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A future for robots in schools: Fact or fantasy?

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Abstract

Will the adoption of robots by the education system mirror its earlier adoption of Personal Computers (PCs)? A future in which education may need to accommodate robots is explored. Examples of current advances in robotics are given which suggest that there is a realistic potential for robots to successfully contribute within the four functional areas of an educational system: learner-teacher, knowledge-problem, control subsystems and support subsystems.

Introduction

The last 25 years have seen an explosive growth in the use of personal computers in business. However, the education sector took some time to come to terms with this phenomenon and to find ways to adapt and adopt this particular form of information technology It is suggested that the "diffusion of innovation" paradigm (Rogers, 1962, p. 42) held true and the same drivers for the uptake of technology (PCs) in business did not exist in education at that period. There is growing use of robots in the manufacturing, health and military sectors and it could be argued that the use of robots in these areas mirrors the introduction of PCs to business prior to their ubiquitous appearance throughout the developed world in homes and schools (Bridgeman & Bridgeman, 2007).

The main drivers for the rapid growth of robotics, which saw a boom beginning in 2005, were the automotive and electrical/electronics industries (Bates, 2008). Recent efforts to provide robotics solutions to industries outside the automotive sector have led to increased demand from general industry. Based on a 2007 World Robotics Survey conducted by the International Federation of Robotics Statistical Department, it is estimated that the total number of operational robots will reach 1.2 million units worldwide by the end of 2010 (Bates, 2008). It appears that the potential for robotics to radically change the way businesses and people operate cannot be ignored.

In addition, the emerging e-learning market is perceived to have a significant business potential of some $25 billion, according to Hossein Sarrafzadeh of the

Auckland Institute of Information and Mathematical Sciences (TV3 News, 2007). In other words, the drivers for education to adopt new technology may indeed have changed in the 21st century from those existing at the end of the last century, and now be aligned more closely with the business model. In which case the diffusion rate may be faster than anything we have seen previously. The questions arise, with some urgency, as to how robotic technology will affect the education system and what guidelines can be developed to assist educators to proactively plan for the transition using a clear pedagogical rationale and an understanding of the complexities involved.

Methodology

Recent examples of robotic developments are aligned to a framework of functional roles within the education process. The framework adopted builds on work by Tiffin and Rajasingham (1995) which views education as a communications system and the theories of Vygotsky (1978) of what constitutes an effective learning process. This framework is restated in this paper and advances in robotics are viewed in terms of their potential contribution to education. Examples given are either custom-designed for educational purposes, or indicative of how developments in better funded arenas may be adapted or adopted within the educational system.

The research into 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. A review of recent journal literature also informs the discussion.

Definitions

In order to discuss the future of robots in schools, it is helpful to define what this paper will take the key terms to mean.

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. The field of robot research is often called robotics and the adjective, robotic, can be used to describe a machine which is a robot (Crozier, 2005).

A robot may be:

a. a programmable moving part capable of picking up cues from the environment (visual, haptic or other) and adjusting its behaviour appropriately (such as industrial robots used on the assembly line); or
b. a machine 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
c. primarily virtual - that is, a robot which is entirely software-based and capable of sensing a selected 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 may operate in electronic networks not readily observable to human beings); or
d. designed as a humanoid - a mobile robot which has human-like characteristics and is designed to interact with human beings and operate within the human environment.

Teaching assistant

A teaching assistant has the role of augmenting the educational functions of a teacher, and 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.

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,

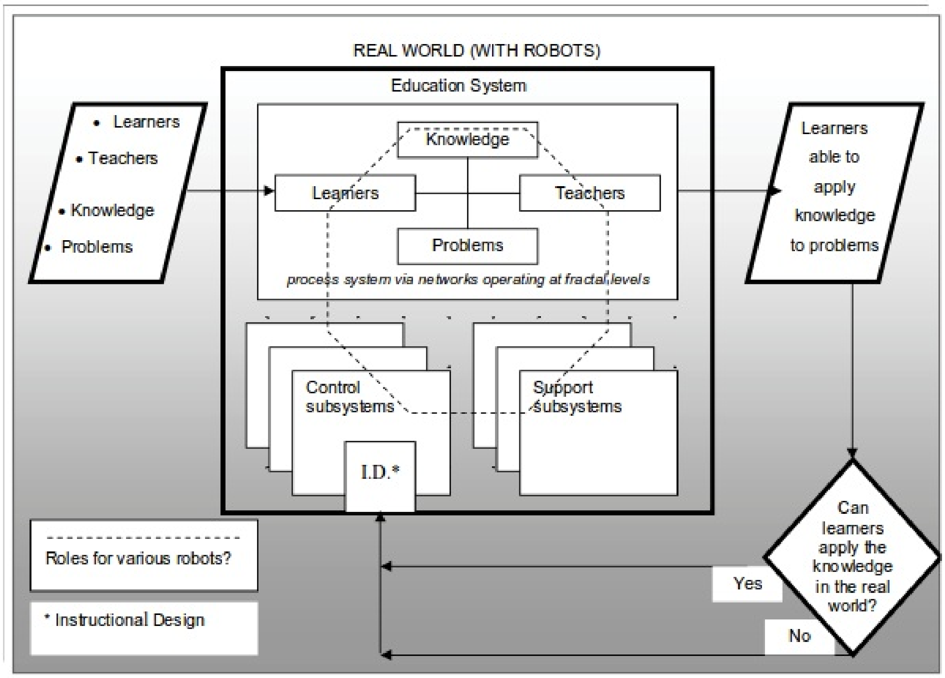

Figure 1. Education as a communication system within a real world with robots
Adapted from Tiffin and Rajasingham (1995, p. 46)

Tiffin and Rajasingham (1995, p.47) 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." All the threads of a reciprocal relationship need to be considered when designing robots to fit into the education system in a teaching role.

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" (Tiffin & Rajasingham, 1995, p.47).

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 information technology. As robots are introduced these techniques will need further analysis and adaptation.

Functional Areas for Robots

This section addresses where robots may be usefully employed in the four functional areas of teacher-learner, knowledge-problem, support systems and control systems, and the form the robots could take.

Learner-Teacher

Although this paper does not propose the imminent replacement of teachers by robots, recent developments of "virtual tutors" suggest that robots can effectively augment the abilities of teachers to meet specific needs of students and as such may have a valid role as teaching assistants. Virtual tutors combine the two concepts defined above, the virtual (software-based) robot, and the teaching assistant.

In the traditional classroom model of education, interaction and feedback are multi-channel: visual, aural, and kinetic. The importance of designing the means for quality feedback and interaction, both for the robot and the student, is highlighted in the examples which follow. This observation is further supported by the evaluation of mathematical applets or "mathlets" (Kennedy, 2007) using the three Underwood Criteria (Underwood et al., 2005) cited by Kennedy :

- Motivation - the student should get "hooked" on solving the problem
- Presentation - it is easy to get started
- Support for problem solving - it makes the student think.

The student comment on the mathlets confirmed that interactive learning software needed to provide encouragement/feedback, help, "show answer" option, different levels, ways to make the student think, fun and ease of use.

Kumar (2007) reports on an electronic Braille tutor developed by US researchers at the Robotics Institute of Carnegie Mellon University to meet the needs of blind students in developing countries. They aimed to develop a low cost, low power, robust, electronic Braille robot tutor. The need for such assistance is highlighted by a literacy rate amongst blind people in developing countries of less than 3%, a shortage of trained Braille teachers and the high cost of traditional Braille writing machines. Funded with a grant from IBM, three electronic Braille tutors are now in use at the Mathru School for the Blind in India.

The previous teaching methods involved students in having to manually press out the Braille dots in reverse on heavy card and then read/check their work from the opposite side. Young children did not have sufficient manual strength to make the dots and were confused by the requirement to write in one direction and read in another, thus severely limiting their progress in their studies. The electronic Braille tutor has an electronic slate and stylus. It uses affordable electronics for tracking the contact between the slate and stylus and text-to-speech software to provide immediate audio feedback.

The software for the electronic Braille tutor uses a digitised version of a Mathru teacher's voice for the audio-feedback, as the children - especially the younger ones - had difficulty in understanding the American accent normally used in text-to-speech software. Even students who were fluent in Braille reported they enjoyed using the electronic Braille tutors because of the audio feedback. For the next generation, the stylus will be wireless as some students were frightened by the wire. The system will be made open source and engineered for mass production using local materials.

A second example of a virtual robotic tutor is from New Zealand. Massey University researchers headed by Dr Chris Messen, senior lecturer in computer science, have developed an electronic animated teacher called Eve to teach maths to eight year olds (TV3 News, 2007). In the words of the news release:

> "Eve is what is known in the information sciences as an intelligent or affective tutoring system that can adapt its response to the emotional state of people by interaction through a computer system.
>
> Linked to a child via computer, the animated character or virtual tutor can tell if the child is frustrated, angry or confused by the on-screen teaching session and can adapt the tutoring session appropriately.
>
> Eve can ask questions, give feedback, discuss questions and solutions and show emotion.
>
> To develop the software, the Massey team observed children and their interactions with teachers and captured them on thousands of images.

> From these images of facial expression, gestures and body movements they developed programs that would capture and recognise facial expression, body movement, and, via a mouse, heart rate and skin resistance.
>
> The system uses a network of computer systems, mainly embedded devices, to detect student emotion and other significant bio-signals.
>
> The system is thought to be the first of its type" (TV3 News, 2007, para. 4-10).

Hossein Sarrafzadeh of the Auckland Institute of Information and Mathematical Sciences led the research and sees that computer programmes capable of "detecting human emotions may become a critical teaching tool" of the future (TV3 News, 2007, para.13).

These two examples show how development of the algorithms for such tutor software could lead to mass production and make research and development for educational robots financially viable for private business, thus changing the drivers in education and encouraging further diffusion of robotic technologies.

Recent research on the use of robotics in medicine may be indicative of other ways in which robots may become useful in education. Examples of tele-operated robots are already in use in medical practice extending the reach of a doctor to interact with patients and a distant location. "Virtually There" technology is the brand name used by InTouch Health (2006) for enabling doctors to be able to see and interact with patients from a distance. "Remote Presence" is another term for the ability to project the user from one location to another (to be in two places at once) to move, see, hear and talk as though actually there (InTouch Health, 2006).

An off-the-shelf user-driven robot with video-conferencing ability, such as developed by InTouch Health, could enable teachers to have a virtual presence in a distant location, deliver a lecture "in person" through the robot, hearing and seeing the students in real time. However, this same functionality can operate in reverse. Thus, a student hospitalised for a long period could use a tele-operated mobile robot from a hospital bed and so be enabled to continue, at a distance, their normal social and educational interactions as if present in the classroom.

Surgical robotics aim to increase the surgeon's dexterity, accuracy and powers of augmented visualization, enabling the surgeon to be "more present" in the operating room rather than to enable tele-operations at a distance, for which the Internet is currently too unstable (Tucker, 2007). Likewise, although distance education is seen as a growth area, robotics may in fact prove useful in the classroom directly assisting the teacher. Future research may enable more detail to be given as to how some of the developments in medicine may mirror means for increasing the teacher's effectiveness in dealing with individual students.

There are several examples of cognitive mobile robots which have been developed for roles as interactive museum guides. One such robot is CiceRobot (Chella, Liotta, & Maculuso, 2007), tested on guided tours in the Archaeological Museum of Agragento. The aim of these researchers was to "integrate perception, action and symbolic knowledge to allow an autonomous robot to operate in an unstructured environment and to interact with non-expert users" (Chella et al., 2007, p. 503). Their experimental results showed that robot cognitive behaviours resulted in a full function robotic museum guide able to interact with clients and customise the tour in response to their preferences. One may argue that such purpose specific robots are a long way from the requirements of the average classroom environment and the flexible learning needs of the average student. But the point is that cognitive autonomous robots able to interact with non-expert users are no longer fantasy: they exist.

Knowledge-Problem

Already, robotics is a taught subject at the tertiary level. At lower levels, examples exist of robotics championed by enthusiastic "pioneer" teachers. This mirrors the sporadic efforts of individual teachers in the 1980s to develop computing skills in their school often with computers donated by IBM, Apple or other suppliers with an eye on the educational market. But these early efforts were not kept up when that teacher moved on and machines were locked away in cupboards or sold off. The authors recall that, in those early days of the personal computers in the 1980s, community-based computer clubs were active. These, not the classroom, were where children and interested adults picked up and shared their gaming, programming and building skills. In general, teachers as a group were technology-shy and it was their pupils who had the confidence to explore and develop computer skills while operating completely outside the curriculum and without formal teaching. Whether this will be the pattern for robotics is yet to be seen.

For whatever reason, more published literature on robots and robotics seems to be publicly available for junior readers rather than for adults. A review of titles held in a small town public library (Te Puke) conducted by one of the authors in February 2008 showed seven non-fiction titles on robots, robotics and artificial intelligence in the junior library and only two titles (a sci-fi novel and a do-it-yourself hobby book on building inexpensive robots) in the adult library. It is not known whether this is indicative of how the market forces are working, or the perception of the purchasing librarian, non-availability of published adult titles, or the influence of the internet on information dissemination; nor how typical this spread is for other libraries and resources. It could be interesting to do more research on the public perception of robotics, the availability of information and the identification of the opinion leaders.

On the pedagogical front, the programming of robots is shown to have a wide range of applications for learning. This presents 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" (Miglino, Lund, & Cardaci, 1999, p. 25).

Apart from building and programming robots, there are other emerging applications for robots in the knowledge-problem learning axis, For example, biology field work has always been very labour-intensive, with the complication that observation has been limited by the disturbances caused by human presence. Connolly (2007b) reports that sensor and intelligent specialist software and remote systems which are automated or tele-operated are helping biologists with their life imaging needs and the selection and storing of the captured data.

Previously, the authors proposed a variety of potential developments for robotics which could be placed in the knowledge-problem axis, specifically for the acquisition of motor (sports) skills and linguistic skills which required repetitive practice (Bridgeman & Bridgeman, 2007). At that time they were speculative, but reports on recent developments suggest that the robotics industry is not so far from being able to deliver. For example, the RiceWrist (Gupta, O'Malley, Patoglu, & Bulgar, 2008) is a force feedback wrist exoskeleton for rehabilitation and training.

Even more significant for New Zealand schools, robotics is now an officially recognised technology area within our education system. According to the document Technology Education in the New Zealand Curriculum, technology education "seeks to empower students to make informed choices in the use of technology and in their responses to technological change" (Ministry of Education, 2007, p. 2). It aims to enable students to achieve "technological literacy" through the development of three strands:

- knowledge and understanding
- ability
- and awareness of the relationship between technology and society.

Within the area of electronics and control technology is included the "knowledge and use of electrical and electronic systems and devices, as well as their design, construction and production. These may be simple electrical circuits or complex integrated electronic circuits or robotics" (Ministry of Education, 2007, p. 12).

Given that robotics is now part, albeit optional, of the approved curriculum for years 1 to 13, it would appear that many teachers will be in need of up-skilling in order to meet the subject brief. This signals an opportunity for tertiary education providers to plan appropriate courses, which include robotics as a technological area. The curriculum document furthermore directs that "The implementation of the technological curriculum requires school-based decisions" (Ministry of Education, 2007, p. 30). The implication of this is that robotics should not be ignored by school managers.

Control sub-systems

In an education system, various control systems need to be in place to facilitate the end objective of imparting skills and knowledge to the students. "Control in a system matches what is going on in the world outside the system with what is going on in the system itself and puts into place changes that guide the direction the system is taking" (Tiffin & Rajasingham, 1995, p. 46). Control requires feedback loops and processes for adjustment if there is negative feedback. There are several levels at which control systems operate, from overall management and school administration to classroom lessons.

Robots have the potential to fulfil at least some of these control functions but the feedback loops built into them need to match both the objectives of their operating level and the education system as a whole. When analysing what kinds of robots could be utilised within an education system, the different levels will indicate different functional requirements. At the classroom level, the robots employed will need the input of instructional design to ensure their control systems facilitate the desired learning objective. At the management level, principals need control systems which ensure that the school operates smoothly and remains relevant to the world in which it operates - the NZ Curriculum is the guiding document for decisions about educational content.

At the administration level, robots may contribute to the efficient and safe functioning of the school environment. At least one example exists of a humanoid robot employed to patrol the school grounds to ensure only "recognised" people are on site, with the capacity to alert teachers if something is amiss (Bridgeman & Bridgeman, 2007). One can imagine that autonomous, cognitive, roving robots may be employed in a variety of similar control and protection capacities with the advantage of being on duty 24/7 with no additional on-going costs of salaries, overtime or holiday pay. Robots both mobile and embedded may be able to do more than security systems can today in terms of monitoring attendance and behaviours, giving alerts about anomalies, and assisting management to deal with emergencies and threats.

Robots need not be stand-alone operators, they may work in tandem or network with other systems and personnel. A constructive relationship by which robots augment the control abilities of the system need not replace personnel but may make difficult, dangerous, labour-intensive or emergency situations more manageable. RAPOSA is a "tethered" robot which, when tested in several scenarios in a fire fighting school, reduced inspection time to 25% of specialist fire fighter teams giving faster and safer inspection (Marques, Cristóväo, Alvito, & Lima, 2007).

An educational environment is more complex and fragmented than the highly organised and well controlled museum environment where humanoid robots have been used as guides. Any mobile robots used in the control or support systems would need to be able to find their own way around without interfering with the normal school flows of students and staff. A variety of techniques are in use to enable robots to operate autonomously within complex environments without the need to be tethered to a human operator or have predefined operational boundaries.

While still a long way from the standard school situation, Vision Robotic Corporation (VRC) is developing an intelligent duo of robots with a scout loaded with image sensors to map out and plan harvesting, while a specialised harvester uses multiple arms to pick delicate produce, such as oranges and grapes, efficiently and economically (Harris, 2007). The economic driver for this development is US immigration reform to tighten border controls and reduce the flow of immigrant workers (Harris, 2007). Robotics is seen as offering an alternative harvesting method able to operate within any field or topography. The developed form of such systems, once proven and commercially produced, could be adapted to urban, domestic and school environments for multiple uses.

The introduction of robots into the educational environment will require new control systems to ensure the safety of both the robots and the people sharing the space. An industry need for more accurate and more productive assembly line robots is now driving development of haptic sensitive robots which can feel surfaces and modify their operations (such as sanding, polishing machine parts, and packing) in response to the varying objects and surface conditions. Furthermore, Bristol Robotics Laboratory (2007), in a three year project into the Human Robotic Interface (HRI) led by Dr Guido Herrmann, is researching feedback from haptic sensors in order to "soften" the motion of robots used in everyday tasks that bring them into contact with human beings, making them "more like us and less like their industrial cousins" (Bristol Robotics Laboratory, 2007, p. 10). It is envisaged that one application of the humanoid HRI is for service roles, such as care and companionship, medical therapy and rehabilitation.

Bionic surgery is also driving developments in touch- and tissue-sensitive robots (Tucker, 2007), to make the instruments more sensitive to the human touch. Such development work suggests that robots with sufficient haptic and visual sensitivity and awareness to work alongside multiple, moving, unpredictable human subjects, as in classrooms with 30 students of any age or in schools with perhaps 1000 - 2000 students, are a future possibility. In a school environment one of the prime considerations will be the safety of students when in the presence of robots. Vincent (2007) reports that the Next Generation Robots (NGR) starting from 2010 will show a "paradigm shift in safeguarding concepts". Industrial robots will provide more safety to users "incorporating inherent safety design and benign operating features that create a bubble of safety for robot operators" (Vincent, 2007, p. 25).

Far from the classic image of insensitive robots trampling over people, the future of robotics may provide for safer human-machine relationships that we are accustomed to. Imagine a car which had the cognitive ability to notice the toddler in the driveway and so refuse to reverse when the driver engaged the engine while the danger was present. Or a guillotine which "knew" when a hand was in the danger zone and automatically stopped the machine operating. In fact, in the tough school environment, robots may present a new control problem if they become the objects of vandalism or human maltreatment.

Support sub-systems

The industrial robot is well established, demonstrating 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. The most likely role for such robots would be in support systems as laboratory assistants, stores and resources handling and batch processing.

Industry is leading the way in developing the capacity of robots to do complex repetitive work to replace seasonal or temporary staff. Droste Holland (2007), chocolate manufacturers of the Netherlands, commissioned four robots to replace 14 temporary staff in packaging chocolates into speciality gift boxes, improving quality and productivity with a payback period of less than 18 months. With such strong financial drivers, robots are likely to take over more of this kind of work. As the range of functions and supply increases, it may become economic for larger institutions to purchase robots for all kinds of assembling and packaging work.

Robotic lawnmowers (Connolly, 2007a) are getting more sophisticated, from larger machines for sports grounds and golf-courses to the domestic market with a special niche market in rooftop garden mowers. This is indicative of a maturing of a consumer product and robotic mowers may well find their way into schools. Robotic vacuum cleaners are another likely member of support systems. Also on the market are mobile service robots with the capability to interact with and assist humans in typical housekeeping tasks such as cleaning glass facades and floors, maintenance and inspection, walking aids, and more. Such robots may be able to manage similar support functions for schools.

Robots used in the area of rehabilitation are likely to enter the classroom attached to individual students. Robotic limbs and equipment will act as supports for students with disabilities to achieve greater parity of access to learning with other students. Experiments in the U.K. (Cooper & Keating, 1999) have showed that robots enabled students with disabilities to do tasks otherwise impossible, such as remote manipulation of equipment, which gave them more direct interactions with the world than a passive role of watching others, such as in science experiments. Even in free play with objects, such as pouring water from one vessel to another, robots put the students on more equal terms with their peers. Students with a variety of disabilities which require human assistants today may well come to class with a care-robot tailored to meet their specific need. Protocols for interacting with such combinations of student and dedicated robotic support will need to be developed.

Potential Robot Development

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; likewise, human teachers have enjoyed a long and relatively successful history. Off-the-shelf robots may meet specific needs in the control and support systems. The questions which are most open to debate are to what extent can robots be used to increase the capacity of human beings and enhance their human performance and how can this approach be applied to education and training.

Education per se tends to be an under-funded area for research and development of new technology. However, industrial, military and medical uses are financing dramatic improvements in robotic functionality and reliability. For example, stimulated by the casualties suffered through the Iraq war, the US Department of Defence is actively supporting research designed to improve soldiers' "wellbeing" through its Peer Reviewed Medical Research Programme established in 1999 to promote military health research (Edwards, 2007). As part of this programme, Vecna Technologies has developed the BEAR, a 6 foot tall, mobile robot able to use its arms to rescue injured soldiers from the battlefield. Amongst other features such as night vision and infrared sensors and the ability to climb stairs, it has a teddy bear like head designed to comfort and reassure casualties (Edwards, 2007). In addition, advanced research is enabling improved rehabilitation of severely injured soldiers by using robotic ankles, hands and limbs. These use feedback from the environment to provide more natural movement. These may even enhance speed and abilities in a supra-human way. This accelerated research programme will quicken the pace of change in the wider community.

Funding need noh3t come from education budgets. Educational robots which are fast-paced, rugged and versatile may evolve from those developed for military use. Robots used in medicine may offer new ways to rehabilitate and integrate people with disabilities and will enter the education system with the individual. There is a potential for medical robotics to be extended into new training techniques. Some industrial robots may be sufficiently generic in their application to be used "off the shelf" in the education system and, once a consumer item, be affordable. Furthermore, as IBM has done with the electronic Braille tutor, private enterprise may also sponsor developments specifically for educational use.

Conclusions

If one considers that the adoption of robots by the education system could follow a similar pattern to that of the adoption of personal computers, and given that robotics is a fast advancing field with increasing numbers of industrial, military, medical and even domestic consumer applications, it would appear timely for educationalists to plan strategies for a world with robots. However, this paper argues that it is unlikely that one form of robot will meet all the needs of the education system. Thus, consideration of a model of education with a number of functional areas would have potential for different forms of robots being required for each of the different areas of the education system.

This paper has outlined four functional areas in an education system and grouped robots into these areas to facilitate discussion of how robots may "fit" within education. This basic framework is suggested for use when evaluating the types of robots available and the benefits they can bring to education. Clarity of purpose will be the first prerequisite for purchasing off-the-shelf robots for school use as well as for the programmers and instructional designers when called upon to design or adapt robots for use in an education system.

While this paper has identified a framework, it has not covered in detail all possible existing or future developments - such as the development of robot networks or robots themselves becoming learners within the education system. Neither does it attempt to detail the operating principles which would be required for real world applications of robots in education. What the authors hope to do is to raise awareness and interest in this area and challenge educationalists to begin forward planning now.

It is the authors' view that, if our technology-intensive information society continues its present trend, unimpeded by recession or climate change, robots will feature more prominently in the near future - a robot near you is no longer a fantastical idea. To remain relevant to that society, it may be that its education systems will need to adjust and adapt accordingly.

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