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RESEARCH ARTICLE



A critical study on the researches about the application of neurotechnology in education

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ABSTRACT

Introduction: The education and pedagogy have been adopted with the development of technology in order to achieve efficient consequences and the new methods in neuroscience and neurotechnology have influenced the educational systems and the classrooms. A great number of researches have been projected in this field to demonstrate the advantages and desirable effects of neurotechnology in education and the classrooms. These researches are examinable in terms of considering both advantages and disadvantages of technology.

Objects: The aim of this study is to demonstrate the advantages and undesirable effects of neurotechnology in education and the classrooms.

Methods: This article surveys the fourteen recent researches about using neurotechnology in education and the classrooms in the framework of critical theory to discuss the adverse and undesired effects of neurotechnology as well as their neglected aspects in education and the classrooms.

Findings: The findings illuminate that crucial disadvantages of neurotechnology are neglected in using computerbased tools in education and the classrooms and their side effects on the participants in the process of learning.

Conclusions: The new methods in neuroscience and neurotechnology have influenced the educational systems and the classrooms. A considerable number of researches have been projected in this field that all try to demonstrate the advantages and desirable effects of neurotechnology in education and the classrooms, but they consciously or unconsciously neglect the immoral and unscrupulous effects of such technologies.

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Neurotechnology; brain right; education; critical studies; innovation

Introduction

In the recent years, the appearance of interaction between neuroscience and education has led to an increase in the knowledge about the role of neuroscience and technology in education. Teaching, learning and education can be considered as a new field of natural sciences, ranging from early years up to old age [1]. Neuroscience relatively is a new area of biological knowledge joining, amongst others, neurophysiology, neuropharmacology, neurology, psychology, and neuroimaging. In the last few years, many aspects of physiology, biochemistry, pharmacology and detailed structure and behavior of invertebrate and primate nervous system have been elucidated.

This new terms of research is completely related to the computer and the electrical devices can read the brain's reactions in the different situations. This method has utilized for lie detection in the criminal investigation. White et al. [2] clarify that 'neurotechnology is broadly defined

as a set of devices used to understand neural processes and applications that can potentially facilitate the brain's ability to repair itself'. It means that this science enables human being to manipulate the nervous system that had been far reach for mankind. In the recent decades, 'an increasingly explicit understanding of basic biological mechanisms of brain-related illnesses has produced applications that allow a direct yet noninvasive method to index and manipulate the functioning of the human nervous system'. That is not the only aspect of the progress, it has other consequences and concerns neglected in the related researches.

Neuroscience was applied to education in the USA for the first time during the 1990s, the so-called 'decade of the brain'. Unfortunately, the initial movement caused the launch of many educational programs claiming to be 'brain based', but was not actually supported by science. These commercially motivated initiatives were accompanied by the emergence of

misconceptions or neuro-myths about the brain and its function, first informed by the Organization for Economic Co-operation and Development (OECD) in 2002, and later found to be widespread across every single country that was researched [3].

Today, Neurotechnology is the main part of this process that attempts to help the educational systems to have a better efficiency in the classrooms. So, the specialists use a wide array of terms including 'neuroscience and education' [4], 'neurolarning' [5], 'educational neuroscience' [6], 'cognitive neuroscience' [7] and 'brain-based education' [8]. All these concepts illuminate the collaboration of neuroscience and the related technology to the brain activities. In other words, all these manipulated phrases 'refer to a common goal of linking the scientific understanding of how the brain functions (including how the brain learns) to an understanding of educational best practices' [9]. The technologies are used in the neuroscience as well as classrooms seek to understand how the brain properly works and which strategies are better for education.

The new researches focus on the learning improvement by the neurotechnology and try to qualify the education and learning systems. 'It is common to encounter the belief that advances in technologies that allow us to measure activity in the brain will lead directly to interventions that improve learning' [10]. It means that the researchers try to understand how can qualify the learning and educational systems by neurotechnology. Moreover, this technology is utilized in some teaching systems to analyze the efficiency of those teaching systems in order to suggest the new methods to improve the teaching models. Surveying on the teachers' brain activities and introducing the new methods and tools are the main duty of these researches. The deeper perception of the mechanisms and limitations of the brain can lead to a powerful effect on teaching practices. 'With enhanced knowledge about how the brain actually processes new information, teachers can reevaluate and adjust their methodologies to reflect how people actually learn, rather than 'how people have learned in the past' [11]. The teachers are in the business of structuring learning experiences for students; therefore, they are curious about the process of learning and how the developing brain grows in its ability to process information, expecting that knowledge of these processes will help them support students in achieving learning goals [12].

Moreover, the assumed linkage between the neuroscience of brain plasticity and education seemed obvious; however, there are a number of problems with the brain-training to-education bridge. First and

foremost, the available literature now strongly suggests that brain training does not reliably generalize beyond the trained tasks [13]; certainly, does not carry over to better education outcomes and may actually result in poorer performance on important indicator variables when the students are removed from the classroom for the training interventions [14]. Second, even if brain training did generalize, establishing the link between the neuroscience underlying working memory (WM) training and education outcomes requires a cognitive theory. The cognitive theory and, in particular, the conceptual models of WM provide the landing spot required for establishing the plausibility of using brain training to improve educational outcomes [10].

It seems that the consideration of these issues is the significant part of this field in which the relation between education and neuroscience and the role of the new technologies in this relation should be defined that is the main part of the studies on neurotechnology to discover the effects of neurotechnology on the educational systems and classrooms. Accordingly, this article seeks to criticize the approaches of so far carried out researches on the relation between neurotechnology and the educational systems, training and learning in terms of their holistic views on the education in the framework of the critical theory. The relationship between these two categories must be differentiated according to the age of learners, the level of education, the sort of educational institutes (the primary schools, the high schools and the universities), the field of education (Social sciences, medical science, engineering) and importantly in terms of ethical considerations and parent's concerns. Also, this paper analyzes the researches in the field of neurotechnology in the classrooms in the framework of the critical theory. This analysis is not only about the process and the methods of neurotechnology, but also is about the technologies using in the classrooms.

Theoretical framework

The critical theory was introduced in the 1930s in social science to challenge the predominant social theories. Indeed, the inventors analyzed the contemporary forms of capitalist stabilization and social control, focusing on the new modes of socialization that increased conformity and diminished the individual autonomy and democratic participation. The critical theory is often associated with the so-called 'Frankfurt School', a term which refers to the ideas of the members of the Institut für Sozialforschung (Institute for Social Research), where Carl Grunberg, Karl Korsch and

Georg Lukacs worked on the critical theories. After Grunberg's retirement in 1930, Max Horkheimer became the Director of the Institute and gathered talented theorists such as Leo Lowenthal, Friedrich Pollock, Erich Fromm, Henryk Grossman, and Herbert Marcuse. After them, T. W. Adorno, Otto Kirchheimer and Franz Neumann joined the Institute and supported theorists like Korsch and Walter Benjamin [15]. This institute published different books in the critical studies like Materialism and Dialectics challenging the Western theories, but the institute could not continue its activities in Germany and most of the philosophers and thinkers immigrated to the USA in order to promote the critical studies used to examine the various social problems. Moreover, the critical studies were outspreaded in other fields and became as a main part of researches in the different sciences and scholarships.

The critical theories have influenced the contemporary social theories, philosophy, communications, cultural theory and other disciplines for six decades. The dream of an interdisciplinary social theory continues to animate the sociological imaginations. The Critical theory has always produced its own particular wisdom to articulate and defend its positions in polemics with the contemporary theories. During the present moment, the critical theorists have been among the most active critics of postmodern theory and the polemics between critical and postmodern theory have inspired many critical discussions and new syntheses on both traditions [16].

Accordingly, this theory provides a valuable foundation to question the intent of neutral performativity and to explore the dehumanizing effects of managerial control [17]. The critical views about the all-human activities are located in the core of this theory. In fact, the critical theory opens up 'possibilities for analysis of power, discourse, and historical understandings. In so doing, the critical theory mandates reflexivity in research', writing and attuning researchers 'to the assumptions underlying their own busy empiricism' [18]. In the realm of education, the critical studies define a theory emphasizing the development of critical thinking and knowledge and the curriculum elements are designed in such a way within which critical political, cultural, economic and social knowledge have been developed for several decades [19].

In this regard, neurotechnology in the classrooms can be evaluated in the framework of the critical theory due to its relation to the humanity and social science. In its simplest form and definition, neurotechnology is the integration of technical components with the nervous system. These components can be

computers, electrodes or any other piece of engineering gadgets that can be set up to interface with the electric pulses coursing through body. In fact, neurotechnology uses these kinds of components to improve the some sort of mental or physical problems. It means that neurotechnology covers the human's attempts to solve the living problems and improve the human's facilities and the treatments of illness in order to modify the level of physical and mental activities. In this regard, 'neurotechnology has two main objectives – either to record signals from the brain' or 'translate' them into technical control commands (like our brain-controlled computer mouse), or to manipulate brain activity by applying electrical or optical stimuli (to help paralysis patient) [20].

Neurotechnology facilitates the better understanding of the brain and contributes the treatment of the neurological and psychiatric diseases of the nerves system in order to offer more effective or efficient solutions [21]. The term neurotechnology can often bring to mind science fiction narratives. In this regard, neurotechnology's 'machines can read our thoughts or harness our brain power to control robotic devices' [22]. This narrative obscures the powerful reality of how neurotechnologies are already revolutionizing people's daily lives. Furthermore, neurotechnology can improve the brain activity and functions in education and 'neurotechnology-based interference in brain's activity can be very effective, allowing for successful treatment of brain disorders' [23].

Today, governments invest on the neurotechnology in different fields. The medical and non-medical institutes attempt to influence in the human life. In other words, the non-medical applications are becoming increasingly popular and available on the market and are reachable for most people in all around the world. In the UK, for instance, 'non-invasive neurotechnology in Northern Ireland, photonics in Scotland, dementia research in Wales, optogenetics in the north east of England, mental health in the Midlands and clinical, experimental and computational neuroscience in the South' [24] demonstrate the British government's attempts to exploit neurotechnology in the medical and non-medical fields. Despite of investment on research in the field of neurotechnology, according to the EU report (2013), the scientists and governments agree that the application of nanotechnology in commerce poses important potential risks to human health and the environment, but the risks are unknown. The Swiss Federation, the Royal Commission on Environmental Pollution of the UK, the German Governmental Science Commission, Public testimony sought by the USA National Institute

for Occupational Safety and Health, the OECD working group, the World Health Organization (WHO), and the World Trade Organization (WTO) have raised warnings about the use of neurotechnology. Beyond these considerations and examples, Artificial Intelligence (AI) is now becoming a big challenge for human being and the governments. The critics of researches' ignorance about the effects of neurotechnology on mankind and education is an introduction to engage in the consequences of AI in the educational systems.

A survey on the researches about neurotechnology and education

In the last 5 decades, the various types of technologies have been used in the classrooms and education to achieve better results in the process of teaching and learning. Analyzing the learning and teaching methods and studying the appropriate ways of effects on the students and childrens' brain are the main part of the researches in this field. In other words, neurotechnology tries to find good ways in the application of the educational technologies. This is a new approach that is 'beginning to be used in the educational field, trying to understand how the brain learns and therefore seeks to make clear how students acquire new knowledge with the help of the Information and Communication Technologies (ICT)' [25]. This approach seeks to improve the quality of education and enhance the learning methods. There are some related concepts in neurotechnology that all of them related to the brain, learning, educating and their relations. The best definition of the neurotechnology is belongs to the Calderón and Barrera [26]. Based on this definition, neurotechnology accelerates the better understanding of the brain and helps to understand how technology can be used to access the better results in the classrooms and education. According to Müller and Rotter [9] 'neurotechnology is defined as the assembly of methods and instruments that enables the direct connection of technical components with the nervous system. These technical components are electrodes, computers, or intelligent prostheses'. Therefore, all of the technologies which are related to the improvement of the learning and educating can count as a neurotechnology tool.

The Educational systems, in the recent years, try to use different neurotechnological tools to assistant the students to 'build their own learning strategies, relying on new approaches that facilitate the resolution of the difficulties that they may go through when learning, this new science allows the teacher to know the

functioning of the brain of their children' [25]. In fact, today's education due to the expansion of the communication technologies, beside the different educational methods, needs to use the neurotechnology to support the learning difficulties that students frequently present in the classrooms. The educational technology draws a path to the applicants to find a better way for learning and make learning simpler for them. Moreover, they draw a line for the brain to how 'learns provides efficient and effective support for the development of skills and abilities that reinforce learning and enable students to cope with these difficulties' [25]. In this regard, different countries and research centers have studied the utilization of neurotechnology in education; the US, The International Mind, Brain, and Education Society and East Normal University are the number of countries and research centers in the world which have research in this field. The theorizing and the definition of the neuroeducation are the main steps in this way [27]. Fortunately, the educational systems approved new methods in using neurotechnology in education and emphasized that the application of neurotechnology is helpful in teaching and learning second language and confrontation of the 'poverty and low socioeconomic' [28]. and discrimination in the different societies and countries. It means that neurotechnology has ability to create the equal opportune for learning and education. However, the most important consideration and risk is its abuse and ethical approaches that is the main purpose if this article.

On the other hand, this concept is utilized in the other fields of like medical trophy and clinical studies and the new perspectives are defined in some researchers such as Jonna Brenninkmeijer's paper entitled 'Neurotechnologies of the Self: Mind, Brain and Subjectivity' [29]. This research is 'an ethnographic and historical study of contemporary neurotechnologies, replaces visions of a reductive cerebralization with an account of how contemporary technologies that provide 'direct access' to the brain expand and complicate, rather than curtail, the possibilities of selfcontrol in the twenty first century'.

For this paper, the authors selected fourteen papers examining the role and application of neuroscience and neurotechnology in the different realm of education and the classrooms. Table 1 shows the researches and their subjects and findings.

Discussion

These articles illuminate the connection and relation between neurotechnology and the classrooms in order to persuade the audiences that the classrooms in

Table 1. Researches on neurotechnology in education and the classrooms.

	Title of Research	Subject/ Purpose	Findings
1	How In-Service Teachers Perceive Neuroscience as Connected to Education	School teachers' knowledge about brain, mind and their educational implications	The role of gender in the perception of the relevance of neuroscience to education
2	The Promise of Neurotechnology in Clinical Translational Science	Potential benefits and hurdles of neurotechnology in the context of clinical dysfunction	Neurotechnologies provide a window into brain activity and better understand the neural processes that underlie socioemotional difficulties
3	Neuroscience and Education: A Bridge Astray?	The failure of neuroscience in generalizing its findings to classroom contexts	The necessity of researches in the areas of cognitive and social psychology to synergize evidence-based interventions in education science
4	Neuroscience and Special Education	Studying links between the rapidly expanding field of neuroscience and the practice of special education	In special education, the process of translating brain research into classroom practice must be handled methodically
5	Effect of a Science of Learning Course on Beliefs in Neuromyths and Neuroscience Literacy	Examining the effect of a one-year Science of Learning (SOL) course on neuroscience literacy and beliefs in neuromyths	The SOL course significantly improved overall neuroscience literacy and reduced neuromyth belief among pre-service teachers, but small effect
6	Neuroscience in the Classroom: Understanding How New Information is Processed	Outlining how the brain processes new information and gets transferred into long term memory	The teachers' role is changed from one who simply introduces new information to one that promotes human learning
7	Educational Neurotechnology in Attention to the Specific Needs of Higher Basic General Education Students	Analyzing neurotechnology as a contribution to the students' specific needs	Neurotechnology affects the improvement of the students' specific needs, since the use of ICT is given the correct neural interpretation and understanding how students learn
8	A Place for Neuroscience in Teacher Knowledge and Education	Promoting the idea that appropriate content of neuroscience for education should be incorporated into both teacher preparation and professional development	Feasibility of utilizing neuroscience in pedagogical choices and positioning students' knowledge as a central focus of teachers' education
9	Assessment of Mapping the Brain, a Novel Research and Neurotechnology Based Approach for the Modern Neuroscience Classroom	Examining the role of neurotechnological insights and approaches in students' critical analysis ability and confidence	Revealing new insights and pedagogical approaches for engaging students in critical analysis, increasing student confidence and data focused mentality and providing a unique model as a modern neuroscience laboratory course
10	Educational Neurotechnology: Where Do We Go from Here?	Outlining the potential of neurotechnology in education and consideration for its successful adoption in classrooms	Special consideration is given to the training needs of pre- and in-service educators whose support will be essential to the successful adoption of educational neurotechnology
11	The Emerging Role of Educational Neuroscience in Education Reform	Exploring the appropriate training of the educational neuroscientist and the emerging ways of the educational neuroscientist	Using the new educational methods requires a new vision for working together of scientists, educators, and the hybrid educational neuroscientist
12	Future of Smart Classroom in the Era of Wearable Neurotechnology	Requirement and infrastructure of smart classrooms throughout advances in neuroscience and machine learning	3 challenges have been discovered: system variability, restructuring the pedagogical materials and internet-of-things design and robustness to errors
13	Neuroscience Research in the Classroom: Portable Brain Technologies in Educational Research	Evaluating the opportunities and limitations of portable and wearable brain technologies	Add value of portable brain technologies in 'engagement in group work', 'cognitive load', and 'self-regulation'
14	Educational Neuroscience: Neuroethical considerations	Integrating ethical positions to research design and methods in educational neuroscience	The leading role of educational theorists, researchers, and practitioners in a mindful radically embodied educational neuroethics

particular and education in general depend on neurotechnology. This idea is somewhat true due to the role of brain and its function in education and understanding. But, it is so crucial to know what kind of technologies try to affect the human brain. In fact, the technologies which are affecting the brain in a bad and undesirable way have to eliminate from experiment. These researches just report the good sides and advantages, while there are no information and discussion about the disadvantages and undesirable effects of neurotechnology.

No one can deny the optimal effects of technology in education, but the harmful effects must not be ignored in the application of any kind of technology. The main point is the ethical problems, which may not to be considered in the studies. There are

different reports that show the ethical factors ignored by the governments or the researchers, especially in the case of disabilities [30]. Moreover, neurotechnology affects the brain and its functions. There is no difference where this kind of technology is used, but the significant point is about its long term effects. This issue is not supported by the researches in spite of using various types of the technology in the human lives in particular education.

The other unconsidered point in these researches is about the satisfaction of the experimental groups and data usage. In this respect, some questions are in concentration; is there any right for using the experimental groups' data? Are experimental groups satisfied by these experiments? In the last three years, the Covid 19 have forced the authorities to develop the

technologies in education and classrooms, but there is less researches and surveys on the bad effects, like the satisfaction of the students and teachers of this kind of education and distance Learning. Neurotechnology is in the same way; on the one hand, the secret and hidden data and information are considerable and ethical issues, on the other hand. This issue is more important all around the world and the governments make strategies in this field. In October 2021, Chile anticipated these problems and tried to find solutions by passing a law protecting citizens' 'brain rights', which covers the protection of neurorights, including the rights to personal identity, free will and mental privacy [30]. In this regard, a study by Dikker et al. [31] proves that using a portable electroencephalogram (EEG) device for recording brain's activity from a class of 12 high school students over a semester during regular activities, analyzing the group-based neural coherence is possible where the brain's activity is synchronized across the students in both class engagement and social dynamics. Another study by Babini et al. [32] comparatively measured the learning of the students in a virtual reality (VR) environment for using a wearable electroencephalogram, but the consideration of the students' rights is not clear in this study. Also, it did not illustrate the harmful effects of these experiments and the avoidance of data misusing.

Furthermore, the teachers have exclusive methods for teaching, which derived from their own culture, educational system and morality. This is the main factor in the difference between the teachers and their ability for persuading the students. These differences and advantages may be lost in the use of neurotechnology. For example, there is a devotional relation between the teachers and the students in some educational systems and academic cultures, while this relation is absent in the other systems or cultures: the use of neurotechnology will eliminate these elegances maybe belong to the traditions and history of a nation. In fact, the mechanized and technologized educational systems will eliminate the devotional culture-based relations between the teachers and students that are ignored in these researches as a disadvantage. Also, 'neurobiological changes occur in the brain and 'fixation' of knowledge occurs in the cognitive structure of the individual's mind, few know how the brain and peripheral nervous system as a whole works as a relevant factor in the educational world' [1]. In fact the teacher's exclusive methods of teaching and education may influence by the neurotechnology. On the other hand, neurotechnology cannot support all types of the students and cannot develop all of the teaching strategies. Most researches basically concentrate on the

advantages of neurotechnology and its power to change teaching strategies has not seen.

The other critical part of neurotechnology's researches about the classrooms is their concentration on the teachers' cognitive and knowing system in the classrooms and about the students. The teachers have their own methods for recognizing and reconnaissance the students' ability and potentialities. The use of neurotechnology changes this procedure and the teachers cannot make a difference between the students. The educational systems during the Corona pandemic are the explicit example of this problem. Due to this matter, the teachers cannot recognize the students' talent and their problems in understanding of concepts because of using the technologies during the teaching and education and all of the process seems great in front of the monitors, so today after the pandemic, the schools face with an academic failure.

Last but not least, the non-verbal communication has enormous role in education and the interaction between the teachers and the students. The teachers use their non-verbal abilities in communication as the supplement to the verbal communication in education. Most of the messages and concepts transfer *via* the non-verbal communication and the process of communication in education will not be completed without using these factors. In this respect, eye contact, mimics and gestures play a significant role in class management as well as powerful communication. The teachers can evaluate the students and the classroom's situation with the aim of these items. According to Zekia [33], the use of eyes and facial expressions is considered in managing the classrooms as well as show a student who is talking that the teacher is taking notice; to check that everyone is concentrating; to indicate to a student that you want to talk to him or you want him to do something; to encourage contributions when one is trying to elicit ideas; a teacher only knows students have something to say by looking at them; and to hold the attention of students not being addressed and encouraging them to listen to those talking and to maintain attention. The reports clarify that a teacher who never looks students' eyes seems to lack confidence and gives the students a sense of insecurity. These researches prove the role of non-verbal communication's significance in education and the classrooms. However, the appearance of the new technologies changes the situation even in education and the learning systems like neuroscience. Most non-verbal factors in communication and the interactions between the teachers and the students are eliminated through using neurotechnological tools. This

factor is the other critical neglected part of the researches in this field.

Conclusion

Most researchers in the field of neurotechnology in education and the classrooms try to clarify and describe the positive aspects of utilizing neurotechnology and its positive and efficient effect in education and on the students. There is no doubt that using technology in all fields, especially in neuroscience and exclusively neurotechnology, make the education most attractive and better for the students and the teachers. Despite of these advantages, technology has harmful effects on the students and education which was described in the previous section. The lack of attention to these critical points changes the function of technology. This paper seeks to discover and highlight the neglected aspects and harmful or parlous effects of neurotechnologies in education and the classrooms in the framework of the critical theory. The important findings of this article including the ignorance of bad and undesirable effects of neurotechnology on human being in the classrooms; the inconsideration of ethical issues based on human rights, brain rights, mental privacy, free will and personal identity; the negligence of teachers' various teaching and evaluating methods and their different abilities; and the reduction of non-verbal communications in the interactions between the students and the teachers. In terms of ethical perspectives, just two articles to some extent payed attentions to these matters. So, the future studies on the neurotechnology and education and the classrooms should notice these shortages in this field in order to present a comprehensive approach and demonstrate the importance of these critical points regarding the role of neurotechnology in education. The appearance of the AI alongside neurotechnology demonstrated the necessity of regulation in the exploitation of these phenomena in education and the necessity of investigating all aspects and effects (bad or good) of new technologies before offering to the markets.

Ethics statement

An ethics statement is not applicable because this study is based exclusively on published literature.

Author contributions

Hatef Pourrashidi: Design of the work, Drafting the work and Analysis.

Javad Alipoor: Reviewing it critically for important intellectual content and Final approval of the version to be published.

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Data availability statement

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

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