The e-Robot Project: A Longitudinal On-Line Research Collaboration to Investigate ERA Principles

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Abstract The Educational Robotic Application (ERA) Principles provides a framework for evaluating Educational Robots and their activities. This paper presents the rationale behind the proposed e-Robot Project, an online community based research resource aimed at gathering data on the use of educational robotics. Collating the data against ERA is an iterative process that will simultaneously verify and improve ERA, which in turn will inform the design and application of educational robotics. e-Robot involves all aspects of the research process from research design to meta-analysis. The project can run indefinitely and will encourage participation from student teachers, teachers, researchers, developers, administrators, politicians and other interested parties.

Keywords: Educational Robotics, LOGO, ERA, Roamer, Education Research

1 Introduction

Writing in the Scientific American, Bill Gates predicted, “Robots will be the next hot field” [1]. Certainly, this rise in popularity has started to appear in education. The first Educational Robots emerged with Logo in the late 1960s and early 1970s. While the use of computers was extensive and received a lot of academic attention, robots stayed in a niche with only a few small, specialised companies providing hardware to schools[1]. The launch of Lego Mindstorms in 1999 raised the profile of robots as educational tools. Since then the availability of affordable technology with the power to support interesting educational robotics has inspired a proliferation of new robotic systems.

This paper presents the rationale behind the proposed e-Robot research project sponsored by Valiant Technology. e-Robot aims to set up a community based online research collaboration that will inspire, gather data and collate multiple research projects using the Roamer® robotic system. The programme will use the ten Educational Robotic Application (ERA) Principles [2], [3] as an evaluation framework. Derived from research and practical experience of robots in classrooms over the last 30 years, ERA needs rigorous testing. The e-Robot project aims to verify and where necessary modify ERA. This paper summarises the Principles. Then it presents an analysis of educational research and the issues affecting Educational Robots. Finally, it presents an outline of the e-Robot Project.

[1] Valiant Technology produced the Valiant Turtle (1985) and Roamer (1989 and 2010). Swallow Systems made PIP (1990) and Pixie (1990). All UK Primary schools have one of these robots.

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2 ERA Principles

We will refer to the ERA Principles throughout the paper. To aid recall we loosely group the principles under three headings. In practice, the Principles combine to describe the nature and the value of educational robotics and robotic activities.

Table 1: The Ten ERA Principles

Technology		
1.	Intelligence	Educational Robots can have a range of intelligent behaviours that enables them to participate effectively in educational activities.
2.	Interaction	Students are active learners whose multimodal interactions with Educational Robots take place via a variety of appropriate semiotic systems.
3.	Embodiment	Students learn by intentional and meaningful interactions with Educational Robots situated in the same space and time.
Student		
4.	Engagement	Through engagement, Educational Robots can foster affirmative emotional states and social relationships that promote the creation of positive learning attitudes and environments, which improves the quality and depth of a student's learning experience.
5.	Sustainable Learning	Educational Robots can enhance learning in the longer term through the development of meta-cognition, life skills and learner self-knowledge.
6.	Personalisation	Educational Robots personalise the learning experience to suit the individual needs of students across a range of subjects.
Teacher		
7.	Pedagogy	The science of learning underpins a wide range of methods available for using with appropriately designed Educational Robots to create effective learning scenarios.
8.	Curriculum and Assessment	Educational Robots can facilitate teaching, learning and assessment in traditional curriculum areas by supporting good teaching practice.
9.	Equity	Educational Robots support principles of equity of age, gender, ability, race, ethnicity, culture, social class, life style and political status.
10.	Practical	Educational Robots must meet the practical issues involved in organising and delivering education in both formal and informal learning situations.

3 Background and Terminology

Originally, the constructivist ideas of Piaget and the constructionism concepts of Papert provided educational robotics with their developmental and philosophical foundations. ERA's Curriculum and Assessment Principle is more eclectic and pragmatic. It views all developmental theories not as description of "absolute truth", but as ways of viewing, analysing and explaining the educational experience. If a theory provides a useful account then it has value. This pragmatic attitude allows for the inclusion of social theories and even behaviourist ideas.

These "grand theories" of development do not describe teaching methods. Developing effective ways of putting theory into practice constantly evolves [4]. The Science of

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Learning [5], [6] is better suited to this process. Whereas developmental theories provide a "big picture", the Science of Learning works at the functional theoretical level [7]. It asks smaller questions, investigating the link between theory and practice. ERA Principles falls within this enterprise.

Despite the tolerant viewpoint highlighted above, ERA intrinsically leans more to social developmental theories and its traditional constructivist roots. Our normal use of constructivism and constructionism refers to teaching practices and the practices embodied in ERA and the Science of Learning. We use these terms and "progressive teaching" interchangeably. We use the opposite terms "traditional teaching" and "instructionism" synonymously.

4 Research Paradigms

The paradigm wars raged in the 90s between quantitative and qualitative research programmes [8]. These opposing forces differ in four respects [9]. Table 2 presents a sense of these paradigms and their implications.

Table 2: Characteristics of opposing social and research paradigms

	Positivistic (Quantitative)	**Nominalist (Qualitative)**
Ontological	Reality is objective.	Reality is subjective.
Epistemological	Knowledge is tangible and capable of direct transmission.	We construct our own meanings.
Response to the environment	Deterministic reactions	Reaction depends on our mental models of the world.
Methodology	Use quantitative research methods.	Use qualitative research methods.

The type of research questions we ask and evidence we seek emanate from our viewpoint [10]. Many of the conflicts in education arise from adherence to these ideological and philosophically opposed paradigms. Johnson and Onwuegbuzie [11] claim that positivistic researchers include qualitative aspects in their work and nominalists cannot escape positivistic elements creeping into their efforts. They and others promote a mixed-method approach. The pragmatic nature of this strategy resonates with ERA and e-Robot adopts mixed-method as its research paradigm.

5 Research Hierarchy

In the USA, the No Child Left Behind (NCLB) Act recognised different research methodologies. Its proposed hierarchy of importance makes Randomised Control Testing (RCT) the gold standard [12]. In the UK, Professor Tymms offers the 6-stage hierarchy summarised in Table 3.

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Table 3 Testing Hierarchy - adapted from Tymms [13]

1.	**Opinion**	A single person's opinion
2.	**Expert Consensus**	A group of experts get together and decide what the best way forward should be.
3.	**Studies**	Non-experimental studies – e.g. case studies – essentially observations about the world
4.	**Quasi Experiments**	In these efforts, we try interventions and look for the response, but do not use control groups.
5.	**Single RCT**	In this method, we use control groups of sufficient size, which we have made equal. Then we randomly choose which group we subject to the intervention under study.
6.	**RCT Reviews**	At this level, we systematically review the results of several RCT Studies.

We do not wish to denigrate the value of RCTs. However, we agree with other critics who question its proposed dominance [14]. One of our complaints is that it judges different aspects of the scientific process as more valuable than other parts. In doing this, it suffocates scientific innovation and insight.

The battle between Ludwig Boltzmann (who's "opinion" was known, as the kinetic theory of gases) and the arch positivist Ernst Mach were emotional and intense. The dispute centred on Mach's refusal to accept something he could not see - the atom. It cumulated in Boltzmann's suicide, ironically 18 months after the publication of Einstein's paper on Brownian motion had provided strong evidence to the existence of atoms and molecules [15]. It is worth reminding ourselves that speculation about atoms had been around since Democritus, circa 460 BC, and had received a significant boost with John Dalton's work on molecular theory [16]. Our point is that conjecture is a part of the process in hard sciences and it can take a long time to gather evidence strong enough to transform it into a theory. We need to allow this to be a part of education research process[1].

Either lack of resources or the nature of the research topic makes it impractical for some areas of education research to meet the gold standard [17]. This occurs in the hard sciences. For example, we could not subject the theory of evolution or the theory of plate tectonics to RCT experiments. Their proof lies in their predictive capability not in our capacity to statistically analyse experimental results.

Qualitative approaches like ethnomethodology, phenomenology and symbolic interactionism, and techniques like case studies, action research and accounts are ideal for investigating educational robotics. Research projects using these methods are normally small scale and produce descriptive data. e-Robot offers the prospect of gathering data from multiples of tests of this type. We propose that, irrespective of the specifics of these studies, we would expect to see the ERA patterns within the data. This *may* make it suitable for mathematical analysis, even meta-analysis as we gather data from different types of studies, but all supporting an ERA hypothesis. Imagine data from a single RCT test supports proposition A and 10,000 qualitative studies support Not-A. Would the "gold standard" trump this claim? We will discuss the weighing of evidence later.

[1] We do not accuse all protagonists of hierarchies of not valuing other parts of the scientific process. However, it is clear that this has a political impact – for example under NCLB, Federal funding can only be spent on gold standard proven projects.

6 Learning Environments

The scientific process involves discovering cause and effect relationships. Generally, it does this by watching what happens when we control specific variables. This is fundamental to RCT, but provokes some criticism. Morrison [18] argues the process of isolating variables neglects the fact that education is about the interaction of multiple variables. The laboratory like conditions of RCT has its limitations because the conditions are not necessarily replicable in the classroom. Moreover, if we stick to strict scientific protocols, changing the conditions in the smallest of details negates the evidence.

Dylan Wiliam [19] points out that even the best-regulated classroom is a chaotic place, only capable of description by Chaos Theory. According to this hypothesis, small changes to variables can dramatically influence outcomes. For example Verhulst's simple looking logistic equation $X_{Next} = rX\ (1-X)$ contains one variable x and a constant r. It describes population growth. Small changes in r can dramatically change the values of x [20].

Classrooms are full of variables. Of course, there are many macro variables like the socio economic status of the community the school serves, resources, the training and experience of the teacher, etc. Research often takes some of these factors into account. However, it is our view that micro factors can influence the situation far beyond expectation. We can understand micro factors by thinking of how fine-tuned Olympic athletes sometimes under perform because of a virus, a miniscule disruption to their mental attitude, a dietary issue… We should note that a change in their performance is not isolated – it affects the whole competition, the team, the games and even the morale of countries. "Evidence" exists claiming that many similar factors can affect a student's performance, [21], [22]. Admittedly, much of this is to education what homeopathy is to medicine. It falls into the category of pseudo science. Nevertheless, keeping an open mind we have to admit that some of these factors might occasionally influence the outcome of some lessons.

7 Theory and Praxis

Thorndike pioneered the application of Scientific Based Research (SBR) in education. He was very much the scientist dispensing wisdom to classroom drudges [23]. Teachers were there to apply other people's thinking. Nothing in Tymm's hierarchical description involves an intelligent thinking practitioner. The opinion is not the opinion of a teacher. The consensus is by "experts" and the studies are researchers watching teachers perform.

In most disciplines, science informs praxis; it does not dictate it. For example, when solving dynamic problems, engineers will use Newton's laws and not the correct scientific theory - Relativity. They will do so because Newton meets most practical needs and is simpler to deal with. Engineers will also make professional judgments on whether they should apply structural calculations to a design. Of course they evolve a body of good practice, which might dictate that in certain cases you always perform such calculations – e.g. to comply with building regulations. However, such codes are the province of the practitioner, not the scientist.

Sometimes research shows strong evidence to support a particular relationship. Right-wing activist Paul Ciotti [24] examines the case of Kansas City, Missouri, School District. In 1985 a Federal judge intervened in an effort to bring the district into compliance with a

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"liberal" interpretation of Federal law. After 12 years and an expenditure of $2 billion, the schools showed no improvement. Ciotti has no doubt that this explodes the "myth" of funding/class size relationships. However, does it? The school system needed not just funds, but a systemic change. According to the ERA Practical principle, apart from resources, implementing successful change requires vision, participant buy-in, teacher training and an action plan. Coitti's report makes it clear that the initiative lacked all of these. This is a clear example where the benefits of generally accepted principles being lost in poor implementation.

An assumption implicit in the SBR demand is that teaching is a science, not for example an art. We would not think of a designer or an architect purely in terms of their technical skills. Carr [25] argues, "*...teaching [is] implicated in a web of complex intellectual, moral and normative questions which must certainly exhaust any training in mere techné*".

8 Research Domains

We believe that e-Robot needs to conduct research in three interrelated domains:

1. Political — This focus aims to inform politicians, school administrators and the public about the nature and value of Educational Robots.
2. Scientific — This research aims to gather data to verify and develop our understanding of the ERA Principles.
3. Educational — This research aims to build an evidential database that will help teachers in the effective use of Educational Robots for the benefit of students.

What counts as argument and evidence differs for each domain. Nevertheless, we anticipate that the results will combine symbiotically and provide a strong evidential basis. Conflicts will indicate the need for deeper investigations.

The prevailing political mood in the USA and UK is for Standards Based Education based on SBR. Governments hold schools accountable and evaluate them through high stakes testing. Corporate pressure [26], [27] concerned with ensuring their future supply of skilled staff, and parental desire to evaluate schools before sending their children to them demands simplistic data provided by test scores. The problem is not the scores, but our attitude to them. The Cambridge Review of the Primary Curriculum [28] concluded that (Standardised) Test results are a poor way of measuring pupils' attainment, teacher and school accountability. Further, national monitoring and high-stakes use of test results leads to practices (like teaching to test) that have a negative impact on pupils.

Traditional teaching enthusiasts claim that instructionism gets better results than constructionist approaches. As far as we know, there is little hard evidence to support this. Bennett produced data damming progressive teaching and upholding good old-fashioned instructionalism [29]. Critics called into question the design and interpretation of Bennett's research [30]. Bennett and colleagues revaluated the work and concluded that there was not a difference [31].

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Despite these issues, we believe it is essential that we can demonstrate the effectiveness of the Curriculum and Assessment Principle. This will provide politicians and administrators with the data they need to support the inclusion of robots in educational programmes. It will provide teachers with the encouragement that the technology can assist their task of meeting the demands on them. Moreover, it will refute the main argument of gainsayers of progressive education.

Robotics is a rapidly maturing field. ERA helps us harness the technology to benefit education. It is essential that we verify and improve our understanding of its concepts. This is the objective of the scientific domain. Some ideas within ERA need more evidence. For example, the Embodiment Principle claims there is a difference between engaging with real robots compared with virtual machines. Most teachers, with experience of using educational robots would agree, but it is a claim not substantiated by any type of study. Developing ERA provides us with a better understanding of how to create useful robots and robot activities and it is essential that we formally build evidence that deepens our understanding of its Principles.

We have argued that role of the teacher is more than unthinkingly implementing some scientific dictat. Teachers spend much of their time in dynamic interactions with students. They cannot stop and consult a science book to see what course of action they should take for each situation they encounter. They cannot subject each intervention to a RCT experiment before they decide what to do. Teachers rely on their expertise. The cultivation of expertise requires the formation of a community of best practice. Like any other profession, teachers can only do this by sharing their experiences. Yes, it needs input from SBR and other aspects of educational research. However, if you ask teachers what they value, they will ask for descriptive accounts and case studies. In these things, they find suggestions on what they can do and how they can improve their teaching.

9 e-Robot

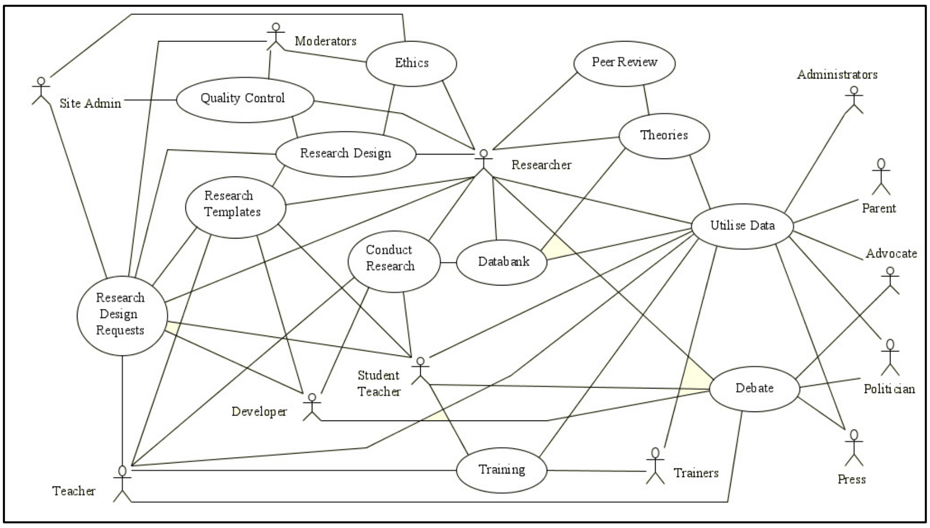
We want to emphasise that we are not anti RCT. We are against the "gold standard" and hierarchical mentality. We are not against quantitative research. We are against the idea that this is "the only game in town". We particularly believe a lot of insight into the nature of educational robotics will derive from qualitative methods. However, if we can gather enough data from these methods then we can conduct a meta-analysis using numerical techniques. Above all, we recognise that this task is something beyond the scope of a two or three year project. The nature of the evidence is cumulative and the longer the project can run, the richer the resource will become. A community project using Web 2.0 technology is the only way of conducting such an enterprise.

We believe a range of motivations will persuade people to participate. For example, teachers in the USA will be able to gain teacher credits[1] for their participation. For student teachers it provides the opportunity to engage in authentic research as part of their training. By providing them accounts of how colleagues have used the robots, the site will help train practicing teachers. Those seeking funding could use the site to gather the evidence they need to present to funders. Educational researchers will find the site useful for

[1] To maintain their certification American teachers must acquire training credits each year.

disseminating information on their efforts. More importantly, they might find the database a useful source of information for their projects. There may be other drivers that encourage researchers, outside the Anglo American influence, to participate. The democratic nature of Web 2.0 is that participants will shape the nature of the enterprise. So the longer the project runs, and the more diverse the participants, the project will become more representative of different attitudes and approaches. We believe the site could provide political evidence to make the general case for the use of educational robotics. Large robotic adoptions by school districts will offer opportunities to provide administrators with the means of monitoring a project's impact and progress.

Fig 1: UML Use Case diagram shown shows the anticipated use scenarios for e-Robot. Actors can play several roles (e.g. moderator and researcher).



Our critical challenge is the creation of research templates that non-expert researchers can use. Because we need to understand how the robots work in a variety of classroom set-ups, we do not believe all research projects need to use control groups. However, this does not mean the research should not comply with high quality standards. We also acknowledge the technical nature of research, which in the main, is beyond a layperson's skill. e-Robot plans to work with some professional researchers, whose task will be the development of these templates. They will also advise on research designs put forward by individuals and respond to requests to design methodologies for particular research questions.

It is crucial that we control this through appropriate ethical polices. In an excellent paper on the issues, Jones starts by claiming the poor quality of the TIMSS[1] makes it virtually worthless [32]. He cites Sackett whose analysis showed that 56 possible biases could creep into research projects [33]. Of these, 27 occurred in the planning and design phases and 18 in execution and data collection: only 5 belonged to analysis and 6 to interpretation. The

[1] 3rd Survey

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latter two are less important because you can always correct these problems. Unless you repeat the tests, the other flaws are fatal. We intend to follow the policies outlined by Jones.

In England, the Report of the Expert Group on Assessment is empathetic to the attitude of e-Robot [34]. It lays emphasis on assessment, particularly formative assessment, instead of testing. More and more educational robotic activities will become available[1]. Activities need assessment schemes built into them. These assessments can form a vital source of data. We need to work on how we can create these assessments, and in particular, how we account for the integration of the robotic work into the other efforts of the classroom. In addition, we need to explore how we assess the longitudinal education aspects of robotic encounters. This will be the subject of another paper.

ERA has a specific role to play in all of this. For example, we can summarise data from diverse activities with the general rule expressed by the Curriculum and Assessment Principle. Other examples include: In what ways did the robot engage students (Engagement Principle)? Are the pupil's sustainable learning skills growing (Sustainable Learning Principle)?

This brings us to the final issue mentioned at the end of Section 5. The evidential hierarchy provides a heuristic for judging the value of evidence. As we have argued, the situation is more complex than such a simple approach can cope with. The only way forward is the time honoured scientific debate. This may be inconvenient. Nevertheless, just as scientists gathered more and more data to affirm the atomic theory, so evidence will accumulate around the use of robots. This is why the e-Robot proposal does not have a proposed time limit.

We plan to develop and launch the e-Robot forum in Spring 2011.

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