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TECHNOLOGY-ENHANCED LEARNING: REVIEW AND PROSPECTS

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ABSTRACT. This paper is a reflection on the history and future of technology-enhanced learning. Over the last century various new technologies were introduced in education. Often, educational revolutions were proclaimed. Unfortunately, most of these new technologies failed to meet the high expectations. This paper reviews the rise and fall of various "revolutionary" learning technologies and analyses what went wrong. Three main driving factors are identified that influence the educational system: 1) educational practice, 2) educational research, and 3) educational technology. The role and position of these factors is elaborated and critically reviewed. Today, again many promising new technologies are being put in place for learning: gaming, social web, and mobile technologies, for example. Inevitably, these are once again proclaimed by its supporters to revolutionise teaching and learning. The paper concludes with identifying a number of relevant factors that substantiate a favourable future outlook of technology-enhanced learning.

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Key words: Technology-enhanced learning, education, innovation, educational technology, research, computer, media, history.

Introduction. It is not easy to identify a starting point in the history of learning technologies. May be ancient cavemen were the first to use their chemically extracted colour pigments for the arrangement of painting lessons. Many centuries after, the invention of writing and the associated tools (goose pens, papyrus parchment) became important learning technologies that had great impact on culture, science and society as a whole. An unchallenged and persistent educational technology would be the chalkboard which forms the robust basis of group instructions as is the case in classroom teaching. Almost a century ago modern technologies like film and radio started entering the classrooms. These developments mark the start of systematic efforts for applying new technologies for learning and teaching. From the 1960s instructional television, tools for programmed instruction, audio cassettes and video cassettes became available. This is when the era of instructional technology started: cognitive psychology-based research on effective instructional methods. The advent of the microcomputer in the 1980s provoked a lot of new interest from educators. Computer-assisted learning developed into a well-established branch of so-called educational technology. Educational technology became the new all-embracing label, covering the study of learning and teaching, including instruction design methods, the supportive technologies as well as organisational and managerial issues. From the mid 90's the emergence of the internet enabled a new type of distance learning that used web technologies for the distribution of learning content across institutional borders. This so-called e-learning paradigm was revolutionary in that it greatly enhanced the flexibility of learning with respect to the time, pace and place of learning. For expressing the innovative power of the e-learning paradigm a new label was introduced: technology-enhanced learning. Initially, technology-enhanced learning strongly focused on learning content systems, content delivery and learning management systems, largely conforming to the instructional notion of information transfer. It is fair to say that learning content was often no more than printed texts that was digitised, along with some navigational structure and search options. Interactivity was low. Recent new technological developments like more powerful processors, wide band data networks, video streaming and compression technologies, webcams and powerful mobile devices procure a step change in the development of the world-wide web, turning it from a web of information into a web of people, services and things. Today, technology-enhanced learning has a wider scope, reflecting a branch of research that includes all types of socio-technical innovations for learning practices, regarding individuals and organizations (Wikipedia). It thus has become the topical successor of instructional technology and educational technology.

This paper is a reflection on the history and future of technology-enhanced learning. Over the past 100 years various new learning technologies were proudly announced, proclaiming great improvements for teaching an learning, but actually only few of these turned out to be successful. In the next section we will briefly highlight and review some major educational technologies of the last century. Three main driving factors are identified that influence the educational system: 1) educational practice, 2) educational research, and 3) educational technology. The role and position of these factors will be critically reviewed as well. Finally, we will identify a number of relevant factors that substantiate a favourable future outlook of technology-enhanced learning.

Review of proclaimed revolutionary learning technologies. In this section we will briefly explain and evaluate a number of major 20-th century's learning technologies: instructional film, Pressey's teaching machine, instructional radio, instructional television, programmed instruction, audio compact cassette, video cassette and the microcomputer. These technologies were all announced with great fanfare as the ultimate breakthrough that would procure a fundamental change of the educational system. But on close inspection they all failed to live up to their promises.

Instructional film. By the end of the 19^{th} century Thomas Alva Edison was the first to create the technology for recording and displaying (silent) moving images. His kinetograph, patented in 1892 [2], was a new type of camera that used film rolls rather than single plates for recording. His invention marked the beginning of motion picture. Edison had high hopes for the instructional value of this new medium. He claimed that film would revolutionise education by enabling a new modality of learning content, bringing recorded realities into the classroom. It was supposed to eventually make books irrelevant, because learners would no longer need to read texts about how things work in practice, but instead they could just watch the recordings. Like Edison many innovators had high expectations. But history took a different turn. First there were some technical practicalities linked with the size and reliability of projectors: the standard film size of 35 mm required bulky, noisy and expensive equipment, that displayed frequent failures. Secondly, the early celluloid strips were composed of cellulose nitrate which could easily break and was highly flammable. Third, the amount of available instructional films was quite limited and the licenses were expensive.

Also, the conditions for film projection in the darkened classroom with 50 or more pupils having different interests were not always favourable. Two additional circumstances created problems at the adoption of film by teachers. First, the swift successes of the motion picture as an entertainment medium made it suspect for teachers to use it as an instructional means. A next problem arose when the sound-film was gradually replacing the silent movie. Now teachers started to oppose against films in their classrooms because they claimed to be the only one responsible for the narration: as a teacher they could do the talking themselves! The build-in narration of film was perceived as unwanted interference with their teaching duties. It was not until the late 1950s that a modest revival of instructional film could be observed, when 8 mm loop films were distributed as "single concept cartridges". These could be considered the audiovisual predecessors of today's learning objects dealing with a single concept or process. Also, in those years 16 mm films became available against affordable prices. But at the same the rise of television as a new medium for sounds and moving images hampered the worldwide adoption of film as an instructional medium. Film in education never lived up to its high promises.

Pressey's teaching machine. In 1924 Pressey [27] presented a first teaching machine for drill-and-practice. It was a mechanical apparatus that offered a series a simple multiple choice questions for rehearsing simple routine tasks. Pressey's machine was based on typewriter technology with a carriage revealing a question to be answered by pressing one out of four alternative buttons. The machine could present a series of questions. By switching a lever at the back of the device the teacher could switch from multiple choice assessment mode to instructional mode requiring the right answer before displaying the next question. Long before the age of computer-assisted learning Pressey's machine already displayed many of its principles and features. The associated instructional strategy is largely based on Thorndike's connectionist model of learning [39]. The model states that recurrence of a response is generally governed by its consequence in the form of reward or punishment, and that stimulus-response associations are strengthened through repetition. As a reward mechanism, Pressey's machine quite appositely released a candy after a certain number of correct answers. Its drill and practice nature reflects its repetitive nature. The machine appeared very effective. Therefore, similar to the case of educational film expectations were high. Pressey claimed that his machine would relief the teachers' burden by taking over time-consuming routine tasks and thus create better conditions "for those inspirational and thought-stimulating activities which are, presumably, the real function of the teacher". He prophesised a radical change of the educational system that would greatly benefit from his new machine that achieved better and faster learning outcomes against fewer teaching efforts [28]. At the time during the great depression this message was not appreciated too much by the teachers, many of which had lost their jobs already and feared that this machine would makes things even worse. So, the teachers opposed because they were anxious to be replaced by machines. As Skinner [36] stated several decades after, the failure of Pressey's teaching machine was because the world of education was not ready for it.

Instructional radio. In the early 1900s radio stations spread all over the world. From 1910 efforts were made to use this new medium within the classrooms. The potential advantages were obvious: just like film, radio would bring the world into the classroom, making available the finest teachers and the inspiration of the greatest leaders [10, 11]. Again there were high hopes: instructional radio was ascribed great innovative potential. Nevertheless, its use in the classroom remained quite limited. First of all, a main disadvantage of radio was that content was predefined and fixed for large target groups of listeners without the opportunity to adapt it to specific needs or local differences. Practical barriers were raised by the fixed timeslots of the broadcasts that not necessarily matched the daily classroom schedules and routines. But the main problem with the adoption of this new technology was associated with the supposed infringements on the teachers' status and autonomous role as the leading professional and omniscient expert. Radio broadcasts were easily perceived as unwanted intruders that overtook the teaching role, compelling the real teacher to become a listener instead. Naturally, teachers did not like the idea, because, as in the case of the sound-film, they preferred to do the talking themselves. As a consequence, the use of radio broadcasts in classrooms remained quite limited. Alternatively, instructional radio offered a new avenue for distance education which in those days was largely based on written correspondence via postal services. Radio broadcasts could provide real-time lectures at people's homes. But over the years instructional radio failed to attract large audiences.

Instructional television. In 1928 the first television sets became available. But large scale market adoption of television did not occur until the 1950s. Very similar to radio and film the expectations for instructional television were quite high: television, as a new mass medium was imputed a bright future. The combined power of words and pictures featuring outdoor scenes, important phenomena and inspiring people created great new opportunities for teaching. Compared with film, the distribution of content was much easier because of wireless transmission. New research was undertaken about how instructional television affected classroom learning. It also raised a broader interest in understanding and generating theory on how these new media could support instruction and learning [29]. Although quite some investments were made to establish instructional television channels offering high quality content, these had only very little impact on formal education. Paradoxically, the wide and successful adoption of television as a commodity conflicted with the instructional role it was supposed to play in education, because more and more television was associated with superficial entertainment. Also, technical and organisational inconveniences hampered its wide adoption in the classroom. Regarding the small screens at the time and the poor sound quality it was not easy to successfully arrange instructional television sessions in a classroom with 50 or more pupils. So, once again teachers exerted their resistance to a new technology entering their classrooms. But at a more principle level it was established that it was very difficult to meet the various conditions for student learning while using a fixed television format [29]. The very idea of broadcasting implied a one-to-many, one-way communication model addressing a wide audience with general purpose content. Hence, television was assumed to trigger receptive viewer modes rather than active learning modes. In one of his studies Childs [1] found no positive contributions of using television in classrooms. The 1967 Carnegie Commission on Higher Education concluded that "the role played in formal education by instructional television has been on the whole a small one" [29]. Nevertheless, from the 1960s the need for alternative approaches to higher education, supporting a vision of open access en independent learning lead to the launch of distance education universities all over the world. Britain's Open University played a leading role in establishing new and innovative delivery models which included instructional television. But doubts remained: television was used for illustration and enrichment, but it seldom became the core carrier of learning contents. Comedian Groucho Marx made a historic joke out of this when he explained that he found television very educational, because every time it was switched on he would go to another room and read a good book.

Programmed instruction. In the 1950s the influx of pupils in primary and secondary schools skyrocketed as a result of the post-war babyboom. In those days teachers were overloaded, which raised many questions about maintaining the quality of education. At the same time Russia launched its first Sputnik satellite, thus suggesting the technological and scientific superiority of communism.

The resulting panic in the western world created a great incentive for the education sector to improve and innovate its methods and tools. Indeed, education was suddenly considered of strategic importance and became top priority. At the time Skinner [36] introduced his programmed learning theory that suggested on small-step approach of reinforcement learning. Based on these ideas various technical devices (teaching machines) became available that claimed faster and better learning. In contrast with Pressey's teaching machine that was based on answering multiple choice questions, students using Skinner's machine were supposed to enter their own responses and compare these with pre-composed answers. Skinner claimed that his approach was superior since it was based on recall rather than recognition. The machines appeared to be quite effective and unlike the case of previous innovations schools and teachers started to adopt these machines at high pace [4]. But all of a sudden the advance of the machine halted. This time the parents strongly opposed against the approach: they feared the adverse effects of the mechanical teacher that lacked the human passion, enthusiasm and open mind of a real teacher. Only two decades after the era of Hitler and Stalin they suspected indoctrination by the authorities: they did not want their children to be "programmed" by robots [24]. This revolt of the parents marked the end of a promising educational innovation.

Audio compact cassette. The audio compact cassette has been one of the very few successful educational technologies. In the late 1960s it became available as a portable alternative for the vinyl gramophone record. Greatly supported by the music industry a world-wide technical standard was adopted, which helped accomplishing a very high market penetration of audio recording equipment: almost everyone used audio cassettes. Its educational use started in distance education. The audio cassettes were mainly used as a lead-in medium for providing guidance through the written course materials [20]. It made a perfect match with the required flexibility because individual students could use it anytime. It was used for teaching scientific concepts, guiding experiments, analysis of source material, and counselling of students. So-called audio books were known already from the 1930s as a means of government communication for blind people, but the audiocassette greatly extended it in distance education. It also aimed to increase the motivation of distance learners by establishing a more personal and intense emotional relationship between the teacher or speaker and the student [20]. Although the production of audio-cassettes needs relatively little professional knowledge, and its production and duplication are inexpensive and not very time-consuming, school teachers more or less neglected the new opportunities. The exception would be in foreign language teaching, where audio cassettes obtained a manifest position for the training of practical speech and listening skills. After the advent of the videocassette many teachers considered the audiocassette a second-chop medium. Nevertheless it persisted quite some time, while it still offered superior flexibility in car radio systems and cassette walkmans, until it was gradually replaced by audio compact disk and MP3 downloads.

Video cassette. Very similar to the cases of instructional film and instructional television, video cassettes were envisioned as the next moving image revolution for education. Indeed they could extend the printed learning materials with sounds and moving images so that the outside world could be represented in a more direct way. Video recorders also allowed for capturing relevant television programmes which could be viewed later on without the restrictions of broadcasting schemes. But still some barriers remained. Video production was much more expensive than audio recording. There was a general lack of appropriate content that was affordable for teachers and that matched the specific requirements of individual teachers (and learners). Although increasingly larger video monitors became available, their size never met the requirements for usability in a classroom setting with 30 or 40 pupils. The main problem was technical in kind though. In contrast with audio compact cassettes there was no agreement on a common technical standard for video cassettes. Instead, the domestic market was confronted with three different technical systems that were fully incompatible: JVC's VHS-system, Philips' V2000 system and Sony's Betamax system. By the time that the winner (which was VHS) became apparent, the interest in classroom video was fading already, while new media became available like the microcomputer, multimedia CD-ROM, DVD-Video and streaming video. The video cassette never redeemed its promise.

The microcomputer. Although in 1943 IBM estimated a world market for only five computers, a few decades later new chip technologies enabled the mass production of affordable and powerful microcomputers that flooded the consumer market. Education once again was confronted with a new technology that raised high expectations. In contrast with audio or video programmes, which offered one-way message transfer, the microcomputer allowed for interactive programmes that smartly took into account the learners' inputs. At the time a new branch of educational technology emerged: computer-assisted learning or computer-aided learning (CAL). It brought forth a whole new range of instructional tutorials, drill and practice exercises, and simulations for training purposes that could be used by learners independently. Various authors claimed that the computer would revolutionise education. Following Piaget's constructivism, Papert [26] suggested that the interaction with the computer would offer the ideal environment for knowledge construction. His microworld approach "Logo" aimed at the development of abstract ideas by children through experimentation. Shank and Cleary [34] promoted the computer as the panacea for compensating all the flaws of the school system. The computer was supposed to return all the things that are absent in schools but that are essential for any learning to take place: creative excitement, eagerness, curiosity, exploration, natural learning, fun. However, six major barriers frustrated this new revolution. First of all, microcomputers were expensive. Schools simply could not afford to buy many of them, which resulted in low computer-to-pupil ratios. In the early years schools were lucky to have one or two computers available to be shared by many hundreds of pupils. Secondly, microcomputers required frequent replacement because of rapid obsolescence. In practice many schools were saddled with outdated computers with performance qualities far below those of the computers that pupils were used to at home. A third problem especially in the early years, was the lack of appropriate courseware that matched the teachers' preferences. Fourth, school staff lacked the technical knowhow for solving minor software or hardware problems, leaving many computers unused. Fifth, the microcomputer which had the potential of supporting the development of individual talents through differentiated content offers, was actually used for the opposite: remedial training in order to reduce deficiencies and level out performance differences of pupils. But the main problem that hampered the proclaimed revolution was the local, instrumental role of the microcomputer within the educational system. The microcomputer was used as a sensible teaching aid, quite useful for a specific subset of learning activities, but it never challenged the educational system as a whole. A renewed interest in the microcomputer as an educational means arose not until the end of the 20^{th} century by the advent of the internet.

The general pattern of failing learning technologies. The failing innovations could have been extended with more examples like the laser videodisc, the PLATO system [5] or intelligent tutoring systems. Cuban [10] notices that the cases reflect a general pattern. First, new technologies go with great expectations and enthusiasm about the new avenues for educational innovation. Then, research cannot establish any appreciable differences between traditional classroom teaching and learning with new technologies. Gradually, it becomes clear that the technologies go along with some practical inconveniences and complications that hinder teaching rather than support it. Sometimes the learners or their parents express their objections. After a while it turns out that application of the new technology in educational practice remains quite limited. In the end everything remains unchanged, and the opponents (mostly teachers) and supporters (innovators and governing bodies who made the investments) end up in mutual accusations. In this pattern three main factors can be identified that influence the educational system: 1) educational practice, 2) educational research, and 3) educational technology. Practitioners, researchers and technologists often have conflicting interests and conflicting views on the domain. Educational practitioners are passionate professionals responsible for the operations in schools and classrooms. It is tempting to blame them for their reluctance against any innovation and change. Teachers seem to be prepared to do anything that preserves their traditional teaching role [3]. It seems they neglect any scientific advances. Compared with other sectors of society like health, agriculture or industry, educational practice is barely influenced by research. Also, any new technology is received with scepticism. Educational researchers are likewise passionate experts, responsible for establishing scientific evidence of the effectiveness of the new technologies. But some authors disqualify educational researchers for not being able to establish any significant effects of the interventions, because of insufficient and failing conceptions, methodologies and instruments [30]. Educational technologists are just as much passionate, creative people who come up with new ideas, new technologies and new initiatives that hold the promise of greatly improving, if not revolutionising, learning and teaching. Some authors [18, 19] blame educational technologist for not fulfilling the high expectations. Frequent failures of new educational technologies may be attributed to the over-enthusiastic if not unrealistic expectations of its supporters. Pressey [27] may have been quite right about the outstanding performance of his teaching machine, but apparently he has underestimated the complex conditions for getting it adopted by established educational institutions.

In the next sections we will elaborate these three driving factors.

1) Educational practice. Today's school system dates from the 19$^{\text{th}}$ century, meant to prepare workers for factory jobs during the industrial revolution. School was conceived as an industry itself dedicated to the conversion of ignorant learners into qualified workers that could demonstrate agreed standards of knowledge and skills. It is beyond any dispute that today's children are not helped by the approaches and standards of days long gone, but need to learn the knowledge and skills required for our modern information-based society. Various authors [3, 9] criticise the conservative culture in educational practice that would be rooted too much in the intuitive and traditional methods of the pre-medieval apprenticeship model, featuring an omniscient master and a naive pupil. Bates [3] blames the fixated organisational model of classroom teaching and passes a scathing judgement on the role of teachers. According to Bates, teaching as such is not professionalised. It rarely uses a design and does not favour required susceptibility for scientific evidence. It has hardly been influenced by research into instructional design, psychology of learning or other topics concerning human functioning. Teaching remains largely craft-based. As a consequence, it hardly allows for any division of labour to increase the efficiency. Indeed, educational institutes fairly resemble a collection of distinct one-man shops. Because other organisational models are rarely considered, the innovation effort is just additional to regular work and readily leads to increased unit costs. This is exactly what can be observed with the introduction of campus-wide learning management systems at the turn of the century: the teachers' workload went up instead of going down. From an economical perspective, such schools and universities are destined to "pine away" on the market of educational service providers, because of poor performance, bad quality education and disproportionately high costs. Great scepticism was raised by Sarasin [33] who ascribed the education system an oppressive impact, hidden behind unseen power relationships and cultural patterns that stifle any change or progress. In his view any school reform action is bound to ignore systemic regularities and inherent obstacles, and thus it will fail. As became clear from the examples discussed earlier, school innovations are being blocked whenever they tend to affect to power or position of teachers, or even when teachers believe so. Not very convincingly, also financial arguments are often given for rejecting innovations: required investments and staff efforts are suggested to conflict too much with running the schools' daily business. On many occasions schools automatically disqualify new promising technologies as temporary hypes that will soon die out. Such an excuse may be valid sometimes, but as a standard response it is insufficient. For many new technologies Gartner's hype cycle [16] demonstrates that after a short period of overhyping eventually a stable level of acceptance may be achieved (Figure 1).

The problem with education is that it does not get in the cycle when things are hot, and it steps out too early when things get cold.

Westera [42] explains that teaching is in many respects very similar to farming. Farmers as well as teachers are endowed with a built-in conservatism,

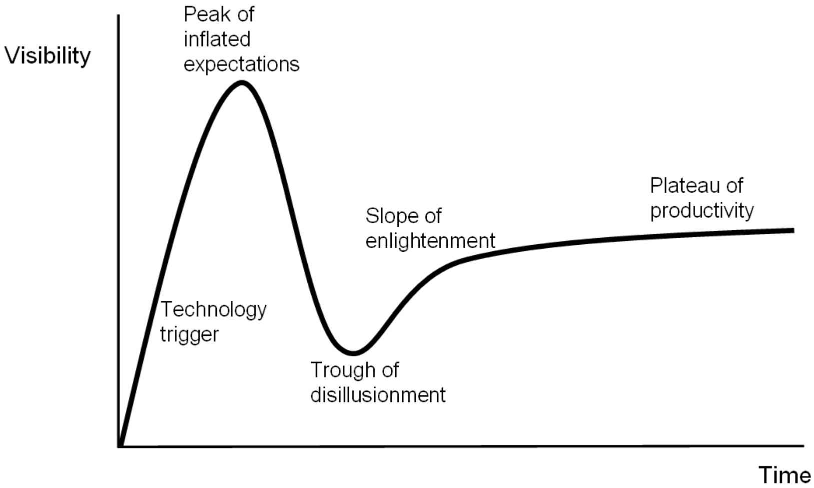

Fig. 1. The concept of the technology hype cycle [16]

which results from the never-changing cycle of sowing and harvesting as takes place year after year. Just like farming, teaching is more than a profession, it is a vocation, a passion, a way of life, a mixture of art and skill aimed at personal care and attention for maturing organisms. New technologies which might harm this vision can, of course, expect scepticism. The attitude of the devoted, humanist teacher does neither agree with the industrial vision of policymakers, managers and politicians, nor with expansion and businesses in which output and cost are dominating and in which pupils have changed into numbers. Of course, the teachers are fighting for a good cause because those who study are not plants. It is common knowledge, that behind the gigantic facades of the schools that once merged, a small-scaled craftsmanship remains hidden in which caring teachers take pity on their plots as crofters. However, it is doubtful whether it can stay this way as in the beginning, the farmers did not like to trade in their shire horse for a tractor. Today's farmer, however, spends more time at his computer than at his fields inspecting the crop. From a romantic viewpoint this may seem a disgrace, but agricultural productivity and quality have reached unparalleled levels.

2) Educational research. In the past, educational research had a dubious reputation and probably today this is still partly the case. Reeves [30] unambiguously states that "... educational research as a whole has been a failed enterprise". Robinson [32] and Lagemann and Shulman [21] point to the immature status of educational sciences, the lack of great achievements and the gap between common educational research and educational practice. Various authors conclude that educational research has failed to live up to its promises, while referring to a long list of innovation failures [12, 18, 19]. De Bie explains that research is isolated and unrelated to practical issues: researchers write their papers only for a small group of incrowd researchers. The renowned research institute of the Organisation for Economic Co-operation and Development OECD formulated similar critical conclusions: according to its findings educational research is "unconvincing" and "irrelevant for educational practice" [8]. This suggests that the research focus is on the wrong types of questions and that research outcomes are questionable. Westera [43] suggests that many educational researchers act like 19$^{\text{th}}$ century instrumentalists, proclaiming that pedagogy is the main driver for educational innovation and neglecting the dominant role and the substantive impact of new technologies. This goes along with a technophobic attitude that neglects any new technology that does not fit into existing pedagogic models. Even when taking into account the conservative nature of teaching practice, educational research is still lagging behind in many respects. Experienced teachers display a lot of practical and useful knowledge about how to treat pupils, when to give support, how to give support, or when to withhold support. Collecting empirical evidence for these intuitive practices is a fair goal of research, but the practical implication of this is that much of the research is oriented on safe verification of common sense rather than mind-broadening issues. A random, but exemplary case would be the large scale study on the learning behaviours of Lover [23]. Claiming the most fine-grained observation of high stakes study behaviour ever reported, the study reports on the self-directed studying of more than 100,000 students using a Web-based tool to prepare for U.S. college admissions tests. In this large-scale (and expensive) research project it was established that the majority of students delay their learning activities until only a few days before the exam. Unfortunately, teachers will not be impressed by this research outcome, because they know already. Although it is fine that well-known patterns are verified and supported by scientific evidence, such studies do not quite extend our body of knowledge: experienced teachers will disqualify such research as being gratuitous and useless. Today's educational research has a similar position as thermodynamics and aerodynamics in previous times. At the time these disciplines were useless, or even nonexistent: the steam engine was already widely used before any scientific theory could prove it would work; airplanes crossed the ocean before any scientific grounding was available. Likewise, education today still has a weak scientific basis, while quite some useful practical knowledge is available [6, 17].

There is no disagreement about the question if educational research should be strengthened. But there are many controversies about the best way to achieve this. Some parties, like the Dutch Education Council [25] advocate stricter evidence-based research methodologies based on randomised controlled trials. Others claim that such randomised controlled trials are just causing the problems rather than solving them. Reeves [31], pointing at the complexity of educational practice, rejects randomised controlled trials as a solution because outcomes are often contradictory and irreproducible, leading to what he calls "pseudoscience". Shaver [35] puts forward that in any practical educational setting the causes and effects cannot be identified unambiguously because of confounding variables. His sobering conclusion is that statistical methods and the notion of statistical significance are useless since many input variables remain uncontrolled. Such criticisms have lead to alternative ideas about doing educational research. Design-based research and action research gain popularity amongst the progressive part of the research community. Design-based research focuses on learning in a practical context while combining generic scientific questions with the development of specific learning environments [6]. Action research assumes the involvement of educational practitioners for investigating and improving the practical context that they're working in [22]. This idea of linking research with practice is not a new one. It is generally accepted that the explosion of knowledge during the last centuries is the result of a successful marriage between scientific research and working practice [13, 14]. University scholars like Galileï closely cooperated with craftsmen and technicians for creating new instruments like the telescope. Casimir [7] uses the term "science-technology spiral" to indicate the alternating and complementary role of both fields in achieving progress. Both design-based research and action research are positioned in the so-called Pasteur Quadrant [38], hinting at the way Louis Pasteur combined his scientific goals (understanding of microbiological processes) with application goals (controlling the effects of microbiological processes for the benefit of products, humans and animals). In education these practical approaches have the potential of closing the gap between research and practice, and contribute to new knowledge with high ecological validity. Exactly such contextualised research approaches, however, are not without problems, because research findings in complex local contexts are difficult to generalise or to transfer to other contexts. So far, the dispute in educational research is not settled.

3) Educational technology. As has been demonstrated above, for over a century educational innovators have proudly announced new technologies that would produce better learning at lower cost. In most cases, however, the outcomes did not live up to the expectations. This does not necessarily mean that innovators should be blamed for this. For a deeper understanding of the notion of innovation, it is necessary to look beyond straightforward, opportunist and superficial reasons for innovation and investigate the intrinsic motives and premises that drive us to innovation. Humans are essentially creative beings that continuously come up with new ways to do things better, easier or faster. The wheel, the alphabet, mathematics, ... it is essentially the ideas that make up our culture. Indeed, civilisations are determined by ideas rather than biological or physiological aspects of human life: civilisations differ precisely in the ideas that compose them and that make them develop in different ways. In essence, "...civilisation is ideas and no more than ideas" [40]. Richness of ideas is a unique human feature that strongly corresponds with innovative power. Therefore innovation is a phenomenon that is inextricably bound up with humankind, and probably a main evolutionary characteristic responsible for our existence.

Over the last centuries innovative efforts have produced impressive technological achievements: sophisticated medical cures, agricultural methods, new modes of transport, communication media, information technologies etc. These achievements keep fostering the optimism for prosperity, higher standards of living or, in a broader sense, better conditions of life. The cradle of the optimism goes back to the Enlightenment, an intellectual movement in the seventeenth and eighteenth century that strongly influenced the portrayal of mankind. It is the era of great scientists, philosophers and writers, like Descartes, Newton, Leibnitz, Locke, Kant, Voltaire and Diderot. They claim that man is rational and good by nature. Also Darwin should be mentioned, whose theory of evolution reflected the conflict between science and religion, while it rejected the idea of creation of life according to the Bible book of Genesis. Rather than the creationist belief that every species was created individually by God and is not subject to change or progress, Darwin claimed that life has developed in a progressive way from primitive forms to complex organisms. The Enlightenment marked the liberation from the medieval doctrines of magic, superstition, prejudices and the fear of God by replacing it with human rationality. The fear of God makes way for a scientific description and explanation of the world. Beliefs are not anymore accepted on the authority of priests, sacred texts, or tradition, but only on the basis of reason. Reinforced by the idea of natural regularity and material cause the Scientific

Revolution successfully proclaimed the ideology of upward development, progress and improvement of the world, encouraged by an ever-increasing knowledge, understanding and control of nature's processes. It asserts that the individual as well as humanity as a whole can progress to perfection. The simple notion that innovation implies progress and leads to a "better" world, unmistakably reflects the values of our modern western society. To mention a few: economy of growth, capitalism, materialism, competition, techno-optimism and scientific positivism. Being tightly linked with the starting points of modern society, innovation is necessary condition for all economic functioning. Innovations further the creation of new products, services and production processes, which will give an economic actor an advantage over its competitors. The predominant motto is "innovate or pine away" and the concepts of growth, progress, innovation and change seem to have become self-evident. Abandoning innovation means stagnation, stagnation means decline. The decline does not only concern our economy but will affect our culture as a whole. Innovation is not straightforward. It is inevitable within the constraints of our societal system [41].

In recent years the pace at which new technologies are becoming available has increased rapidly. Internet, computers and mobile phones are a fast-growing market. By their very nature these information and communication technologies may have great impact on the ways teaching and learning are arranged. So far, educational institutions, largely being positioned as public utilities rather than competitive business, lacked the stimulus for displaying innovative power and they could afford to ignore new technological trends and resist radical changes. Today, however, educational systems are confronted with a strong demand of learners to incorporate new technologies in their services (cf. Figure 2).

In the past direct technology push (broken arrow 2) on the educational system largely remained without any effect. As we have explained above a range of technological innovations failed for various reasons. Today the influence of technology takes another route. Technology push is highly effective on the consumer market: new computers, smart phones, music players, cameras, e-readers achieve fast and high market penetrations. Today's learners grow up immersed in new digital communication technologies and may wonder amazedly why they cannot use the tools at school that they use at home. The associated market pull establishes a reinforced innovation driver for education, creating an indirect bypass for technology push. Also, cross-national e-learning initiatives and increased competition in corporate and vocational training will increase education's innovation preparedness. The main conclusion of these developments is

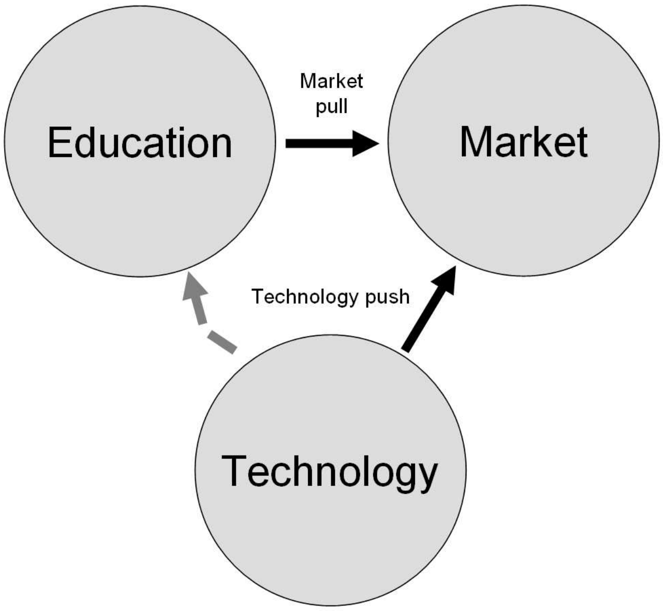

Fig. 2. Technology's indirect influence on education

that education must and will make great efforts for its innovation. This would suggest that despite all failures in the past, technology-enhanced learning will be of major importance for education.

Prospects of technology-enhanced learning. The domain of education is confronted with the great challenge to improve its practice of learning and teaching, to improve its research efforts and to achieve valuable innovations.

The experience of failing innovations in the past may help avoiding new fiascos. Importantly, the conditions have changed: the pressure on education is high, new technologies are flooding the markets, and learners, be it schoolchildren or adult professionals, expect high quality, flexible, modern and tailored learning services. After the gloomy analysis of failing innovations in this paper, we will now identify a number of relevant factors that explain a favourable outlook of technology-enhanced learning.

The internet as a societal revolution. The emergence of the internet in the 1990s marks a fundamental change of the way society functions. The all-embracing nature of the internet produced a new conceptualisation of information access, information services and social connectedness. By enabling the self-evident access to an abundance of information it promotes liberal, democratic (western) values and the independent, self-directed, responsible citizens that represent these. The all-embracing nature of the internet has amplified the global economy and the exchange of cultures. The values of openness and self-directedness are more and more adopted in today's school pedagogies: by offering internetaccess to their pupils, schools literally raze the boundaries between the school buildings and the outside world. Also, the internet embodies the first technological innovation that enables education providers to implement changes at an institutional, organisational level. This way the microcomputer transformed from an isolated, local tool into a worldwide communication station.

The large scale adoption of new technologies. New information and communication technologies like laptops, smart phones, navigators and wide band network access are adopted by the market at unprecedented rates. In contrast with former days new devices are affordable and reliable. Over the last decade, the number of people in Europe having access to wide band internet showed a steady growth each year, reaching levels up to 80% or higher. Taking also into account the growing market of smartphones it is fair to say that being connected to the internet is the default. Also schools and training institutes have adopted these new technologies as follows from the widespread connections to the internet, the increased number of school websites, and e-learning tools for content management. In accordance with the indirect technology push mechanism illustrated in Figure 2, general internet services like YouTube, Hives, Facebook and MySpace set the standards for quality, speed and flexibility of services that are pursued by educational institutions. Schools should not offer inferior solutions.

The pervasive nature of new technologies. New technologies and devices are entering our daily lives at an unprecedented pace. PCs, laptops and mobiles increasingly become personal devices, thus transcending the level of simple, instrumental tools. They provide ubiquitous access, they become portable or even wearable, or they are seamlessly integrated in the environment. Their use gets fully integrated in our daily activities and they literally become extensions of our physical and mental being: without our artificial extensions we would not be ourselves. These new technologies are becoming self-evident. They will transform our whole culture, just like radio, television and telephone did, and it will bring forth a new type of man: technology-enhanced man.

Digital natives. The digital divide between children and adults indicates that the new generation has a more positive and natural attitude towards new technologies. Today's children grow up amidst new information and communication technologies and take these for granted as a natural condition of life. Exactly this new generation will bring forth tomorrow's teachers and researchers. Any complaints about the teachers' unlimited conservatism or the researchers' 19^{th} century instrumentalism and technophobia will become superfluous, since time will solve all these problems.

Natural human interfaces. Today's user interfaces will probably be popular and hilarious gadgets in tomorrow's museums. Keyboards, mice and game controllers are awkward and unpleasant devices that reinforce unnatural interactions. At the semantic level, computers hardly understand the user's intentions. These poor conditions still are severe barriers for the adoption of new technologies. New technological developments will partly remove these barriers. Already today technologies for semantic web, speech recognition, gesture recognition, body movement tracking and facial expression recognition are available that demonstrate the power of painless interaction with computer devices.

More cross-disciplinary work. Educational innovation and research are no longer the exclusive domain of pedagogues and psychologists, but will need increased support of computer scientists and graphic designers. In the Centre for Learning Sciences and Technologies of the Open University of the Netherlands, which is a well-respected technology-enhanced learning institute, the fraction of computer scientist has dramatically gone up. A decade ago the fraction of computer scientists was just below 10%, while their role was simply the engineering of applications. Currently, computer scientists make up to 45% and their role is much more a leading one in educational research and innovation. Technology-enhanced learning is multi-disciplinary domain. Exactly the balance between multiple disciplines is an important requirement for high quality research in technology-enhanced learning.

Maturing of the technology-enhanced learning community. In recent years, the positioning and visibility of the technology-enhanced learning community has been strengthened substantially. The EU Commission has rated education and learning systems among the top 5 of most important societal challenges requiring ICT [15]. In 2009, for the first time in history, research in technology-enhanced learning received a separate funding target in a European Framework Programme. Also in 2009, a European Network of Excellence in technology-enhanced learning was established. The yearly ECTEL conference on technology-enhanced learning displays a continuous growth of participants. But also outside Europe technology-enhanced learning gains more attention. In USA, the Obama administration proposed investments for education for the 21st century in which around $650 million for education-technology grants.

Web 2.0 implications. The emergence of Web 2.0 entails a new philosophy of powers that also influences education. Web 2.0 replaces traditional content development models that are hierarchical and company driven with bottom-up models that engage individual contributors in social spaces, like Wikipedia, Blogspot and Youtube. In education this translates in open learning content and open content creation spaces like Wikiwijs (`www.wikiwijs.nl`) where teachers can create, adapt, share and annotate learning content in an open licensing model. Such developments have great implications for education: the relationship with educational publishing companies who used to unilaterally create and deliver the learning materials will change, as will the roles of teachers and learners.

Epilogue. Technology-enhanced learning will be of paramount importance for the emerging knowledge society, in which knowledge operations are much more important than any material operation. ICT will be a dominant characteristic of any professional task. The knowledge society requires a higher level of education of the population as well as a continuous updating and upgrading of its knowledge and competencies. For being successful on a global market knowledge, creativity, collaborative innovation and competitiveness will be essential. Accordingly, learning demands will increase in volume, will be more diverse and will entail easy customisation, personalisation and flexible delivery. This not only calls for increased innovation efforts, but also indicates that despite frequent failures in the past technology-enhanced learning has great prospects. For this practitioners, researchers and innovators should align their ambitions and jointly take the challenge. As Sarason stated "the biggest risk in education is not taking one" [33].

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