Educational Robots: Past, Present, Future

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Abstract

Over fifty years ago, Seymour Papert invented the Turtle, the world's first educational robot. In doing so, he created tools that supported a Constructionist approach to education. A hero to many people, he challenged the established teaching methods and principles, upsetting traditionalist educators. What were Papert's educational ideas? When he began formulating them, robots belonged to the pages of science fiction stories; we now have robots with what some people call Alien intelligence. Saudi Arabia has granted citizenship to the social robot Sophia, and many countries ponder the status of such robots; do they need protection from humans or humans from them? How will they change our world? Should we invite them to our schools and ask them to look after and educate our children? Irrespective of whether we should or shouldn't, we continue developing technology that could become robot teachers. Will that bolster the traditional factory education model, or do Papert's ideas still have value and offer a better way forward? This is what we will explore.

Keywords
Social Robots, Seymour Papert, User Robots, Turtles, Roamer®, Constructionism

Introduction

The first educational robot, the Turtle, came to life in January 1970. We will review the academic credentials of this robot before peeking into the future and suggesting how social robots can combine with these early efforts.

> "Margie always hated school, but now she hated it more than ever. The mechanical teacher had been giving her test after test in geography and she had been doing worse and worse until her mother had shaken her head sorrowfully and sent for the County Inspector" (Asimov, 1951).

In Issac Asimov's story, *The Fun They Had*, personal robot teachers teach home-schooled students, and the Inspector is a robot mechanic. Margie's friend, Tommy, had found “a real” book telling them about school centuries ago. Margie complained the school still had a teacher, prompting Tommy to say, “...it wasn't a regular teacher. It was a man.” Shocked, Margie responded, saying she wouldn't want a strange man in her house. Tommy explained that in those days all the children went to a building, and the teacher taught everyone at once. “But my mother says a teacher has to be adjusted to fit the mind of each boy and girl it teaches, and that each kid has to be taught differently.”

According to Sir Anthony Seldon, Vice Chancellor of the University of Buckingham, “Robots will begin replacing teachers in the classroom within the next ten years in a revolution in one-to-one learning” (Bodkin, 2017). If robots were to replace teachers, we need to understand what they're replacing. What makes a good teacher? What do they do? Suzzane Bouffard claims teaching is an art and a science (Bouffard, 2018); can robots simulate a flair for teaching or would they have stilted personalities and teach robotically? We must consider what makes good teaching: Will the robot crank out questions, or is something else possible? How must we organise education to support the regular use of robots? Asimov’s story imagines home-schooling with the robot teacher firing test questions at the hapless Margie. Is this practicable? Is it desirable? These questions raise ethical, psychological, and social issues that we must answer.

We will examine the work of the father of educational robots, Seymour Papert. While his technology belongs in a museum, his educational principles don't[1]. Two foundational ideas underpin Papert's educational thinking. First, he didn't want to find a better way to teach, he tried to find a better way for pupils to learn (Papert, 1993, pp. 82-105); second, he asked: “Do we want computers to program kids or kids to program computers?” (ref). Reviewing his work, we uncover ways to adapt robots with social abilities and keep his principles intact. In doing this, we will reference the *Educational Robotic Application (ERA) Principles*, which Catlin and Blamires wrote based on 3 decades of working with robots in schools (Catlin & Blamires, 2010).

Then we’ll appraise the history and ideas of social robot teachers and teaching assistants before looking at some prophecies of their future. We'll critique the political and economic ramifications of robot teachers and classroom assistants. Then, we'll finish with an alternative idea of robots as teaching aids managed by teachers. First, we want to answer a simple question, “What is the purpose of education?” Philosophers have debated the issue for aeons; countries adopt different strategies, and the approach in many countries changes with the political wind. Despite this, 192 countries have approved UNESCO's Rights of the Child in Articles 29 and 30 (UNESCO, 1989). In the associated document “The Right to Education” (UNICEF, 2001) elaborates on the convention, effectively defining the aims of education and implying how we should implement it.

> “The development of the child’s personality, talents and mental and physical abilities to their fullest potential.”

[1] We use dated educational reference because their relevant and valid. You can trace good educational practice back to Confucius, Aristotle and others.

> "Education must be child-centred and empowering. This applies to the curriculum as well as the educational processes, the pedagogical methods and the environment where education takes place."
> "Education must be provided in a way that respects the inherent dignity of the child and enables the child to express his or her views in accordance with article 12 (1) and to participate in school life."
> "Education must include not only literacy and numeracy but also life skills such as the ability to make well-balanced decisions; to resolve conflicts in a non-violent manner; and to develop a healthy lifestyle, good social relationships and responsibility, critical thinking, creative talents, and other abilities which give children the tools needed to pursue their options in life."

This answers our question and sets our objectives: school education should benefit the quality of the child's life, but job training isn't the responsibility of school education —that comes after school. Plato supported the notion that we should educate people for a role in life (Cooper, 2001). Aristotle thought we should develop a pupil's talents; however, he realised that talented people would cope with the vagaries of the future better than those trained for specific tasks (Hobson, 2001).

We will refer to the EduRobot Taxonomy, which classifies robots used in education, ranging from toys to the most sophisticated robots laden with AI[1] (Catlin, et al., 2018).

- **User Robots**: you can take them out of the 'box' and immediately use them in a lesson (Example: Turtles).
- **Build Robots**: students learn by building the robots for a purpose (Example: Lego Mindstorms).
- **Social Robots**: Autonomous robots that, "Interact and communicate among themselves, with humans, and with the environment and are designed to operate according to the established social and cultural norms" (Li, Cabibihan, & Kee Tan, 2011) (Example: Kaspar).

We need to explain a taxonomic rule with the example of a platypus, a mammal with reptilian characteristics (it lays eggs and the male is poisonous). Despite these traits it's still a mammal. You can build a Turtle (User Robot) using a Build Robot kit like Lego, but this doesn't make Lego a User Robot (Catlin, Kandlhofer, & Holmquist, 2018).

[1] The taxonomy doesn't include virtual robots.

Seymour Papert

Seymour Papert had a degree in philosophy, and two mathematics doctorates, he also worked with the developmental psychologist Jean Piaget before joining London's National Physics Laboratory computer team. In 1963 he went to MIT, then a hotbed of AI development. He wasn't out of place; his technical skills matched those of his contemporaries. But he also had a passion for education, leading him to develop Logo, a LISP like computer language for learning and the world's first educational robot, the Turtle. Papert explains:

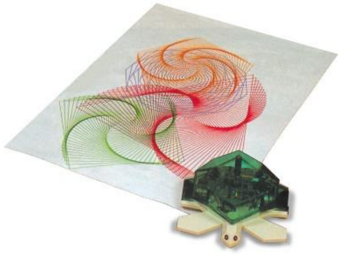

Figure 1 The Valiant Turtle 1985.

> "[Logo] We tried to achieve a number of goals, first of all that it should be easily accessible, there should be corners of the language that you can get into like baby talk in English that are easy for the youngest beginner. But it shouldn't be a toy language. It's not that Logo is easy, it's easy to get into but once you're in there you can progress to the most sophisticated ideas in the world of programming just as in English you can start off with baby talk but the same language is also the vehicle for the expression of poets and philosophers" (Papert, 1983, p. a).
>
> "The Turtle started because I wanted something that could be picked up by very young children. Now I think of it as something that is just as valuable for people of any age as it is for the young children and again that's a general principle, what's good for thinking is good for thinking whether we're a 5-year-old or a sophisticated scientist" (Papert, 1983, p. b).

These aims led to people describing the language as low floor high ceiling. Later, Mitchel Resnik adjusted Papert's phrase to low floor, high ceiling and wide walls. "It's not enough to provide a single path from a low floor to a high ceiling; it's important to provide multiple pathways" (Resnik, 2018, p. 64). The metaphor also applies to the number of subjects students can explore with the software and robot.

The instructions needed to control the robot became known as Turtle Graphics, which formed a new geometry. Ableson and diSessa compared Turtle with Cartesian Geometry: Turtle Geometry code describes the nature of, for example, a rectangle; Cartesian Geometry code doesn't—it's more abstract (Ableson & diSessa, 1981, pp. 11-15).

Logo Code

```
TO RECTANGLE SIDE 1 SIDE 2
      REPEAT 2
           SIDE 1
           RT 90
           SIDE 2
           RT 90
```

Cartesian Code

```
TO RECTANGLE (WIDTH, HEIGHT)
       SETXY (WIDTH,0)
       SETXY (WIDTH, HEIGHT)
       SETXY (0, HEIGHT)
       SETXY (0, 0)
```

The Cartesian Geometry presents an abstract description of a rectangle related to the coordinate framework. The Logo code describes a rectangle in the form of a procedure, which the student can walk through, a process called ‘Playing Turtle’. Papert called the Turtle a ‘transitional object’ because it links the student's body awareness to the growth of their mental models. Sylvia Weir explained, “The inventors of Logo treated the physical Turtle as much the same as the screen Turtle, but children do not” (Weir, 1987, p. 156). The *ERA Embodiment Principle* states, “Students learn by intentional and meaningful interactions with educational robots situated in the same space and time” [1].

Papert explained his methods in a TV programme which showed children describing their projects (Papert & Solomon, 1971). The first task in any lesson is to engage a student's interest—hard to do for maths. But the children had decided what they wanted to do, which isn't unusual in an art lesson but rare for maths lessons? They were working as mathematicians, straying into topics done by older students.

Papert also drew attention to the girl who made a mistake. “The child doesn't have to be told by the teacher whether [she's] right or wrong [she] can see for [herself] whether it works, that's what science and knowledge are about.” Unlike school maths with right and wrong answers, Papert gave students tools they could use to explore mathematical ideas, and debugging is a natural part of learning. Using neural scans, Jason Moser and colleagues at Michigan State University have shown that making mistakes can increase brain activity and improve learning capacity (Moser, Schroder, Heeter, Moran, & Yu-Hao, 2011).

Papert agreed with the approach of Hungarian-American George Polya, who claimed his students knew many mathematical facts but didn't understand how to act as mathematicians. Polya introduced a set of mathematical heuristics used by mathematicians to study problems. Papert showed how working with Logo-and-Turtles gave students tools which naturally used Polya's rules-of-thumb; instead of focusing on mathematical facts and procedures, students learnt by doing and solving problems. However, you make a mistake if you think they don’t learn mathematical facts; their project dictates what they need to know, not an arbitrary curriculum.

When reviewing Papert’s book, The Children’s Machine, Daniel Dennett echoes these ideas when mentioning Logo. He comments, “But one can learn even more from ‘mistakes’ than from a string of successes—that is a central tenet of Papert's vision of learning, and he practices what he preaches” (Dennett, 1993). Dennett testifies his experience with undergraduates who were, “experts at piling in the facts, drilling for the big test—and they were pathologically uncomfortable in any setting where they had to think.” He ran a course using Logo which he thought was spectacularly successful: “The students forgot their phobias and inhibitions and took flight, creating a trove of idiosyncratic projects, effortlessly learning the fundamentals of programming, and building a robust base on which we could then help them construct a more ‘adult’ set of edifices.”

High school mathematics teacher Albert Cuoco got his students to use Logo to explore algebraic topics like functions, counting and mathematical induction, and number theory. In the Introduction to his book, he explains how Papert's ideas reflect good teaching practice.

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[1] We still reference Logo research when it’s relevant to the physical Turtle.

> "In school, the idea of using experiments to develop both conjectures and plausible arguments to support the conjectures was almost never discussed, and I arrived in high school thinking (like many people) that mathematics is a set of facts and procedures. Luckily, my high school mathematics teacher saw things differently; he immersed his classes in carefully constructed problems that required pages of calculations. These calculations were really mathematical experiments, and wonderful patterns emerged from them. I began to understand something that wouldn't be clear to me for almost another decade: the heart of mathematical research is tinkering" (Cuoco, 1990, p. 7).

Further serious studies showed the ability of Logo and Turtle robots to engage students in a diverse range of topics from beginner to expert levels. For example: Mathematics (Hoyles & Noss, 1992) (Hoyles & Sutherland, 1989), Language (Goldenberg & Feurzeig, 1987), Visual Modelling (Clayson, 1988), Computer Science, (Harvey, 1997a), (Harvey, 1997b) (Harvey, 1997c) and Special Needs Education (Weir, 1987). Classroom teachers have used Turtles in many other subjects: science, history, geography, art, design technology, social studies, religion. . .

It's interesting to compare Albert Einstein's views on education and how they succinctly align with Papert's thoughts (Einstein, 2023).

> "This is Piaget's real message, learning rooted in experience" (Papert, 1983, p. b). *"The only source of knowledge is experience" Einstein*.
> "Education has very little to do with explanation. It has to do with engagement; its falling in love with the material" (Papert, 1983). *"It is the supreme art of the teacher to awaken joy in creative expression and knowledge" Einstein.*
> "I believe with Dewey, Montessori, and Piaget that children learn by doing and by thinking about what they do. And so, the fundamental ingredients of educational innovation must be better things to do and better ways to think. . ." (Papert, 1972). *"Education is not the learning of facts, but the training of the mind to think" Einstein.*
> "The beauty of microworlds[1] lies in their ability to engage students in meaningful, self-directed learning. By experimenting within a microworld, learners develop a deeper, more intuitive understanding of the concepts being studied" Papert ref. *"I never teach my pupils; I only provide the conditions in which they can learn" Einstein.*

Constructivism, Constructionism, and the Maker Movement

John Dewey believed that teachers pass knowledge on to students, who rebuild it in a way that makes sense to them. Piaget calls this 'cognitive constructivism', and he believes this happens by: 'assimilation'—we absorb new information without changing our existing mental models and 'accommodation'—we accommodate the information by changing the model (Piaget, 1931). In essence, we construct our own understanding. Papert introduced the term Constructionism, which agrees with Piaget's theory. It adds a new perspective, "The idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public

[1] Microworlds contain objects, ideas, information and problems, which students explore with a robot.

entity, whether it's a sand castle on the beach or a theory of the universe" (Papert, 1991).

In the eighties, Papert and Harel formed the theory of Constructionism, and their adherents ran many projects (Papert & Harel, 1991). His ideas impressed Lego owner Kjeld Kirk Kristiansen, who asked him to develop Lego robots. Students started to design and build robots using Lego bricks, including a Smart brick to control the robot (Watters, 2015).

In 2006, Dale Dougherty promoted the idea of Maker Spaces, creating an international Maker Movement; he defined makers:

> "As someone who creates and shares projects. There are all kinds of makers. Some people make bread. Other people make airplanes. Some make sweaters. Others make robots. And some people make pumpkin-hurlers" (Dougherty, 2016, p. 41).

In creating the Maker Movement, Dougherty brought together different groups of hobbyists labelling them 'subcultures' which included hackers. The term hacker came from a group of MIT students who, in the early 60s, formed *The Tech Model Railway Club*. They wanted to computer-control their train sets, so they hacked into MIT's mainframe machines (Levy, 1984, p. 3). When Papert 'invented' Constructionism, he linked formal education with a mindset of hacker-like people who liked to find out stuff and make them work—people who learnt for the heck of it.

Early in the 1970s, a few teachers in the UK started to change workshop lessons, which taught metal and woodwork skills. They got their students to design and make their ideas, which began to include electronics, computing, control and robotics. In 1989, with the support of the Engineering Institutes, Design Technology became a subject in the UK's first National Curriculum. Both of these movements arose independently of Papert, and both reflected his idea of Constructionism.

Professor Michael Eisenberg extended Papert's notion of transitional objects to Constructionism. He discusses the potential of combinations of computation, intelligent and traditional materials to help enrich the goals Papert expressed in Mindstorms (Eisenberg, 2003). The KidStory Project is a practical (but independent) example of Eisenberg's ideas. Teachers and children collaborated to design and make tangible, intelligent tools, then used them to create storytelling Microworlds (Stanton, et al., 2004).

Robots Go to School

In the 70s and 80s, computers started appearing in UK and US schools. Logo and Turtles became popular in British schools, while the take-up in America was more sporadic. The 1967 Plowden Report on Primary Education in England put the ideas of Piaget at the heart of education (Plowden, 1967). In America, University education departments talked about Dewey. But schools followed the behaviourist ideas of people like Thorndike and Skinner, causing ex-Harvard Dean of Education Ellen

Condeliffe Lagemann to write, “Edward L. Thorndike won and John Dewey lost” (Lagemann, 2000).

The BBC ran an episode of their flagship science TV programme on Papert's ideas. Between September 1987 and December 1988, the British government ran a Turtle Logo project in 21 school districts using 350 robots. The positive results led to using 'programable toys' (robots) inclusion in the UK's first National Curriculum, published in 1989. They retained that place in all curriculum revisions. In January 1989, Valiant Technology launched Roamer®, (a Turtle), which you could program using its onboard keypad (not needing a computer). A few months later, Swallow Systems launched a similar product called PIP.

Teachers started using robots to improve lessons and found ways to integrate the technology into a wider range of topics. The British Educational Training and Technology Show (BETT) started an award programme. Enamoured teachers voted Roamer®, best Primary School product, reflecting a grassroots appreciation of Papert's ideas.

Fig 2. A: The Classic Roamer® a platform for constructionism. B: Examples of children’s designs. C: Roamer® transformed into a Greeting robot for the London Science Museum; it detected guests and told them how to get to the Japanese Robot exhibition.

Do Papert’s Ideas Work?

> “a good school, in short, is not a place of compulsory instruction, but a community of old and young, engaged in learning by cooperative experiment. . . the curriculum is to be thought of in terms of activity and experience rather than of knowledge to be acquired and facts to be stored” (Hadow, 1931, p. xvii).

Teachers don't sit around waiting for academics to tell them how to teach. The UK government tasked Hadow to discover what was happening in English schools, and his reports found good teaching practices existed long before the computer age. Papert seems to have arrived at the same conclusion with the added idea that technology could give students and teachers experimental tools they could use to gain experience. And so, he invented Logo and Turtles as tools to support that approach. Papert didn't claim these were the only tools, saying these were the first of many and went on to develop Lego robots and Constructionism (Papert, 1980, p. 11). But it's important to realise that he wasn't unique and he acknowledged others like Maria Montessori who had come to the same conclusions.

Some people say Papert's ideas don't work, so to make his ideas clearer we’ll address these issues. For example, Price makes many easily dismissed statements like, "[Constructionist say to know] Paris is the capital of France, it's necessary for children to construct this 'new' knowledge for themselves" (Price, n.d.). Papert noted, "[Piaget's method] does not call into question the value of instruction. That would be silly" (Papert, 1993, p. 139). Mr Price fails to recognise Piaget's cognitive theory, which explains a mental model that happens even if you tell the student the capital of France is Paris. If they didn't already know, then it's new knowledge, and according to Piaget, they will probably assimilate (memorise) that without subconsciously changing the structure of their mental models. But telling them 4 is a square number and 12 isn't is likely to change how they think about numbers—Piaget calls this accommodation.

A more rigorous yet flawed review of Papert comes from Morgan Ames (Ames, 2018). She cites several projects claiming they failed but neglects to mention the successful efforts, like the UK Talking Turtle project already mentioned. She ignores the 7 international projects published in the book Logo Philosophy and Implementation (Papert, 1999). The successful Costa Rican project is one of these. In 1988, the Costa Ricans invited Papert and his MIT team to set up their computer education using Logo and Turtles; the project is still running. However, Costa Rica continued with Papert's ideas, and in 2024 Harvard's ReVista magazine reported although the country faces significant future challenges, Costa Rica's educational strategy has led to economic development and improved employment opportunities, attracting companies like Intel, Amazon, HP, and Citi Group. And their focus on English and technological advancement "placed Costa Rica as a leader in innovation and technological advancement in the region" (Artavia, Ilie-Cardoza, & Fernández, 2024)

Ames cites Richard Mayer's paper, where he makes the case for methods of guided instruction, while debunking the discovery learning ideas of Bruner, Papert and Piaget (Mayer, 2004). The oft-quoted research of Pea and Kurland makes a similar claim (Pea & Kurland, 1984). However, Roy Pea stated, that when he saw Logo working in the way claimed by Papert it was because, "*Someone has provided guidance, support, ideas, for how the language could be used"* (Pea, 1984). They seem to ignore Papert:

> "Even the statement (endorsed if not originated by Piaget) that every act of teaching deprives the child of the opportunity for discovery is not a categorical imperative against teaching, but a reminder to keep it in check" (Papert, 1993, p. 139).

Teachers don't just start children on a project and then leave them alone, as Beryl Maxwell shows in an excerpt from the Horizon Talking Turtle video (add ref). The teacher's role transforms from "the sage on the stage, to the guide on the side" (Woolf, Beck, Eliot, & Stern, 2001, p. 143). Ames mentions and dismisses the work of Clements and Gullo (Clements & Gullo, 1984), which provides formal research evidence concluding Logo works, but they also support the role of the teacher as a guide. The Plowden report, for example, never suggested a teacher free classroom:

> "There is therefore, good reason for allowing young children to choose within a carefully prepared environment in which choices and interest are supported by their teachers, who will have in mind the potentialities for further learning" (Plowden, 1967, p. 195).

Ames cites several projects that fell apart once researchers left, and some of them blamed Logo: why? Papert answered these criticisms, “Consider for a moment some questions that are 'obviously' absurd. Does wood produce good houses? If I built a house out of wood and it fell down, would this show that wood does not produce good houses?” (Papert, 1987). His response drew attention to the issue of culture. Remember Hadow’s quote describing “A community of old and young, engaged in learning by cooperative experiment. . .” and Albert Cuoco’s High School maths experience provides examples of vibrant learning cultures with no technology involvement.

The *ERA Practical Principle states*: “Educational robots must meet the practical issues involved in organising and delivering education in both formal and informal learning situations.” Catlin and Blamires also point out that many education initiatives (not just Logo projects) “produce spectacular results in research or other controlled circumstances, followed by limited success or even outright roll-out failure.” They suggest one reason for this is the researchers 'parachuted in’ did the research then left without establishing a suitable culture. Even national initiatives heavily supported with training programmes fail if they don’t create a committed ethos. Table 1 based on work by Thousand and Villa (Villa & Thousand, 2005) explains what's needed to achieve systemic change, and what happens if an element is missing.

Table 1. Requirements for Systemic Change.

Vision	Buy-In	Skills	Incentives	Resources	Plan	Change
×	✓	✓	✓	✓	✓	Confusion
✓	×	✓	✓	✓	✓	Sabotage
✓	✓	×	✓	✓	✓	Anxiety
✓	✓	✓	×	✓	✓	Resistance
✓	✓	✓	✓	×	✓	Frustration
✓	✓	✓	✓	✓	×	Hard Work
✓	✓	✓	✓	✓	✓	Change

Ames believes in learning through collaboration and cooperation and thinks Papert’s ideas oppose those objectives. She fails to understand that learning is always personal, even when it takes place in a collaborative setting. When using Turtle robots or occupied on constructionism projects student’s normally work in groups. And the *ERA Sustainable Learning Principle*, notes the robot activities help students sharpen their cognitive aptitudes and develop personal, emotional, and social skills.

Schools

Papert didn't like school, perhaps because he was “home-schooled.” His father was an entomologist studying the tsetse fly. This meant Seymour spent his formative years living what Daniel Crevier characterised as something out of an Ernest Hemingway novel. His South African jungle lifestyle meant he'd lived among black Africans (Crevier, 1993, pp. 84-87). So, when the Papert family moved to

Johannesburg he suffered a cultural shock; his reaction to formal schooling and Apartheid got him into trouble (Levine, 2000, pp. 64-65). “Like most people with generally bad memories of school, I have wonderful impressions of individual teachers [Mr. Wallis]” (Papert, 1993, p. 58). Students often foster quality relationships with individual teachers. Yorkshire Television recorded an example of these connections when ex-Arsenal and England footballer Ian Wright met his old mentor Mr. Pigden (Theakston, Barker, & Jones, 2004). The *ERA Engagement Principle* recognises the bond children form with robots; Sherry Turkle and others show people treat robots as though they're alive (Turkle, Taggart, Kidd, & Daste, 2006); however, we doubt they could ever match the intensity of the Wright-Pigden relationship.

You could summarise Papert's well-known aversion to schools as his dislike of the education factory model. He didn't have problems working with schools like those in Costa Rica when they adopted a different approach. Morgen Ames stated, “School in Papert’s writing draws on a common US mythology of school-as-factory.” In 1913, Henry Ford began the world's first assembly line. In 1917, Dean of Education at Standford Elwood Cubberly used the factory metaphor to describe school.

> “The business of schools was to build its pupils according to specifications laid down [and this requires] continuous measurement of production to see that it is according to specification, the elimination of waste” (Cubberly, 1917).

Seldon and Abidoye are among many who disagree with Ames.

> “The third educational revolution introduced the factory model where massed ranks of students sat in front of a teacher/lecturer at the front of the room, all moving at the same pace and all trying to learn the right answers in the right way” (Seldon & Abidoye, 2018).

In his entertaining talk, *Changing Education Paradigms*, Sir Ken Robinson describes the factory model in detail, highlighting its unsuitability for the modern world (Robinson, 2011). In this and other presentations, Robinson summarises a view of education that empathises with Papert's attitudes towards schooling:

> “Human flourishing is not a mechanical process; it's an organic process. And you cannot predict the outcome of human development. All you can do, like a farmer, is create the conditions under which they will begin to flourish. So, when we look at reforming education and transforming it, it isn't like cloning a system, it's about customising to your circumstances and personalising education to the people you're actually teaching” (Robinson, 2015). “[What high performing education systems do] They individualise teaching and learning. They recognise that it's students who are learning and the system has to engage them, their curiosity, their individuality, and their creativity. That's how you get them to learn. The second is that they attribute a very high status to the teaching profession. They recognise that you can’t improve education if you don't pick great people to teach and keep giving them constant support and professional development. Investing in professional development is not a cost. It's an investment. [And] they devolve responsibility to the school level for getting the job done. You see, there's a big difference here between going into a mode of command and control in education. That's what happens in some systems. Central or state governments decide, they know best and they're going to tell you what to do. The

> trouble is that education doesn't go on in the committee rooms of our legislative buildings. It happens in classrooms and schools, and the people who do it are the teachers and the students, and if you remove their discretion, it stops working" (Robinson, 2013).

In this 2013 talk, Robinson identifies 3 principles on which human life flourishes and how we stifle them:

- Diversity: which we replace with conformity.
- Curiosity: If you guide and support children's curiosity, "they will learn without further assistance, very often." We replace curiosity with compliance—expecting children and teachers to do the same things and "follow routine algorithms."
- Creativity: instead of awakening creativity, education replaces it with "a culture of standardisation."

Reading the comments added to Robinson's talks reveals how his (and Papert's) ideas resonate with people's school day memories. In addition, a National Survey conducted by the Yale Center for Emotional Intelligence and the Yale Child Study Center reveals that 75% of students had negative feelings about school (Belli, 2020). If a company had that level of customer satisfaction they wouldn't survive long.

Teachers and Teaching

When learners reflect on what qualities they liked and remembered about a good teacher, their ability to engage them and support their learning experiences stood out.

- **Passion for Teaching**: Students respond positively to passionate teachers who love their subject and genuinely enjoy teaching. A teacher's enthusiasm can inspire students to engage more deeply with the material.
- **Effective Communication Skills**: Clear communication fosters effective teaching; educators who explain ideas clearly and actively listen to students will engage them.
- **Empathy and Understanding**: Teachers who empathise with their students, understand their needs, and provide support create a positive and inclusive learning environment which fosters trust between the teacher and student.
- **Creativity and Innovation**: Teachers who incorporate creative and innovative teaching methods can make learning more engaging and memorable for students. They can adapt their approaches to suit different learning styles and preferences.
- **Patience and Flexibility**: Patience is essential in handling diverse student needs and challenges. Patient and flexible teachers better support student learning and adapt to changing circumstances effectively.
- **Respect and Fairness**: Students appreciate teachers who respect them, value their opinions, and treat them fairly. Creating a safe and respectful classroom environment is crucial for effective teaching.

- **Sense of Humour**: The teacher's ability to use humour and see the funny side of things while still taking responsibility for behaviour and safety in the class

When educators blend these qualities with subject knowledge, social skills, and good classroom management, they create positive learning environments. But what of teaching styles? We've met a few metaphors explaining ways we teach: the sage on the stage, the guide on the side, the farmer, the factory model, command and control. . . Other metaphors for teaching and teachers include:

- **Chalk and Talk**: the teacher stands before the class and lectures the students.
- **Gardener**: Friedrich Froebel suggested teachers nurture and care for their students' growth, like a gardener tending a plant; this led him to invent, the kindergarten.
- **Demonstrator**: The teacher shows students a method or a skill, which the students then practice.
- **Facilitator**: The teacher organises projects or problem-solving tasks to engage students in discovery learning.
- **Coach**: Here, the teacher pushes students to exceed their limits and achieve their goals.
- **Manager**: As a manager, the teacher has to multitask before, during and after a lesson; tasks may include organising materials, classroom discipline, and looking after student safety.
- **Socratic method**: the teacher starts a debate among students and prompts student thinking by asking questions in the style of Socrates.

The *ERA Pedagogical Principle* notes 29 different characteristics of robot lessons (Catlin, 2016). You can use combinations of these as tags to define the nature of the activity. For example, a lesson using Roamer®, with number lines helps students **conceptualise** negative number arithmetic while they build a new **mental model** through **experience**.

Apart from the grand developmental theories of Piaget, Vygotsky and others, a set of principles emerged from research projects to form the Learning Sciences (Sawyer, 2006). The design of robots and lessons needs to utilise these findings, which include a student's prior knowledge, time on task, motivation, and context. Learning with understanding (a hallmark of Papert's ideas) proves better than memorisation. In an experiment, researchers gave two groups of students a series of problems to solve. They showed Group A how to get the answer but helped Group B understand the nature of the problem. They presented both groups with the final problem without any help. In response, Group A said, "We haven't done that yet," while Group B set out to find a solution (Bransford, Brown, & Cocking, 2000, pp. 51-78).

In the words of the Prussian General Helmuth von Moltke, "No plan of operations reaches with any certainty beyond the first encounter with the enemy's main force." (Ref) Less dramatically, neither does a lesson plan. Assessment for Learning (AfL) focuses on the learning process, as opposed to Assessment of Learning, which evaluates the results. AfL emerged in the late eighties and early nineties (McDowell, Sambell, & Davison, 2009). Professors Paul Black and Dylan Wiliam from King's

College London wrote a small, influential booklet, *Inside the Black Box* (Black & Wiliam, 1998). It reviewed what happened inside the classroom (the Black Box) and how teachers managed lessons. They defined AfL as "All those activities undertaken by teachers, and/or by their students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged."

Dave Catlin looked at how to apply AfL methods to educational robots

> "I found it puzzling that one teacher could use a robot and create a wonderful lesson, and another teacher with a seemingly similar group of children ran the same lesson but it flopped. Good constructionist teachers, faced with extremely diverse challenges, seemed to have a knack for doing the right thing at the right time, but I couldn't see a pattern in how they did it. AfL revealed heuristics, a framework plus 'tricks and techniques' employed by good teachers to make lessons work" (Catlin, 2012).

Dylan Wiliam explains "No Hands Up" as an example of an AfL technique (Wiliam, Dylan Wiliam on effective questioning in the classroom, 2019). Traditionally, a teacher asks questions, and children put their hands up if they know the answer. The same 4 or 5 clever students typically raise their hands, and the teacher chooses one to answer; meanwhile, the others daydream. With no hands up, the pupils don't know who the teacher will ask, so the class pays more attention. If the same pupils always answer, the teacher doesn't know whether the other 80% of the class understands the lesson. No Hands Up offers teachers better feedback. There's no point in them continuing and leaving most of the students behind, mystified; they should clarify issues before moving on.

Table 2: AfL Elements.

Element	Explanation
Learning Intentions (Catlin, 2016)	The student's perspective on what they're learning. These aren't the lesson objectives written in curriculum-speak but what the students say when they've understood the point of the lesson.
Success Criteria	How will the student recognise when they have successfully completed the assignment.
Quality interactions and feedback	Understanding in real time if the students understand or are confused by anything in the lesson. How the teacher responds to the feedback, interacting with student to help improve their educational experience.
Peer and Self-Assessment (Catlin, 2014)	What students think about their work and the work of their classmates—conducted in a way that helps improve the quality of their understanding.

But apart from such technicalities, there's a human story; London teacher Andria Zafirakou, winner of the 2018 Global Teacher Prize, explained:

> "There is no other job like being a teacher. In what other profession are you selfless and completely devoted to creating the right opportunities for another person to achieve? Being

> in a classroom and watching a student have an idea and transform it into a formidable outcome is so satisfying and fulfils me” (Varkey Foundation, 2018).

In an interview with Dominique Russell, Andria stressed the importance of forming a bond between the family, the school, and the child (Zafirakou, 2018).

Social Robots

John’s contribution.

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Robot Teachers?

Will we ever realise Asimov's prediction of homeschooling with robots? Given the state of today's technology, it's unlikely, but never say never! Should it ever happen? That's a different question, and you'll likely get a different answer depending on who you ask. However, it seems inevitable that politics and economics, not education, will decide. Visiting the Costa Rican project, A South American Finance Minister didn't embrace the educational spirit, instead expressed the desire for command and control, "You install machines. The children learn. Teachers are dispensed with. The State payroll shrinks. And best of all you do away with strikes" (Fonseca, 2001).

Every country's education policies differ. However, it's worth reviewing the journey of English education from Plowden's child-centred learning to today's sad factory model[1] (it represents situations familiar in many countries). Prime Minister Margaret Thatcher set a revolution in motion, slowly installing centralised command and control over British education (Beauvallet, 2015). Private entities now run UK schools as Academies, removing local government participation in education. Ofsted (Office for Standards in Education) took over school inspection, replacing professional civil service inspectors with part-time people. Their checklist school inspections are notoriously brutal and have led to suicide and significant mental stress. For example, an Ofsted inspector criticised a school because an 8-year-old girl hadn't made enough progress. Ofsted's mechanised evaluation couldn't allow for the death of the girl's mother.

We've mentioned heuristics like those of Polya and AfL (others include the Design Process and Computational Thinking). Instead of being tools teachers and students use as needed, they've become a set of rigid, must-do, or-else rules. Worse still, Ofsted doesn't grasp the thinking behind AfL. For example, inspectors criticise lessons if the teacher doesn't start by writing the learning intention on the blackboard, replacing the student perspective and understanding with the teacher's "this is what you're learning." AfL deals with the small exchanges between teachers and pupils in a lesson. Ofsted decided they wanted to know about these and lumbered teachers with another unnecessary administrative nightmare (Kirby, 2013).

Various organisations provide schemes of work, and there's anecdotal evidence that some school administrations insist that teachers follow each lesson plan without deviation. A "chef" in a fast food restaurant flipping burgers works to prescribed standards but doesn't have the enthusiasm of a Michelin-rated chef. Teachers not invested in the lesson plan lose their passion. This mechanisation of education makes it ideal for robot teachers but abandons the quality and principles of Papert and Robinson.

In the USA, book publishers create detailed lesson plans and fight over State adoptions. In a keynote speech at a teacher conference, Dylan Wiliam reacted:

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[1]The 4 countries in the UK have separate education systems, but they tend reflect UK national priorities.

> "[They'd] give these teachers scripts, you know, designed by experts on how to teach really well. And they were really scripts; there were things like 'Now, walk around the classroom' [laughter]. And the point is they were useless because classrooms are effectively chaotic places. Actually, even well-behaved classrooms are chaotic places, in that the difference between one course of action and another course of action is so small that it's effectively only described well by chaos theory. So, you cannot prejudge the complexity of the situations that teachers will face" (Wiliam, 2007).

The Esmée Fairbairn Foundation, a charity, commissioned Professor Robin Alexander to produce the Cambridge Primary Review Report, the most comprehensive education review since Plowden 40 years earlier (Alexander & et al, October 2009). The Guardian Newspaper headline reported, "Devastating criticism of primary education dismissed by ministers" (Curtis, 2009). Every teacher union backed the report, and some leading voices in education appealed to the government to act on the report's recommendations. Politicians, pressure groups and corporate interests also dictate the curriculum. Scientific American reported the Texas School Board voted to "emphasize the 'positive' aspects of fossil fuels in science textbooks" instead of allowing students to investigate and debate the issues (Waldman & E&E News, 2023). Board members included an oil company lawyer and the CEO of an oilfield service company.

Economist Stanislav Ivanov's paper "Will Robots Substitute Teachers" makes the economic case (Ivanov, 2016).

- **Unlike humans, robots and online AI technology is available all the time.** It isn't when the Internet is down, the batteries need charging, or the robot's blown a fuse. AI is already available all the time on computers or mobile phones. "As of 2018, mobile phone penetration is around 100% in low and middle income and 55% in low-income countries." (Farooq & Kustor, 2021).
- **Robots can simultaneously deliver multiple subjects with up-to-date knowledge**. Early Years and Primary school teachers teach all subjects. Thirty classrooms would need 30 teachers, human or robot; subject expertise is an organisational issue.
- **Robots provide constant or improving quality of work, whereas illness, stress, and many other issues can affect human performance.** The Asimov robot broke down—this happens to machines; they require regular maintenance. Teachers constantly improve with training and experience.
- **Robots fulfil their administrative work correctly and promptly.** The need to micromanage classrooms creates unnecessary paperwork.
- **Robots can repeat the explanations multiple times.** Teachers wouldn't try; they'd find a different way of explaining the idea.
- **Robots do not discriminate.** Neither do good teachers.
- **Robots do not complain.** This is a political desire to control society. It's got little to do with good education.

> "The class would take quite a long time to settle down. I noticed it was only a small group of students who caused the unsettling atmosphere. On a number of occasions this would last for the majority of the lesson. . ." (Barnett & Greenhalgh, 2003).

This incident occurred in Japan, demolishing the stereotypical Western view of ‘perfect’ Japanese schools! How would robots cope with disruptive students? Some teachers would consider this mild misbehaviour, and we need to understand how robot teachers would cope without becoming Terminators.

Could you imagine parents meeting with a machine to discuss their little darlings’ progress? Any Google search asking whether robots could replace teachers brings out a full range of answers, from uninformed to expert, ill-considered to deeply thoughtful. It’s hard to imagine robots forming affinities of the quality of Wright-Pigden and Andria Zafirakou’s parent relationships. But we must admit that, given the pace and scope of AI and robotic development, we couldn’t rule it out.

Astronauts aboard the International Space Station had to switch off their robot CIMON (Crew Interactive Mobile Companion) when it began to behave like Hal 9000 from the movie 2001 Space Odyssey (Kooser, 2018). Facebook shut down robots Bob and Alice when they stopped speaking English and started talking in a more efficient language they invented (Kenna, 2017). Glitches, teething problems? However, the ingenuity of such machines and our inability to predict undesired outcomes is the stuff of science fiction stories.

Figure 3 shows a version of Gartner’s Hype Cycle, which shows Amara’s Law: “We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run” (Netorama, 2012). We’re at the start of that cycle; there are many differing visions, hopes, and expectations. However, we need to look at the features of systemic change and get a clear vision of what education should be doing, and Papert and Robinson provide that.

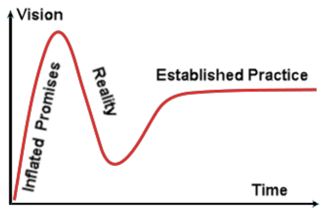

Fig 3. Gartner’s Hype Cycle.

Conclusion

On the one hand, we have the stark image of robot teachers manning the school production line, churning out children to a specification: it’s dehumanising. But so is Cubberly’s factory model when run by human teachers. We see the alternative in Asimov’s story, where Tommy and Margie engage in natural learning. Gripped by fervent curiosity, Tommy’s passion drives him to discover and prompts Margie to think and ask questions.

Papert’s ideas still provide the vision for a modern approach to K-12 education. Instead of robot teachers, tutors, or assistants, we prefer the idea of a robot teaching aid, which the teacher can use in a constructionist environment. Effectively, we see a User Robot (Turtle) with the possibility of social robot features. We can summarise some key ideas:

- The “low floor, high ceiling and wide walls” metaphor.

- Children teach the robot, not the robot teach the children.
- Learning by doing.
- Students learn by exploring Microworlds.
- Constructionism: students gain knowledge more readily by making.
- The teacher is more of a guide than an oracle of all knowledge.
- The ERA Principles should guide the development of the robots, learning activities and environments.

We've used Turtle robots for 54 years. Despite technological advances, the lessons devised for these simple robots still have educational value; they work, so why abandon them? We could use social features to improve some activities, but others don't need them. We must remember that it's not the technology that matters; what the children learn by using it counts. Often, using a super-sophisticated robot to help pupils understand a simple idea is like taking the proverbial sledgehammer to crack a nut.

A Turtle robot, like Roamer®, provides a platform teachers can configure in a few minutes to create the ideal robot for a lesson. Or, it's a robot that students can adapt to build a robot character from their imagination, using the arts, crafts, and construction techniques typically found in schools. This complies with the ERA Equity principle by encouraging children to express themselves and their culture. Making social modules available increases the scope and versatility of the robot and its applications. The ERA Interactive principle accepted that Human-Computer Interactions (HRI and HCI) would offer other ways for children to control Turtle robots. Social modules can make that a reality. The school could buy modules, or the students could make them. Eisenberg's paper about transitional objects outlines exciting opportunities for the new breed of Turtle. With Arduino, Raspberry Pie, and the BBC MicroBit, students or teachers can create intelligent Microworlds that children can explore with a Turtle with social abilities. Combining the increasing use of 3D Printing with traditional craft skills and the creative future looks exciting. These Maker challenges offer great potential for communal projects.

This evolutionary design approach creates robot modules to support specific lessons, correctly putting education before robotic development.

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