) visit motivation and expectations, (2) prior knowledge, (3) prior experiences, (4) prior interests and (5) choice and control. We looked for each in the interview data.

The visit motivation was mainly mentioned by the parents. In the interviews, the parents were asked why they chose to go to the play. Most parents (n = 7) claimed that they did so following a recommendation by the museum staff. In five cases parents chose to see the play since they wanted to enrich the visit experience and in three cases parents expressed a general liking of plays. In only one case did the parent say that the child asked to be taken to the play and in another the decision to go was made together. It seems that the children did not express much control over choosing whether to go to the play.

We found it difficult to decipher between prior knowledge, experiences and interests of the children and hence these three factors were merged into one category. When children were asked about the intended learning goals, they often also provided previous knowledge they tapped into to understand the play. Lacking this previous knowledge seemed to impede viewers' knowledge and understanding.

When asked in the interviews if they had learned something from the play, the children were divided. In eight interviews children claimed they had learned a lot or stated a specific idea they learned in the play. In six other interviews, children claimed they learned nothing new from the play, either because they already had a sound knowledge of robots and robotics or because they disliked robots. Parents were also divided in what they thought their children had learned. Some believed their children learned something from the play, whereas others thought that while the children enjoyed the play, they did not gain conceptual knowledge from it. A major issue that arose in the parents' self-reports was age suitability, with many parents thinking their children were too young to understand.

Table 7 Children's claimed knowledge compared with their concept of the protagonist's knowledge

Aspect (category)	Nature of children's beliefs	School group (out of 16 interviews)	Family group (out of 15 interviews)[a]	Sample reply
A—Does a robot snake or a robot that goes into volcanoes exist?	Positive	5	6	'I think there are such robots … but she made it up' (girl, school group, grade 3) 'I know it from the encyclopaedia of "how things work".' (boy, family group, age 9)
	Negative	8	4	'In fairy-tales there are' (boy, family group, age 9) 'If someone invents them, they'll be real.' (girl, school group, grade 3)
B—Does Ori/Yaeli know that a robot snake and a robot that goes into volcanoes exist?	He/she knows	1	2	'I think she knew … from television or from the animal robots [exhibition]' (boy, school group, grade 2)
	He/she made it up	11	7	'I think she made it up' (girl, school group, grade 3) 'There can't be such robots. Robots are made of electricity, but lava is a liquid, and if a liquid touched electricity it can all blow up.' (boy, school group, grade 3) 'If he likes school then he likes science. If he likes science then he would know it. But Ori doesn't go to school, so he doesn't know about the robots' (boy, family group, age 7.5)
C—Does Ori/Yaeli know how to build robots?	He/she knows	0	3	'[She built the robots] from her imagination … but it was right, you need everything she said' (boy, family group, age 4.5) 'She said it was from the science museum.' (boy, school group, grade 2)
	He/she made it up	7	5	'She's a girl in first grade how can she know' (girl, school group, grade 3)

The number shown is the number of interviews in which a positive or negative response was provided. Interviews in which the aspect was not discussed or those in which the response was neither positive not negative were omitted from the count

[a] Excluding interviews with parents

Children's prior experiences and preferences seemed to have a significant effect on their engagement (or disengagement) with the play, the protagonist and robotics. Children were also divided in their attitudes towards robots, with 6 children expressing favourable attitudes in the interviews and 7 expressing unfavourable ones. The children apparently had predetermined attitudes towards robotics before the play and the play did little to change them. These predispositions guided the children in engaging with the play. Several children said that they would or wouldn't like to be the protagonist's friends since they liked or disliked robots. One girl presented another perspective when she said: 'I don't like boys, I don't like boys' things and I don't like scary robots'. Indeed, most of the children expressing negative emotions towards robots were girls (5 girls, 2 boys) and most children expressing positive emotions to robots were boys (6 boys, 2 girls).

The Theatrical Experience

The theatrical experience opens a window for the learning process of viewers of a science museum theatre play, as seen from their perspective. We also elaborate on children's and parents' attitudes towards viewing the play and the play's design.

Cognitive Dimension The cognitive dimension, which 'covers the spectator's intellectual dealing with a performance' (Boerner et al. 2010, p. 174), was the most prominent in the interviews and reviewed here with regard to their meaning making of the play and recognition with characters.

Understanding of the meaning of the performance This was the most grounded category in our interviews, with children showing a sound understanding of the plot and the characters' motives and intentions. When asked about their first recollection of the play, children did not recite the scientific learning outcomes but rather focused on the plot. Children mainly mentioned the protagonist building robots to help his/her mother and little brother. A few children also mentioned the second part of the play when the protagonist pretended to be a robot and save the village. Memories were more vivid and complete in the school group, since these interviews were conducted in pairs. Often after one interviewee started recalling an episode from the play, the other interviewee, who at first claimed not to remember anything, joined in.

Children's perceived authenticity of the story interacted with their understanding of the plot and the science. Children often distrusted the protagonist's knowledge of building robots and his/her knowledge of robots (Table 7, aspect C). When asked if the protagonist's process of designing robots was correct, most children stated that it was not genuine and that real engineers' work is completely different although in the play the protagonist's planning is based on real robotic principles. In the second part of the play the protagonist mentions a robot snake and a robot that monitors volcanoes. When asked whether such robots exist, children were divided in their answers (Table 7, aspect A). When the children were provided with the fact that such robots really exist and then asked where the protagonist got the idea of these robots, virtually all children said that the protagonist made them up (Table 7, aspect B).

The writers chose to have a child present the idea that there is a wide variety of uses for robots with the hope that the children would be more willing to relate and engage with these ideas. However, having a child character voice this information apparently made it less credible. Interestingly this did not seem to fundamentally affect the children's learning outcomes as was seen by the divided replies of whether such

Table 8 Types of confusion between the fictional world on stage and the real world that emerged in the interviews

Type of confusion	Occurrences		Example
Voice-over	4	Children found it difficult to imagine a voice-over character as a real character	When interviewer asked about the mother, the children argued that 'the one in the loudspeaker, there wasn't really a mother. There was only one person in the play.'
Actor-character	7	Children found it difficult to distinguish between the actor and the character he/she played	Interviewer: 'Would you like to be Yaeli's friend if she was real?' Boy: 'But she already is real'
			Reference to Yaeli as 'the woman' instead of a child: 'The woman built robots for her mother.'
			Interviewer: 'Where do you think Yaeli learned how to build robots.' Boy: 'First of all it's a play, so you do a lot of rehearsals.'
Physical-fictional world	2	Children confused the off-stage physical world with the fictional world	A girl showed her grandmother the space underneath the stage as the cave in which the robot snake enters to save a cat (although the actor does not refer to this space in the play).

These statements occurred spontaneously in response to interview questions on other topics robots exist. The learning outcomes seemed to be more affected by the child's previous knowledge than by the extent to which the source of information was perceived as credible.

In several interviews children made statements that showed confusion between the real world and the fictional world. These included (Table 8) difficulty imagining a real character that is not seen and only heard in a recording and difficulty distinguishing between the child character and the adult actor.

Recognition The writers wanted the protagonist to be a child approximately the audience's age and chose a situation which was intended to be familiar to them (having an annoying little brother that steals mother's attention). Children often reported recognition with these familiar circumstances (61 instances), for example that the baby reminded them of their siblings, that the mother reminded them of their own mother and that they also sometimes try to build things. This category was highly linked to recognition with a character (understanding the character's motives) with 17 co-occurrences (c-value of 0.18). In a constructive sense recognizing the circumstance led to a recognition with the character's actions and to a favourable attitude to designing and building robots. For example:

> Girl: 'I would also do what Yaeli did [build robots] to find her brother's pacifier because I really hate looking for my brother's pacifier.' (girl, school group, grade 3)

The flip side is that if the viewers do not recognize the circumstance, they might find it harder to empathize and understand the character's actions. For example a boy who likes school, couldn't recognize Ori's desire to stay home. This led him not to want to build robots like Ori.

> Interviewer: 'Would you invent robots if you were Ori?'
> Boy: 'No, I would just quickly help and go to school… Because I like school.'
> (boy, family group, age 7.5)

In summary, viewers understood the play well, yet despite this, they mistrusted the protagonist's knowledge of robotics. This process appeared to impede their acceptance of some of the concepts thus making prior knowledge the main source of knowledge on robotics. While the viewers often recognized familiar circumstances that did not always allow them to identify with the protagonist's actions, sometimes the contrary was true.

Perceptual Dimension This dimension concerns 'the perception per se' (Eversmann 2004, p. 151). In contrast to studies with adults (Boerner et al. 2010; Eversmann 2004), who could often recall their perception in the event itself, we found that our interviewees provided very little reference to perceptions (only two children mentioned something related to perception). Limited evidence came from parents mentioning in their interviews that their child was 'hypnotized' or 'fully engaged' (in six out of 20 parents' interviews) and that their child 'laughed in the right places' or 'laughed so hard they must have heard it in the entire theatre' (four interviews). From our self-reported data it is difficult to know if and how the perception dimension affected the learning process.

Emotional Dimension Children only related to their feelings connected with the fictional content, not to the actual theatre-going experience. These feelings can be classified into two kinds (Boerner et al. 2010): the spectator's presumed feelings towards the characters if encountering them in real life ('I would like to be Yaeli's friend if she was in my school') and having the same feelings the characters on stage were believed to have ('I was excited as she when building the robots'). No references were found for the latter, i.e. children never expressed excitement about building robots when the protagonist built them. There were, however, many mentions of feelings towards the character, both positive and negative. Fourteen children stated that they would like to be friends with the protagonist because he/she was imaginative and they could build robots together (n = 11), he/she was funny or intelligent (n = 6) and because they themselves like robots. Eleven children were hesitant to befriend the protagonist because of something in his/her attributes (n = 5), because they themselves disliked robots (n = 5) or because the protagonist did not know how to build robots (n = 1). From the interviews it seems that the emotional link to the play was through the protagonist. This link stemmed from personal preferences and did not elicit direct excitement about the process of building robots.

Communicative Dimension The communicative dimension relates to the interaction between performance and spectators. This has three subdivisions: 'communication between spectator and actor', 'communication between audience and other aspects' (such as with the writers) and 'feeling of collectivity' (feelings of being part of a group with the other viewers). Children in the school group related to the first, since the actress allowed them to asked questions at the end. Several (n = 12) children remembered this and even claimed this is the part they learned most from. To our surprise, the children did not relate to the feeling of collectivity, not even in the school group when watching the play with their school friends. From a socio-cultural perspective the lack of feeling of collectivity is surprising. It is possible that the forward-seating configuration of the theatre forms stronger connection between actor and spectator than between the spectators.

Summary and Discussion

This study investigated learning in the informal environment of museum theatre. Learning was seen both as a cognitive product as well as an experiential process. The latter was investigated using a model of the theatrical experience. The cognitive learning outcomes were investigated in light of different contexts as laid down by the contextual model.

The first aim of our exploratory study was to identify cognitive learning outcomes of watching the play, the content of which was examined against the intended learning goals of the writers. The idea that every robot needs to have a motor, sensors and a 'brain' unit, was mentioned several times by the protagonist and was well accepted by the entire sample. Another well accepted intended learning goal was that robots do not love like humans (subdivision of 'robots are not human'). This was also presented explicitly as a conclusive statement at the end of the play.

The other intended learning goals, namely that robots can help humans in a multitude of ways, that children can be inventive and that robots need not look like humans, were all encoded in the play in an implicit manner. To show that robots need not look like humans, the protagonist constructed robots with no human like features. To show that children can be inventive, the protagonist was a highly imaginative character. And finally to convey the idea that robots can help humans in a multitude of ways, the protagonist turned into a number of robots with different functions. None of these statements was well accepted by viewers.

Based on this and two previous studies (Peleg and Baram-Tsabari 2011, 2016), evidence is building that children may not assimilate implicit messages presented in plays well. This presents a problem for designing educational plays, which are expected by society, the museum management, parents and perhaps children to teach canonical science. Yet on the other hand a play that is too explicit and didactic might jeopardize its chances of success (Carpineti et al. 2011; Jackson 1980)—who wants to go to a play to hear a lesson on stage? This dilemma is not unique to museum theatre and is of general concern in the design of museum exhibits (Allen 2004).

One potential solution to this dilemma is to expand the definition of learning to include not only cognitive learning outcomes (Rennie et al. 2003; Rennie and Johnston 2004): If a museum is measured only by its cognitive learning outcomes it is bound to be inferior to the classroom. But the museum offers experiences the classroom cannot. In this study, we expanded our definition of learning to include the process of meaning making and interacting with the play by means of investigating the theatrical experience. Naturally, choosing other theoretical perspectives to guide our search for learning outcomes may have resulted in a slightly different array of outcomes. These additional aspects of learning in museum theatre may lend themselves to study using theories of gender, motivation, identity, etc. However, it is important to keep in mind the perspectives of the intended audiences of parents, managers, politicians and policy makers, who may hold a cognitive definition for learning (Allen 2004; Brody et al. 2007). Would the parents feel their child learned something even if he/she cannot remember the main components of a robot after watching the play?

Investigating how learning contexts interact with learning outcomes helped situate the theatre viewing experience within the ensemble of the whole museum visit. We were surprised at the lack of synergy between the play and the exhibition, since the play was designed to accompany the exhibition, and its educational messages and the plot were shaped and approved by the museum's educational staff. In some learning goals a conflict arose between the two environments and in the others each had an independent learning outcome. Simply adding activities didn't necessarily have a cumulative effect and might have even caused some confusion for the visiting children.

The intended learning goal that robots are not human, is not part of a consensus in robotics education. There is an ongoing debate whether the anthropomorphic learning outcome is desirable. Anthropomorphic robots can aid learning by human-robot interaction (Verner et al. 2012) and using anthropomorphic explanations of robot behaviour can in fact help children understand and design robots (Levy and Mioduser 2007). However, anthropomorphic thinking on robotics can lead to a misunderstanding of the complexity of robots, and anthropomorphic formulations have generally been discouraged in science education (Tamir and Zohar 1991). This debate might have led to the ambiguity between the two environments.

An important aspect of the personal context was that in the family group girls claimed to have enjoyed 'Robot and I' and to enjoy theatre in general more than boys. Also, younger children expressed positive emotions more often than older ones. This is congruent with studies showing that girls and younger children prefer narrative educational television programs (Calvert and Kotler 2003 in Klein 2005), that girls outperform boys when learning science from a television series (Rockman et al. 1996), that girls prefer learning science through role play and drama more than boys (Klepaker et al. 2007) and that generally there is a female bias in young people's (aged 14–30) theatre attendance (TSP 2012). Given girls' preference for theatre, science theatre could create an advantageous entry point to the world of science and technology. However, despite this preference we did not find a gender difference on the knowledge questionnaire and girls expressed more negative attitudes towards robots (with one girl even explicitly claiming they were 'boys' things'). Perhaps prior knowledge and experience played a greater role than engagement in this play. Alternatively engagement with the play and a focus on the narrative and the plot might even interfere with cognitive learning

(Fisch 2000). Contrary to our expectation the picture did not change in performances where the protagonist was female. These findings raise interesting questions for future research: When and why does girls' preference to theatre and drama develop? How can this preference be tapped to provide girls with an advantageous entry point? Is there a correlation (be it positive or negative) between engagement with the plot and cognitive learning?

These questions and others regarding the learning process may be approached by investigating the theatrical experience which mediates learning during the play. For example, within the educational framework a science play seeks 'integration' of knowledge into the child's pre-existing world knowledge (rather than 'compartmentalization'). In the play, despite (or perhaps because) the protagonist is a child and the high levels of recognition with both the protagonist as well as with familiar circumstances, viewers mostly did not believe the performers really knew about robots and their construction. This in turn seemed to hinder integration of the intended learning outcomes. In a previous study this disbelief was suspended because the young protagonists obtained their knowledge from a book and from an adult teacher (Peleg and Baram-Tsabari 2011). This finding is compelling and should be taken into account in the design of plays and exhibits that rely on narrative and on fictional characters.

Some children also found it difficult to distinguish between the fictional and the real world, in particular imagining voice-over characters that were not seen. This is explained in Klein's model of aesthetic processing: 'One of the biggest, ongoing myths about children's minds is that they have vast imaginations whereby they "fill in" missing imagery on stage' (Klein 2005, p. 46). Klein reports that even fifth-graders ignored off-stage characters and dramatic actions discussed only in dialogue. Klein concludes that 'child audiences are "concrete" (literal) processors who focus on seeing the explicit visual images and hearing the explicit verbal dialogue presented to them' (p. 46). This too might clarify a point made earlier that the viewers of the play were better at understanding the explicit learning outcomes compared to the implicit ones.

Viewers of the play seemed to recognize familiar situations. In that sense the choice of protagonist and story was appropriate. This recognition allowed the children to understand the protagonist's intentions and motives which at best could nurture positive attitudes towards building robots. But if these intentions contradicted the child's beliefs they could cause the opposite effect. From our findings the children's emotional link to the play was through the protagonist. However, this link was limited as no viewers claimed to have felt the excitement the protagonist felt on stage. The links between recognition, emotional links, the protagonist and the story should be investigated in other plays to facilitate the design of future plays.

Actor-spectator interactions were more significant for the viewers than spectator-spectator interactions. In a way if mediation in exhibits is mostly led by peers or parents, in the theatre this mediation is almost solely the role of the actor. This highlights the importance of choice of characters (and actors) and is another direction for future research.

Limitations

One limitation of this study was that the data were collected differently from the two samples. The family viewers filled in the questionnaire in the auditorium with their parents, the family non-viewers were given the questionnaire in resting areas and the school group filled in the questionnaire in the classroom. Likewise the interviews were conducted by phone with family viewers and face to face in the school group and at different times due to logistical reasons set by the school. While a limitation, these differences also present an advantage with regard to ecological validity, since each group was presented with the questionnaire or interviewed in a setting corresponding to its authentic socio-cultural context.

Designs of pre- and post-questionnaires often provide a partial picture in informal learning environments (Allen 2002). We complemented these questionnaires with interview data. Future studies might develop new tools to investigate reactions during the play and interactions after it. Reactions could be collected using smart devices that are moved during the play to show excitement (IDL 2014). Interactions after the play could be collected and analysed using tools developed for studying family conversations in museums (see Allen 2002; Ellenbogen et al. 2004). We also suggest that questionnaires incorporate more items concerning prior knowledge and experience, such as testing for theatrical literacy.

Conclusion

The goal setting us out on this journey was to explore the characteristics of learning science in the distinct informal learning environment of a science museum theatre play. We defined the learning environment as one that is characterized by a fictional narrative that engages the imagination thus transporting the audience to a different time and place. Indeed, we found that the audience was engaged in the plot, the characters' motives and intentions. This, however, could both promote or hinder cognitive learning. When messages were encoded explicitly and clearly into the plot, they were decoded as intended by the audience. When messages were encoded implicitly into the story due to aesthetic considerations, the decoding was much related to the child's attitudes or recognition with the character.

This exploratory study showed the viability of learning in one museum science theatre play. It also showed how the learning is mediated by other museum contexts (such as concurrent exhibitions), the personal context and how the narrative is portrayed (recognition with protagonists; portrayed source of knowledge). Some important questions were raised for future studies, such as a deeper analysis of the mediation of learning by the theatrical experience, and tools and frameworks were provided for such investigations. The study extends the empirical knowledge and theoretical thinking on museum theatre to better support claims of its virtues and responds to its criticism of not being sufficiently educational or sufficiently artistic.

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