EDUCATION: A ROLE FOR ROBOTS?

Dr Noel C Bridgeman
Unitec New Zealand
Private Bag Mt Albert
Auckland 1025
New Zealand
nbridgeman@unitec.ac,nz

Elizabeth Bridgeman
Words Worth Ltd
36 Waiwaka Tce
New Plymouth
New Zealand
words.worth@xtra.co.nz

ABSTRACT

To facilitate discussion on what kinds of roles robots may potentially play within the education system, a model of education as a communications system is taken as a framework for evaluating the different functions they may perform. Four functional areas are identified: learner–teacher, knowledge–problem, control subsystems and support subsystems. Some examples of robots in the wider environment and possible uses within the education system are given for some of the functional areas.

KEY WORDS

Robot, education system, communication system, Vogotsky.

1 Introduction

This paper is not concerned with the teaching of robotics, but rather it addresses the issue of the application of robotic functionality across the various functional areas of the education sector. Recent developments in information technology (IT) now mean that the once esoteric field of robotics has developed to the extent that it has established useful, rather than fantastical applications for industry, medicine and even the home. Outside education, the current paradigm for robotic development appears to be directed towards robots designed either to replace the human worker or to augment human power over the environment. An example of the former is the assembly line robots as in industry (Fanuc Robotics 2007) and, of the latter, in the military application of a robotic rifle grip (iiRobotics.com 2007b). In the area of education, there is scope for rather different levels of involvement.

This quality assured paper appeared at the *20th Annual Conference of the National Advisory Committee on Computing Qualifications* (NACCQ 2007), Nelson, New Zealand. Samuel Mann and Noel Bridgeman (Eds).

Replacing the student or even the teacher is surely not the issue. By turning that design paradigm on its head, designers may develop robots which enhance our human skill levels and extend our innate capacity for excellence.

Ad hoc development of robots for education by enthusiastic robotic programmers, however, could easily lead to a proliferation of clever or ingenious “solutions” looking for designer-centric “problems” without a clear pedagogical rationale or an understanding of the systemic complexities involved. This paper looks at the functional roles within the education process and proposes a framework for determining educational policies and procedures for the adoption of robots in a planned and rational manner. It builds on work by Tiffin and Rajasingham (1995) which views education as a communications system and the theories of Vogotsky (1978) of the effective learning process. It then overviews a range of current developments in the field of robotics to identify what contribution if any they may make to education. As educational systems are very complex systems with many interacting networks, there is scope to accommodate a variety of functionally distinct robots.

2. Methodology

The authors build on the model of education as a communication system, supplied by Tiffin and Rajasingham (1995), to identify the different areas within education where robots appear to currently operate or may do so potentially in the future. The research for typical types of robots currently existing has been conducted primarily through accessing information posted on the Internet on the assumption that advances in technology and practice of this nature would find a natural avenue for self-promotion and discussion through this medium. Examples of such websites are Engadget (2006), Fanuc Robotics (2007), Hasbro (2007), iiRobotics.com (2007a), InTouch Health (2007), Royal Institute of Technology KTH (2007), Musemstung de Berlin (2007) and Stanford University (2007). The aim of this paper is to give an indication of how robotics may fit the functional needs across the educational system. The proposed framework may help principals, Boards of Trustees and educational administrators in making decisions and predictions about future robotic usage in our institutions of learning.

2.1 Definitions

In order to discuss Education and Robots, it is helpful to define what this paper will take the terms to mean.

2.1.1 Robots

For the purpose of this discussion, a robot is defined as a machine system characterised by some degree of autonomy in its programmable interaction with its environment. A robot may, or may not, operate in a completely different manner to human beings and may, or may not, be designed to directly interact with them. It may be a machine:

- fixed in position at a work area with a programmable moving part capable of picking up cues from the environment (such as touch sensitivity) and adjusting its behaviour appropriately (such as industrial robots used on the assembly line); or
- with the power of locomotion through a terrain in order to achieve the design functions such as carry weights / accomplish hazardous tasks in areas dangerous or toxic to man (such as a space probe), or facilitate a distant user's virtual presence (as used by medical consultants); or
- essentially virtual – that is, a robot which is entirely software based capable of sensing its environment, making autonomous decisions according to its design parameters, and initiating appropriate action through its agents (such robots may be difficult to recognise as they operate in electronic networks not readily observable to human beings).

A humanoid can be described as a robot which has some human-like characteristics and is designed to interact with human beings and operate within the human environment.

2.1.2 Teaching assistant

The authors' interest in the subject of robots in education was first stimulated by being approached by a robotics programmer for ideas for how a robot could function as a teaching assistant. We determined that a teaching assistant has the role of augmenting the educational functions of a teacher. Characteristically a teaching assistant will be:

- under the supervision/control of the teacher
- able to relate directly with students or provide resources on demand to facilitate the learning process
- flexible/reprogrammable enough to be adapted to a range of new content
- able to distinguish between tasks it can do and those which require the attention of the teacher.

Human teaching assistants do not take over the planning and directive roles of the teacher, but may fulfill supplementary functions such as supervise a group activity, supervise examinations and tests, listen to children reading (as in an infant class), prepare/distribute/maintain resource materials, mark papers according to guidelines, tidy and manage the physical environment (for example laboratory assistants). The aim is to free up the teacher for higher-level duties rather than substitute for the teacher. The same parameters could be the basis for designing a robot to usefully operate in a similar role.

The authors then looked further into the way the education process operates to see in what other capacity robotic functionality may be potentially appropriate. Just as the computer is now ubiquitous, we are making the assumption that a real world with robots will become the new "normal" environment and that the education system will adjust and adopt accordingly.

2.1.3 Education as a communication system

In their analysis of Education as a communications system, Tiffin and Rajasingham (1995) added a fourth factor, knowledge (in a particular context) to the three critical factors of education (learner, teacher, problem) specified by Vygotsky (1978) and state that it is the interaction of these four factors that constitutes "the fundamental communication process that is education". They further stated:

> "....all [four critical] factors need to be present for education to take place, but the factors only exist in relation to one another and only for the period of time it takes for the learner to master an ability to solve a class of problems." (1995, p24)

In the decade since, the communication systems in the real world have expanded to increasingly include robots. Within the foreseeable future, the learning process and the accompanying education systems, if they are to remain relevant, will need to reflect the real world in which robots exist, and this can be expressed in a diagram as shown in Fig 1.

Tiffin and Rajasingham (1995, p47) state that "the weaving together of the weft of learner and teacher with the warp of knowledge and problem is something that no text or handout can do." This reciprocal relationship needs to be considered when designing robots to fit into the education system. They further emphasise that the criteria for a communication system for education should include the control and support systems: "To be capable of a broad spectrum of instruction, educational systems also need support and control subsystems. The latter needs to include an instructional design capability. "

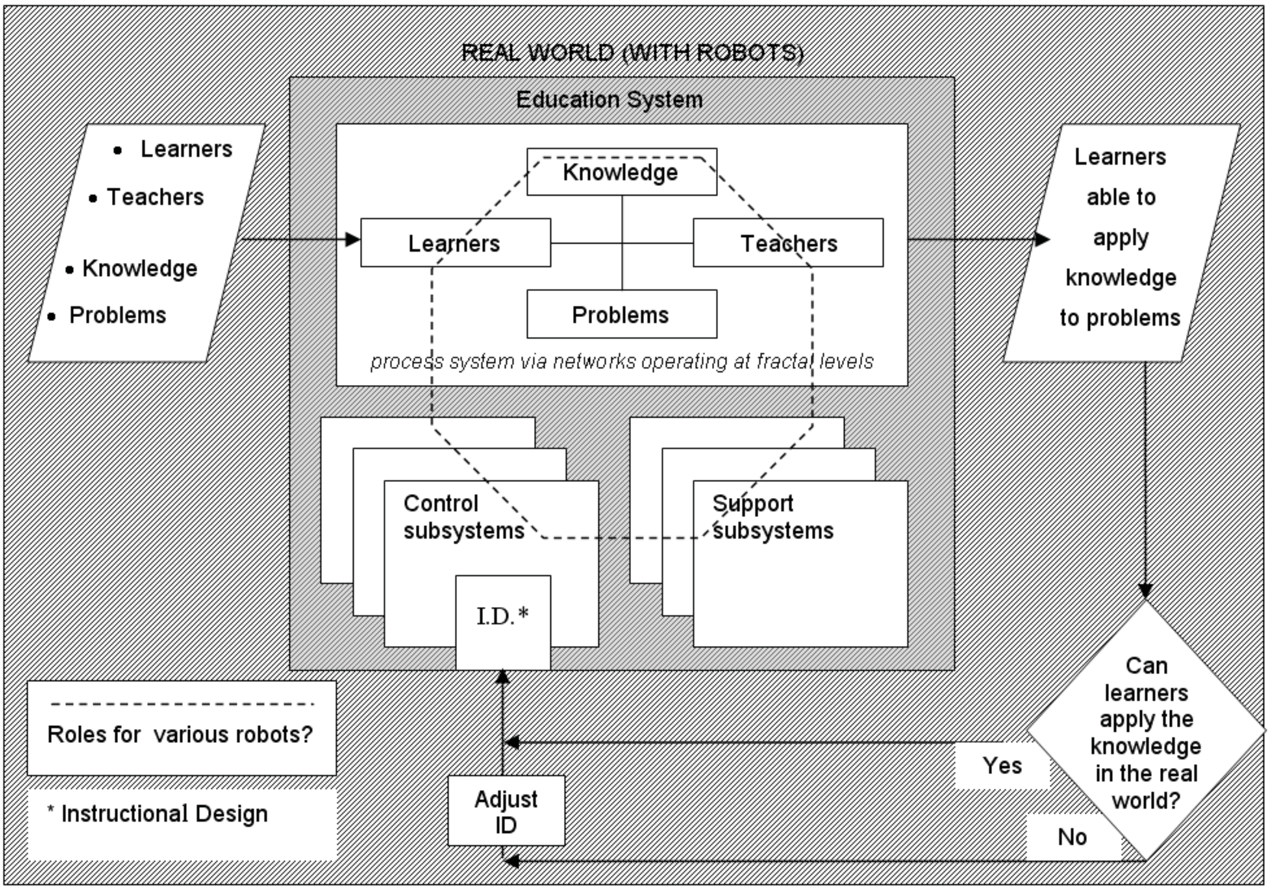

Figure 1 Education as a communication system within a real world with robots *(*†Adapted from Source: Tiffin, J and L. Rajasingham, 1995 In Search of the Virtual Class p 46)

Many different techniques have been developed to maximise the effectiveness of education systems and the learning process, the most recent innovation being the widespread adoption of IT. However, different techniques may be required if one introduces robots (with their various purposes). These will fall into the four functional areas of teacher–learner, knowledge–problem, support systems and control systems.

3. Roles for robots

This section addresses where robots are currently appearing in society and where robots may be usefully employed in the functional areas described within the education system and the form the robot is likely to take.

3.1 Learner–teacher

"Virtually There" technology is a term used by Intouch Health (2006) for doctors to be able to see and interact with patients from a distance. "Remote Presence is the ability to project yourself from one location to another (to be in two places at once) to move, see, hear and talk as though you were actually there."

Ganeshan (2006) discusses the increasing awareness and use of telemedicine and how these robotic assistants may be used in the practice of telemedicine and patient monitoring using only inexpensive and therefore very affordable robots and other equipment. The design and development, of such highly adaptable, networked, intelligent, mobile robot assistants and systems for use in patient monitoring and telemedicine could be a model for robots in teacher – learner roles in education.

This telemedicine model uses a robot to provide the user-driven functionality. With very little adaption, teachers may therefore be able to have a virtual presence in a distant location, delivering a lecture to a group or tutoring one-on-one "in person" through the robot, hearing and seeing the students in real time. Likewise, students may have a virtual presence in a classroom if, for example, they are prevented from attending in person because of prolonged hospitalisation. A successful early trial of a remote-control videoconferencing system (VCS), P.E.B.B.L.E.S.™ (Providing Education by Bringing Learning Environments to Students), has developed and successfully trialled to allow a student access to his/her regular classroom from a hospital bed. Remote control is provided by a game pad, which allows the student to direct the system to participate in typical classroom activities and have a sense of presence in the classroom (Fels, Williams, Smith, Treviranus, & Eagleson 1999).

Robotic toys are becoming more sophisticated and life-like in their behaviours and built to appeal to children particularly as pet substitutes, with a recent example being a dinosaur bipedal toy Dino-robot, the latest toy from Hasbro creator of Furby. Furby itself was first on the market in 1998 selling over 40 million "creatures". The evolved Furby, released in 2005, features a wide range of emotions and motions, advanced voice recognition, enhanced communication between children and other Furby toys, and a "bilingual" vocabulary of "Furbish" and English. By parental demand this version of the talkative toy was also enhanced with an off button (Hasbro 2007). In crowded city environments, these types of interactive toy "pets" may appeal to parents as easier to live with and more cost effective than cats and dogs.

As the younger generations grow up with robotic toys, robots will become more accepted in other areas of day to day life. Robotic "nannies" which can read stories to young children, provide information resources such as a common knowledge base (encyclopaedia), and otherwise entertain while providing child-centric interactive "warm fuzzies". Intelligent teddies, cuddly enough to take to bed, could also be used as "grandparents" to nurture indigenous languages and convey heritage items such as traditional songs. "Robots increasingly have the potential to interact with people in daily life. It is believed that, based on this ability, they will play an essential role in human society in the not-so-distant future" (Kanda,, Hirano, Eaton & Ishiguro, 2004 p.61).

In May 2000, Standford University advertised a "Grade Grinder" provided with the purchase of a new text book, *Language Proof and Logic* according to Stanford Online report. (Stanford University, 2007) In this system students used the Internet to interact with Grade Grinder, "a robotic teaching assistant that doesn't give answers to problems, but gives them hints and reminders of principles they have previously encountered. The robots advice is personalized to address the specific shortcoming of the last answer each student has submitted and is delivered by email within seconds. That compares to the week or more typical of feedback from a human grader." The lecturer can watch real time as students submit their homework to see how they are doing.

This is an extension of current on-line or computer-aided learning systems (such as Mavis Beacon Typing Tutor) which give feedback on progress to the individual student and present new learning material in a logical skill-based sequence, in that the teacher is also an integral party and the virtual robot handles more functions.

It may be possible to develop a mobile robot able to negotiate its way independently around a classroom. The intention would be for it to move to students who "call" it for assistance. Within the classroom, it may be able to:

- match student work observed through a camera with a model answer and identify differences or "errors" and bring these to the student's attention
- have a Help function to handle FAQ
- give hints if the student is stuck while working on an exercise relieving the teacher of more mundane queries
- move around the room to set points or to ends of rows for students to pass their work under the robot's scanning eye and "affirm" their progress
- refer on to the teacher any students who are able to demonstrate progress or whose work is clearly not matching the model
- query each student's understanding of the topic by posing random questions (programmed by the teacher as part of the lesson preparation) and matching answers (keyed in) to the model – students could self-test in this way and the teacher could view the results from a teacher's monitor either handheld (such as a cell phone interface or on a desk monitor).
- digitally record the lesson and offer various search functions so that a student could ask it to play back sections of the lecture which the student could not follow, or show the written version of a spoken word, replay a graphic etc. One characteristic of many students in this age of globalization is that they may be studying in a foreign university in a language other than their first language – even for native language speakers, the accent of the lecturer may be from a different region – so students often miss important points in the lecturer's presentation which then inhibits their ability to proceed. By using earphones on the robot, the student could review the section without disturbing fellow students or taking up the teacher's time with questions not relevant to the class as a whole.

3.2 Knowledge–problem

While a search of the CSE and IEEE library literature reveals there are many articles on teaching about the building and programming of robotics, this paper does not address this area. However, in their paper on robotics as an educational tool, Miglino, Lund and Cardaci (1999) explore "a new educational application of Piaget's theories of cognitive development, that is, the use, as a teaching tool, of physical robots conceived as artificial organisms. . . The process of constructing real robots helps students to understand concepts about complex dynamic systems – in particular, how global behaviour can emerge from local dynamics. This is done through a construction process."

3.3 Control sub-systems

Another use for a mobile robot could be to provide security for examinations. It could:

- monitor the entrants to the examination, taking in their digital code (either from a card or a manual entry) and comparing facial features with preloaded photos to ensure the student sitting the exam is not a substitute
- monitor the room for cell phone use (this is a new mode for cheating) and identify a student using a cell phone (either physically locate next to the student or show the location in the room on its monitor to alert the supervisor)
- answer selected questions from the student if clarification was needed
- give out exam papers tagged with the student code and receive them into a sealed container at the end of the exam then deliver them to the correct department to obviate paper substitution.

3.4 Support sub-systems

The industrial robot is well established. According to its website of 4 April 2006, one robotic manufacturer, FANUC Robotics (2007) has over 160,000 industrial robots installed worldwide. Its site lists the robot application zones as assembly, material handling, welding/laser, material removal, and painting and dispensing while the industrial application areas cover aerospace/defence, automotive, composite, consumer goods, distribution centres, electronics and clean rooms, fabricated metal, food and beverage, foundry, glass, medical devices, off-road vehicle, paper and printing, pharmaceutical, plastics and wood. This demonstrates that processing and material handling roles can be handled by robots. They may therefore be able to handle similar processing and sorting functions within the field of education. Looking at Fig 1. the most likely role for such robots would be in the support systems as laboratory assistants, stores and resources handling and batch processing (including marking short answer test papers).

The Centre for Autonomous Systems (CAS) is a research centre at the Royal Institute of Technology (Kungliga Tekniska Högskolan), KTH (2007) in Stockholm. The centre does research in (semi-) autonomous systems including mobile robot systems for manufacturing, domestic and field applications. One of their developments is the Care-O-Bot – a mobile service robot which has the capability to interact with and assist humans in typical housekeeping tasks.

- Cleaning of glass facades, floors
- Maintenance and inspection, e.g. boiling water tanks in reactors
- Rehabilitation: e.g. service robots as walking aids
- Entertainment: e.g. robots as museum guides
- Mobile Security robots

Such robots may be able to manage similar support functions for schools.

Robots used in the area of rehabilitation are likely to enter the education system attached to individual students and act as support for students with a disability to achieve greater parity of access to learning with other students.

Japan has developed a programmable hand which can translate speech into sign language (iiRobotics.com a 2007) This could have a wider application for education and skill acquisition.

In April 2003, Wakamaru, an humanoid robot developed by Mitsubishi made a guest appearance at the Embedded Systems Conference in San Francisco. Claimed to be the first human-sized robot able to provide companionship or act as a caretaker and house-sitter, it operated on batteries which it could recharge itself, and moved on wheels (induxDevices 2007),). Human-friendly robots could be programmed to deal with students and children in educational settings. Wakamaru has developed further into a premises security guard. The bright yellow plastic robot was introduced to stand sentry at a primary school in Tokyo, monitoring students' movement and demanding IC-chip based identification. Able to take a picture it can also ring the administration to come in help if it meets problems (Engadget 2006).

Since 17 March 2000, three mobile robots have been the main attraction of the re-vamped Museum für Kommunikation (Musemstung.de Berlin 2007) in Berlin, Germany. One entertains by playing ball, one welcomes visitors as they enter the museum and another gives guided tours. The welcoming robots can recognize new people by analysing their legs and can distinguish between visitors who have been welcomed and new ones; the tour guide accompanies visitors around the exhibits and the ball player entertains by playing catch but it has "emotions" seeking out the ball if it is hidden by a player and behaving "despondent" if it cannot find it.

Humanoid robots welcoming students on to campus and into lecture halls could also record attendances and act as guides on campus. However, the humanoid which interacts with people by playing ball could lead to robots designed to assist in the learner–teacher area.

4. Potential robot development

The examples below are a thought exercise in the learner–teacher category. Each is designed to enhance human potential.

Generally speaking, the focus of automation has been on building machines, and now robots, to replace workers in industry by working longer, better and faster without fatigue or boredom. In an educational application, there is nothing to be gained by replacing the students and little benefit to attempt to replace human teachers. This may be why so little development has been done of educational robots. Let's turn the whole paradigm on its head. To what extent then could robots be used to increase the capacity of human beings and enhance their human performance? How can this approach be applied to education and training?

4.1 Repetitive practice robots for sport

There is currently a great deal of research into climbing and walking robots. Claimed to be one of the most successful to date is the BigDog from Boston Dynamics (iiRobotics.com b, 2007) This is a quadruped robot which runs, climbs and maintains its balance dynamically on rough terrain, powered by a petrol engine with articulated legs like an animal. The size of a small mule it can carry 120lb loads. Such advances in locomotion coupled with improved sensory perceptions will rapidly enable more robotic applications relevant to the educational environment.

In sports training, robots could be designed to give the repetitive practice that the human brain requires to perfect a physical skill. Take the example of the robot that throws a ball, an extension of that function would a robot to pitch softballs or cricket balls at different speeds and heights to give stroke practice. Linked electronically to the bat itself, it should be possible for the robot to calculate the drive, distance and angle of the ball when it leaves the bat. This could be relayed to the hitter through the helmet so that the hitter can get immediate feedback on the result of each stroke and make the adjustments needed by trying a slightly different position or grip. The video eye of the robot could also record for payback the body position, and sensors could record breathing rates, pulse rates, transfer of weight and other body dynamics which could dynamically lead to the virtual construction of the most productive model for each particular player. The robot could then provide feedback to the player on the most successful combinations and even calculate suggestions for optimizing the results. It could determine which strokes needed more practice and throw balls aimed to provide the required practice. The robot would remember each player and automatically reset for the individual's skill level at each practice session. One can imagine this robot being programmed for golf and tennis tuition as well.

4.2 Repetitive practice robots for acquiring manual skills

In the classroom or home, an educational practice robot could have a similar role for any skill which requires practice and feedback for self correction. Taking a skill requiring manual dexterity, for example, a table top robotic hand or pen programmed to write could guide the hand of a novice through the motions for any type of script desired (italic, gothic, cursive, calligraphy, Chinese characters, Roman, Indian or Arabian script) for example. A screen could present the tasks (words and style) which the student and robot are to copy onto page set on a pressure sensitive pad. At the start the robotic aid, programmed by an expert human user (the teacher), would fully guide the human hand at a beginner's pace. As the human hand started to anticipate the correct movements the robotic aid would just accompany without intervening unless a mistake was in progress, then gentle pressure would be applied to guide the hand correctly. The robotic teaching assistant would observe the hand movement and set tasks sequentially inside the nearest "zone of proximal development" (Vygotsky, 1928) as the skill level increased (new letters, faster motion, longer exercises etc). It could provide suitable encouragement and positive verbal affirmation of success, much as a good typing tutor on the computer does; the robot could do this verbally and would remember the student's name so that the student feels personally rewarded for improvement and achievement.

One can imagine that any dexterous skill could be taught by this kind of modeling. It could apply at the tertiary level, for example, in training novice surgeons in applying the correct pressure and stroke for cutting through different "tissues" so that before ever touching a patient the surgeon would have the confidence built up through sufficient practice with precision feedback. Learning to play a musical instrument and read musical scores may also benefit from this type of robotic teaching tutorial.

Brooks, Berlin & Gray (2005) say "personal robots are an increasingly promising new platform for human entertainment. In particular, socially interactive game playing can be used as a mechanism for imparting knowledge and skills to both the robot and the human player. Simultaneous advances in untethered sensing of human activity has widened the scope for inclusion of natural physical movement in these games. In particular, this places certain human health applications within the purview of entertainment robots. Socially responsive automata equipped with the ability to physically monitor unencumbered humans can help to motivate them to perform suitable repetitions of exercise and physical therapy tasks. We demonstrate this concept with two untethered playful interactions: arm exercise mediated by play with a physical robot, and facial exercise mediated by expression-based operation of a popular video game console."

4.3 Repetitive practice robots for general motor skills

To extend the principle further: robots could be designed to train human beings in other motor skills which require safe situations for learning and graded practice. A robotic climbing wall could create a simulated climbing terrain with holds and slopes being reconfigured according to the skill level of the climber. The BigDog ability to negotiate terrain and carry heavy weights could lead to a robot horse which trained its riders.

4.4 Teaching assistant robots for language learning

In language learning, the problem is that the teaching context tends to be classroom based and so the vocabulary is difficult to align with real situations in an authentic way. Practice makes perfect but book-based practice does not create fluency in verbal communications, and group-based conversational practice with other learners provides poor models for verbal skills. Language teacher assistant robots could be humanoid or virtual robots which talk, read and interact with the student in the target language at whatever pace the student requires without getting exasperated or bored. It could also role play various typical conversations, such as a visit to the doctor, buying at a shop, answering the phone which could be accompanied by virtual reality simulations of the appropriate context for each conversation. Vocabulary and language rules could be provided by the software, with the opportunity for the verbal models to be read into the system by the teacher so that the pronunciation would be authentic for the region. The teacher would be able to set the parameters of the lesson content to be practiced, while the robot would be able to tailor the level of content delivery to the rate and accuracy of the responses received from the student. It would be able to synthesise speech, and it could be optional whether the student feedback was to be oral (requiring accurate speech recognition by the robot) or by some other means to indicate that understanding had been achieved.

Kanda et al. (2004) report on a Japanese trial using Robots for second language and social interaction with young children

> "Two English-speaking "Robovie" robots interacted with first- and sixth-grade pupils at the perimeter of their respective classrooms. Using wireless identification tags and sensors, these robots identified and interacted with children who came near them. The robots gestured and spoke English with the children, using a vocabulary of about 300 sentences for speaking and 50 words for recognition. The children were given a brief picture-word matching English test at the start of the trial, after 1 week and after 2 weeks. Interactions were counted using the tags, and video and audio were recorded. In the majority of cases, a child's friends were present during the interactions. Interaction with the robot was frequent in the 1st week, and then it fell off sharply by the 2nd week. Nonetheless, some children continued to interact with the robot. Interaction time during the 2nd week predicted improvements in English skill at the posttest, controlling for pretest scores. Further analyses indicate that the robots may have been more successful in establishing common ground and influence when the children already had some initial proficiency or interest in English. These results suggest that interactive robots should be designed to have something in common with their users, providing a social as well as technical challenge."

4.5 Funding the development of robots

Education per se tends to be an under-funded area for research and development of new technology. However, industrial and military uses are funding the drive for dramatic improvements in range, camera resolution, sensor development and functionality. For example, the war in Iraq provides a market for new robots – in September 2005, new improved bomb-seeking robots MARCBOT came off assembly lines. These can be operated remotely from inside a protective vehicle. For marksmanship, a robotic rifle grip enhancer improves shooter accuracy (iRobotics.com b 2007)

Educational robots which are fast-paced, rugged and versatile may evolve from those developed for military use. Some industrial robots, such as Care-o-Bot, may be sufficiently generic in their application to be used "off the shelf" in the education system.

5. Conclusions

This paper has outlined four functional areas in education as a communication system that robots could be and have been developed for. The advantage of grouping robots in this way is to facilitate discussion of the challenges involved in developing robots for education. It should clarify objectives for programmers and instructional designers when evaluating the benefits of robots for the future of education.

While this paper has identified a framework which describes the functional areas of education within which robots could be used, it has not covered in detail all possible existing or future usage or developments, such as robots being learners within the education system. Neither does it attempt to detail the networks and operating principles which would be required to for real world applications of robots in education.

As we have argued in this paper, the four areas of learner–teacher and knowledge–problem networks, plus control and support sub-systems, provide a useful framework for the development and use of robots in education.

References

Brooks, A. G., Berlin, M., & Gray, J. (2005), Untethered robotic play for repetitive physical tasks, Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology, Valencia, Spain ,Pages: 27 - 34

Engadget (2006) **http://www.engadget.com/2006/02/07/wakamarus-latest-job-guarding-your-kids** (retrieved 4/3/07)

Fanuc Robotics (2007) http://www.fanucrobotics.com (retrieved 4/3/07)

Fels D. I., Williams L. A., Smith G., Treviranus J., Eagleson R., (1999) Developing a Video-Mediated Communication System for Hospitalized Children, *Telemedicine Journal* Jul 1999, Vol. 5, No. 2 : 193 -208

Ganeshan K (2006) - Networked intelligent mobile robot assistants: patient monitoring and telemedicine Proceedings of the 24th IASTED international conference on **Biomedical engineering**, Innsbruck, Austria, 2006 Pages: 45 – 50

Hasbro (2007) http://www.hasbro.com/furby/default.cfm?page=faq

iiRobotics.com (2007a) http://www.iirobotics.com/webpages/hotstuff.php?subaction=showful&id=113771314 (retrieved 4/3/07)

iiRobotics.com (2007b) http://www.iirobotics.com/webpages/hotstuff.php?subaction=showfull&id=11418240 (retrieved 4/3/07)

induxDevices (2007), http://www.induxDevices.com/news (retrieved 4/3/07)

InTouch Health (2006) http://www.intouch-health.com/ith/explore-RP7.html#virtual (retrieved 4/3/07)

Kanda,,T., Hirano, T., Eaton, D., Ishiguro, H., (2004) Interactive Robots as Social Partners and Peer Tutors for Children: A Field Trial, *Human-Computer Interaction*, 2004, Vol. 19, No. 1&2, Pages 61-84

Miglino, O., Lund, H., and M. Cardaci, M., (1999) Robotics as an educational tool, *Journal of Interactive Learning Research 10* (1), 1999, 25-47

Musemstung.de Berlin (2007) http://www.musemstung.de/berlin/ (retrieved 4/3/07)

Royal Institute of Technology (Kungliga Tekniska Högskolan), KTH (2007) http://www.kth.se (retrieved 4/3/07)

Stanford University (2007) http://newservice.standford.edu/news/200/may31/gradegrind-531.html) (retrieved 4/3/07)

Tiffin, J. & Rajasingham, L. (1995) *In search of the virtual class* London: Routledge.

Vygotsky L.S.,(1978), *Mind in society: the development of the higher psychological processes* Cambridge, MA: Harvard University Press