

# MULTIMODAL ROBOTS AS EDUCATIONAL TOOLS IN PRIMARY AND LOWER SECONDARY EDUCATION

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## ABSTRACT

Multimodal humanoid robots have been used as educational tools in primary and lower secondary schools. The pupils involved were between 11 and 16 years old. The learning goals included: programming, language learning, ethics, technology and mathematics, e.g. practised by 7th grade pupils who programmed the robots and made the robots recite poems about the future. We conducted workshops for the teachers in didactical planning and programming of the robots. In the most successful settings, the pupils worked with academic objectives beyond programming and robotics. Through examples, we highlighted the potentials and the shortcomings in multimodal-robot-supported learning.

## KEYWORDS

HCI, Human Robot Interaction, Design Education, Robots, Multimodal interfaces.

## 1. INTRODUCTION

In this article, we describe how humanoid NAO robots can be used as an educational tool in primary and lower secondary schools in Denmark. A NAO robot is a multimodal interface which uses touch, speech, gestures and eye gaze for interaction (Aldebaran Robotics, 2015). It is assumed that multimodal interfaces support more flexible, efficient and expressive means of interaction that are more akin to humans' experiences in the physical world (Sharp, 2007). And this is supposed to provide a richer and more complex user experience (Sharp, 2007). The paper contributes with an indicative example of how to use this technology in teaching and a summary of its educational multimodal properties. Multimodal interfaces have been used in primary and secondary education for many years in the form of LEGO Mindstorm, where children build and program mobile robots. The LEGO Mindstorm concept was inspired by Papert's (1993) ideas on creative and innovative learning (Resnick, 2009). The LEGO robots often look like futuristic vehicles. In contrast, the NAO robot has already been built and looks like a human being with arms, legs, body, and head. This provides a totally different approach. When you see the robot for the first time, you expect it to have some kind of humanlike behaviour (Kahn, 2007). As an educational tool, it provides the children with the possibility of exploring the design of multimodal human-robot communication. We give the schoolchildren in the project the possibility to design physical humanlike gestures and speech. We also prepare the pupils for a future, where robots might have prominent roles as social and assistive tools e.g. for people with disabilities. This provides a new and different perspective that has not been studied before in schools with normally functioning children. Maybe a multimodal humanoid robot motivates for learning and collaboration in a different way. Perhaps it gives rise to ethical discussions about robots' roles in society, in the future.

While working with the robots, the pupils receive initial insight and skills in the relationship between digital design, translation, symbolic coding and diagramming on the one hand and physical expression and communication on the other hand. According to Resnick (2009) digital fluency and literacy is an important learning goal in schools. The children should be able to produce interactive behaviour and not only react and consume others' interactive designs. This will provide a deeper understanding of the digital world. Blikstein (2013) even believe that digital fluency can have a democratizing effect because children are going to explore a technology that was previously controlled by experts only.

Children between 11 and 16 years of age used the robots in the classroom. There were about 24 children in a normal class setting and they shared 3 NAO robots. The teachers were initially on a two-day intensive introductory course in the technology and ICT-based educational design. The teachers then conducted experimental teaching for about eight to twenty hours.

The research question is: How can the multimodal NAO robots enrich children's learning? The methodical approach is qualitative, and in order to answer the research questions we collected lesson plans, evaluations, observations and in-situ interviews from the workshops and the classrooms. These empirical data are the basis for the examples and discussions in this article. The research methodology is based on design-based research, which is a research method suitable for studies of how technology and instructional design can support learning in the classroom (Majgaard, 2011).

The article is organised as follows: First, an introduction of robot technology in an educational context. Second, a theoretical section on how constructionism constitutes a theoretical basis for using robots in the classroom. Subsequently, we introduce the setting for the experiments and describe illustrative examples. These are related to the theory. At the end of each example there is a selection of the teachers' evaluations.

## 2. THE MULTIMODAL NAO ROBOT AS AN EDUCATIONAL TOOL

The NAO robot is a 58 cm tall humanoid developed by Aldebaran Robotics (2015), see figure 1(a) below. The NAO robot perceives the world through sensors, such as microphone, camera and tactile pressure sensors. And it communicates with the outside world by means of effectors, such as the motion of arms and legs through electric motors, sound and LED lights. The robot is programmed by a graphical block programming language, Choregraphe which is relatively easy to master for the novice, see figure 1(b).

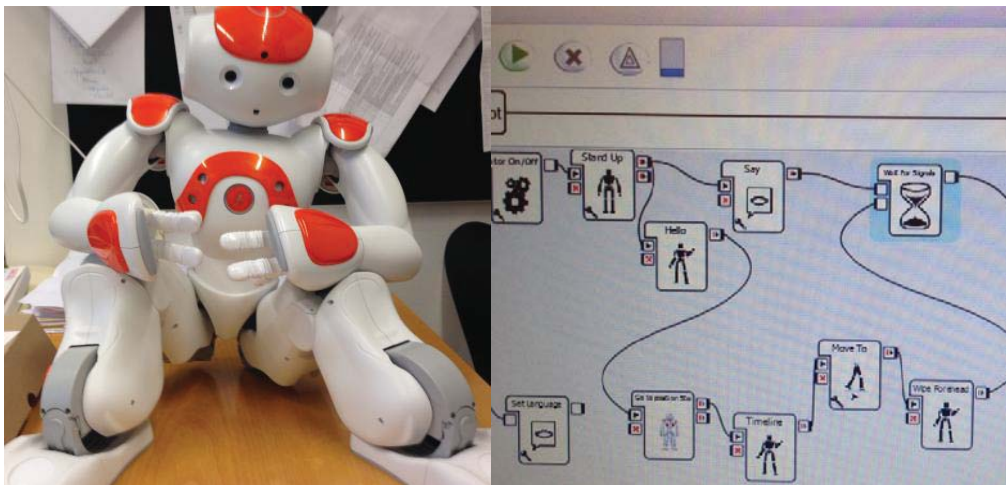


Figure 1. (a) A NAO robot; (b) Choregraphe programming environment

The robot is designed for use in education and research contexts and is currently used mainly in technical higher education and research environments. Pupils and research groups have, for example, developed interactive soccer-player behaviour into the NAO robots and enrolled them in a special RoboCup (2014). It is popular in the research field of human-robot interaction (HRI). The main goal of HRI is to enable robots to successfully interact with humans as they increasingly make their way into functional roles in everyday human environments such as homes, schools, and hospitals.

Other robotic concepts such as LEGO Mindstorm (2014) have been used in primary and lower secondary education where the pupils construct and program robots. Educational goals are related to innovation, experimentation, construction, electronics and programming.

Others have been using robots for language learning. Tanaka et al (2011) has been exploring different types of robots for foreign language learning. Latest she explored the use of a child-operated telepresence robot for the purpose of remote education. The robot was a medium for video conferencing between the pupils and a native English-speaking teacher in a remote destination (Tanaka et al, 2011).

Han (2005; 2009) has also been exploring home robots and robots as a teaching assistant in the field of language learning. In the case of the home robot Han explored the children's learning interests, concentration and academic achievements (Han, 2009). The robot delivered the content which was English dialogue for 6th graders. The results showed that the children were concentrated for a longer period of time and that the academic achievements and interest were higher using the home robot compared to web-based instruction and books with an audio tape. In the case of using robots as a teaching assistant in the classroom while learning English Han found that the children liked to relate to the robot.

Educational humanoid robots have been used as therapeutic tools for children with autism (Dautenhahn, 2007; Kozima, 2007). A popular example is tele-operated Keepon (Kozima, 2007) which was also used therapeutically for children with autism. The children were taught basic social skills such as eye contact and so-called joint attention. Social robots can motivate by creating new relationships and offer the children new social roles (Bertel, 2013). Kanda et al (2014) explored how robots can form long-term relationships with pupils. They developed the robot's behaviour so that it could recognise children, and the robot confided its personal matters to children who interacted a lot with the robot.

Humanoids have also been used as instructors for teaching, for example as a fitness instructor in a school setting, but the robot has a lot of motoric and interactive shortcomings (Nonaka, 2014). Our view is the opposite. We want the robot to become a partner – i.e. more than a mere object.. The children instruct the robot and evaluate the consequences.

### **3. LEARNING APPROACH - CONSTRUCTIONISM**

How can pupils' learning abilities be stimulated by multimodal physically interactive educational tools such as NAO robots? To investigate this further, we looked back at the history of Papert's (1993) concept of constructionism. Papert was one of the first to combine physical interactive educational tools and learning theory. His thoughts built on Piaget's concepts of constructing cognitive schemes, based on the individual's interaction with the environment. According to Piaget, the learner constantly adapts his knowledge to new experiences. Papert believes that learning and physical interaction are linked, e.g. a child learns about construction while building a tower.

In Papert's perspective, learning takes place when developing physical or virtual productions, for example construction of a robot's behaviour. Papert further highlights the easy accessible programming languages as so-called "object to think with", where you get immediate feedback. Papert also emphasised that learning took place by solving problems and by developing an experimental approach to design processes (Papert, 1993).

### **4. RESEARCH METHOD AND THE DIDACTIC DESIGN**

In this project, we use the previously mentioned design-based research, which is suitable for development of didactic design supported by technology (Majgaard, 2011; Van den Akker, 2006).

Structurally, the research process was divided into three phases: (1) Two-day workshop for teachers. The theme was hands-on technology activities during which two children from each class participated. Additionally, they developed didactical plans. (2) Teaching in the class ranging from for eight to twenty lessons and they had access to three NAO robots in that period. In some of the lessons the researchers participated as observers. (3) Teachers completed a questionnaire to evaluate the teaching.

Three schools attended each round of the workshop – so approximately nine school classes used the NAO robots. Lesson plans and evaluations can be seen in Danish on the project's Wikipedia page. The teachers also had access to each other's lesson plans and evaluations.

The questions asked in the written evaluations were part of the following categories: Educational goals; examples of activities; potentials; drawbacks; recommendations to other teachers, and achieved learning.

## 5. FINDINGS

The following section describes experiences from the workshops and an illustrative example from the teaching. Text bits in italics are quotes from the teachers' didactical plans.

### 5.1 Findings from the Workshops

On the first day of the workshop one or two teachers from each school participated in the event, each accompanied by approximately two pupils. This resulted in a few technical super users from each school. In addition, teachers could see how the pupils understood the technology, which they implicitly could use in their educational planning. The second day of the workshop had a didactic approach, and the teachers were presented with a didactic planning model. The model contained items on learning goals, activities, outcome, and organisation.

In their didactical plans, they defined goals such as: *"Foreign language - English: students talking in/using complete sentences. Focus on spoken English. Body language used as support for meaning and if you can't remember the word in English."* As an activity, they planned on working with "tongue twisters" e.g. she sells sea shells. The robot should recite the tongue twister and use supportive body language. In mathematics, they defined goals as: *"Mathematics: focus on oral mathematics and programming"*. And they defined ethical learning objectives as well: *"Consider various ethical issues related to the use of robots in everyday life."* Learning in basic electronics: *"Fundamental understanding of circuits, components and programming."*

At the workshops, there was a tendency for teachers to initially formulate activities, and then articulate the learning goals. It might be a way for teachers to reflect on what the objectives of the activity are, and whether they are aligned with the overall curriculum.

### 5.2 An Overview and an Illustrative Example from the Classroom

A lot of different academic subjects and concepts were explored by the schools. Most of the teaching was multidisciplinary and combined disciplines such as programming and robotics in combination with English or Danish language teaching. The figure below summarises the subjects explored in the project.

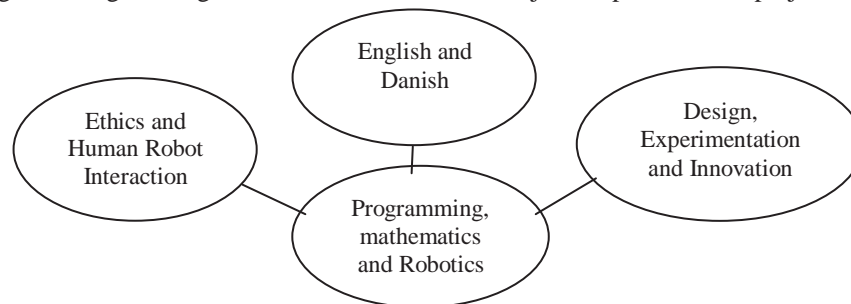


Figure 2. Overview of the academic subjects and concepts explored by schools

In programming, mathematics, and robotics they developed programming skills and got an initial understanding of sensors and effectors. In Danish, the pupils for example developed poems and robotic presentations. In foreign language learning of English, the pupils for example developed dialogues between the robot and users or robotic presentation of tongue twisters. The pupils also discussed ethical dilemmas such as the robot's role in everyday life in the future. Additionally, some of the pupils conducted real-life experiments in which they tested the robot in an everyday context such as how customers in the local grocery store experienced a talking robot, the robot as a fitness trainer or a dancer.

In the following, we introduce an example from a 7th grade school class, where 24 pupils worked for five weeks, two-four hours per week, with the NAO robot. The robot classes were run by two teachers. One teacher taught the pupils science and the other Danish. The first part of the process was carried out solely by the science teacher and provided basic knowledge and skills on how to program the NAO robot. The second

part of the course was based on the first part. It was multidisciplinary and combined technology and Danish. The course ended with a presentation, where the robots recited and analysed poems written by pupils under the theme "future".

In the introductory part, a number of technical tasks in programming Choregraphe were carried out. They would get the robot to stand, dance, say self-chosen words in simulation mode, etc. Then they moved their applications to the physical robot and carried out the same tasks again, now in the physical world. Then they carried out activities, where the robot went into the adjoining rooms, avoided obstacles and turned its engines off, when it had carried out its activities. They worked with the robot's opportunities for physical animation using tactile programming, speech, and image recognition.

In the second part of the course, the activities circled around creating, analysing and presenting poems. The pupils worked in groups of four and each group implemented three types of presentations using the robot: (1) presentations of homemade poems which referred to a specific photo or picture, (2) self-selected poems which referred to specific pictures or photos, (3) analyses of their selected poems, and (4) analyses of their homemade poems. Technically, the robot walked towards a picture and pointed to it whenever it fitted into the presentation. During the entire course, two technically-minded pupils (who had also participated in the workshop) had a special responsibility for the robots. Other pupils had a responsibility for the computers, cables and so on.

In the following we discuss the illustrative example:

First: Cyclic repetition and learning depth. In a subsequent interview the Danish teacher emphasised that the pupils dived into the poems a second time after writing them, and they got the robot to present the poems in accordance with their ideas. They heard their own and others' poems several times. As they encoded the poem into the robot, they adjusted and expanded the poem. The teacher describes it as follows: "*they got more deeply into the subject matter*". In Papert's terminology, the robot was "an object to think with", when programming behaviour into the robot, the pupils saw how the robot responded. They then adjusted and refined the robot's behaviour.

Second: Orchestration of robot motion and time. Along with the encoding of the poem into the robot, they coupled physical movements. They took an active stance on how the robot should recite the poem, and the poem's content. Some had the robot sit while presenting and others experimented more actively with movements and gestures to support the recitation of the poem.

Third: Academic requirements led to synergy between technological and Danish academic immersion. After learning the most basic commands, they got an assignment which triggered their creativity and enthusiasm. There was established an academic and creative playing field in terms of the requirements for the final presentation. The clear requirements and objectives of the assignment gave the children a playing field where they could unfold. Through observation, we learned that the children used many facets of Choregraphe e.g. the digital animation.

In some schools, we observed that the children after having learned the basic commands – got an open assignment e.g. "*make an interesting experiment*" which they either completed quickly, got stuck in, or gave up on. Articulated goals and requirements, beyond getting to know the technology as in the example above, helped the children to unfold themselves academically and creatively.

## **6. HIGHLIGHTS FROM THE TEACHERS' EVALUATIONS OF THE NAO ROBOT**

The following section presents quotes from teachers' evaluations of their teaching with NAO robots. Text bits in italics are quotes from the teachers' responses.

### **6.1 Motivation, Experimentation and "an Object to Think with"**

The teachers were asked in a survey to articulate what made the NAO technology special in a school setting. They thought the robot itself was motivating in the beginning of the teaching process. "*The robots are in themselves very motivating for learning. They engage some of the children, who may not always be "very" concerned about school work. The trick is to find tasks that challenge the children to search out "academic" knowledge.*"

The teachers highlighted the robot's opportunities to support children's active experiments, as it provided immediate feedback. *"It gives the opportunity to experiment. But some children experienced that they were more primitive than they had imagined ..."; "The robot's communication in spoken English was super."; "... The children were very motivated to use the robot's potential in terms of movement, speech, voice, recognition, etc.."* The robot responded immediately according to how it was programmed, which was not always the same as the children's ideas. This is comparable to Papert's description of "an object to think with", as this is one of the strengths of constructionist learning.

The teachers also expressed, what they thought worked well in their teaching. They highlighted that pupils quickly became self-propelled and that they had a good professional dialogue in the classroom, *"The pupils were quickly self-propelled"*. There were good academic discussions amongst the pupils and between teachers and pupils. Other colleagues and pupils at the school were curious. A teacher expressed the following: *"It was a different way of teaching: learning rather than teaching."* This ability to be self-propelled may also be a result of pupils' interaction with the robot, in the development of the robot's behaviour, e.g. an aspect of constructionism's idea of experimentation, problem solving, and "an object to think with".

## 6.2 Danish, English, Ethics and Programming as Academic Themes

The teachers also drew attention to the positive link between Danish or English and the programming of NAO robot behaviour, including body language. One of the teachers wrote: *"The pupils' programming of the English tongue twisters worked really well. And they had to make the body language suited to what the NAO was talking about."*

In addition, the NAO robot puts focus on ethical dilemmas and real-life experiments with the robots. A teacher describes it like this: *"The ethical dilemmas worked really well, and the pupils felt that the discussions were interesting, and we saw a high degree of reflection regarding robots' influence on our future society. A group brought NAO to the local grocery store to see how other people would react to the presence of a robot, and if it was possible to get a dialogue going between the robot and the customers in the store. This group kept the motivation to work through the entire period and wanted to continue working with robots that interact with other people."*

Moreover, teachers described what they thought the children had learned. They featured programming and robotics skills: *"They have obviously learned to program." "The pupils have gained a greater understanding of robots functioning and applications. They related this to future dilemmas we will face as the technology gets better."*

Moreover, they highlighted the Danish and English academic skills with an emerging understanding of the supporting body language while presenting: *"I think the Danish technical terms and concepts rooted themselves better with the pupils. The pupils were very aware of the supporting use of body language." "English: Exercises about responding in complete sentences worked fine, but not as convincing as the supporting body language"*.

A drawback in Danish was the robots' pronunciation. The pupils worked around this by spelling the words, so they fitted the Danish pronunciation. But then the spelling was not correct according to the Danish dictionary.

## 6.3 The Teachers' Recommendations: Clear Learning Objectives which go Beyond Getting to Know the Robot

Below is a selection of the teachers' recommendations. They emphasised in particular clear teaching objectives in addition to getting to know the robots. Moreover, they mentioned some technical problems, and the fact that the teacher must be familiar with the programming of the robot. A teacher explained it like this: *"Make sure to make the topic about more than robots."; "It is important that the teacher is familiar with the programming of robots. I think the hardest part was getting the robots to connect to the network. There were some network problems."*

To begin with, the NAO robot functioned more easily among older pupils. A teacher described it like this: *"The time aspect plays an obvious role. There was a long start-up, especially in the 4th and 5th grades. But the motivation makes the hours after the start-up super effective - compared to the outcome. (I conducted a*

*small course with the 7th grade in IT electives where start-up clearly went much faster, and we quickly came to the important stuff).*" Another teacher wrote: *"We have worked with the NAO in the 9th-10th grades, and our use of community-related topics and ethics made the project exciting and educational for all pupils."*

## 7. SUMMARY

In the table below we summarise the findings based on observations and the teachers' feedback. The findings are divided into: Ways to learn; Interaction; Practical issues; Educational settings and didactics.

Table 1. Summary of multimodal properties found in the NAO robot as an educational tool.

<p><b>Ways to learn:</b></p> <ul style="list-style-type: none"> <li>➤ <i>"An object to think with".</i> The robot provides immediate feedback to user during the development process and then becomes "an object two think with" (Papert, 1993).</li> <li>➤ <i>Active experimentation and problem-solving.</i> The robot is suitable for active experimentation and problem solving, as the robot provides immediate feedback (Papert, 1993).</li> <li>➤ <i>Self-propelled.</i> The children quickly became self-propelled in programming of robots.</li> <li>➤ <i>Cyclic repetition and learning depth.</i> The children processed the subject matter in several rounds, which gave rise to a greater depth of learning. For example, the children adjusted their poems while coding it into the robot.</li> </ul> <p><b>Interaction:</b></p> <ul style="list-style-type: none"> <li>➤ <i>Body language and robotic gestures.</i> The robot is suitable to support interaction using body language.</li> <li>➤ <i>Dissemination.</i> The robot is very suitable for oral presentation using supportive body language. The robot has an easy to use text to speech function.</li> <li>➤ <i>Affordance:</i> Form and expectation. Form and expectation must be closely linked in order to maintain the motivation. Because of the robot's muscular form some of the pupils explored the robot's potentials in the fitness area. E.g. one might think that the strong looking robot would be able to carry heavy objects – which it can't.</li> </ul>	<p><b>Educational setting and didactics:</b></p> <ul style="list-style-type: none"> <li>➤ <i>Clear goals beyond getting to know the technology.</i> Exploring the "new technology" is not a full academic goal in itself. Additional academic goals in programming, mathematics or language are necessary.</li> <li>➤ <i>Motivation.</i> The robot is motivating as an educational tool especially in the beginning.</li> <li>➤ <i>It's faster and easier to introduce the robot for older pupils.</i> Children in 7th-10th grade worked more focused with the robots.</li> <li>➤ <i>Multidisciplinary learning processes.</i> The robots were largely used in multidisciplinary disciplines e.g. programming and foreign language learning.</li> <li>➤ <i>Academic requirements led to synergy between technological and language learning.</i> The requirements in the field of language learning made the pupils develop more complex programmes.</li> <li>➤ <i>Organisation and structure.</i> Robots in the classroom sometimes presented a risk of chaos and turmoil. The experienced teachers countered this by structuring and organising the activities.</li> </ul> <p><b>Practical issues</b></p> <ul style="list-style-type: none"> <li>➤ The robot may have difficulties to connect to the network due to local firewall settings and so on.</li> <li>➤ Pronunciation is sometimes more phonetically correct rather than grammatically correct at least in Danish.</li> <li>➤ <i>Problem with speech recognition</i> if the background is noisy.</li> </ul>
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## 8. SUMMARY AND CONCLUSION

In this article, we introduced the multimodal NAO robots as learning resources in the classroom. We investigated how technology can support and enrich the learning environment.

The pupils experienced both academic and technological benefits from the teaching. It was largely the constructionist way of learning that was the robot's strength. It became "an object to think with" as it immediately gave feedback in the development of programmes. The robot was used for teaching Danish, English, ethics, programming, and technology. The pupils particularly used the robot's text-to-speech and gesture features.

The teachers must be prepared for minor technical problems, such as network issues. Furthermore, three robots to 24 pupils are an absolute minimum.

Moreover, the two-pieced didactical plans were most successful. Piece one: getting to know the technology. Piece two: subsequent academic topics e.g. language learning with the robot as a lever for learning, more advanced programming and robot behaviour.

Be prepared to spend a couple of days to familiarise yourself with the technology and planning the course. There are no ready-made courses. But on our Wikipedia page you can locate individual course plans and evaluations from the study (Fremtek Wikipedia page, 2014).

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