A theoretical proposal for the development of educators' preparedness in relation to educational neuroscience

Una proposta teorica per sviluppare le competenze degli educatori alla luce delle neuroscienze educative

Spyridon Doukakis[A*], Maria Niari[B] and Chrystalla Mouza[C]

A) Ionian University, Department of Informatics, Corfu, Greece, sdoukakis@ionio.gr*
B) Hellenic Open University, School of Humanities, Patras, Greece, niarimaria@gmail.com
C) University of Illinois, College of Education, Champaign, IL, USA, cmouza@illinois.edu

*correspondent author

HOW TO CITE Doukakis, S., Niari, M., & Mouza, C. (2022). A theoretical proposal for the development of educators' preparedness in relation to educational neuroscience. *Italian Journal of Educational Technology*, *30*(3), 78-90. doi: 10.17471/2499-4324/1268

ABSTRACT Educators' knowledge transformation in line with educational neuroscience principles is a crucial step to the potential improvement of educational practice. We argue that similar to other knowledge domains this transformation seems to go through five developmental stages (Recognize, Accept, Adapt, Explore and Advance), along with five - distinct but complementary - axes: curriculum implementation, student assessment, learning, teaching and access to non-invasive portable and wearable technologies for neurophysiological measurements. With regard to the aforementioned axes, research in educational neuroscience has offered important findings. In this vein, the article proposes that the development of in-service and pre-service educator knowledge on educational neuroscience could be based on the five developmental stages and according to the five axes. The aim is to prompt educators to develop the knowledge and skills they need to integrate the principles and findings of educational neuroscience in the planning of their teaching, in the teaching and assessment approaches they use, and in the collaborative endeavours with researchers in educational research activities.

KEYWORDS Educational Neuroscience; Developmental Stages; Educators' Professional Development.

SOMMARIO L'allineamento delle conoscenze degli educatori ai principi delle neuroscienze educative è un passo cruciale verso il potenziale miglioramento della pratica educativa. Analogamente ad altri domini di conoscenza, riteniamo che questa trasformazione possa avvenire attraverso cinque fasi di sviluppo (Riconoscere, Accettare, Adattare, Esplorare ed Avanzare), insieme ad altrettanti assi distinti, ma complementari: l'implementazione del curriculum, la valutazione degli studenti, l'apprendimento, l'insegnamento e l'accesso a tecnologie non invasive, portatili e indossabili per le misurazioni neurofisiologiche. Per quanto riguarda i suddetti assi, la ricerca nel campo delle neuroscienze educative ha offerto importanti risultati. In questa cornice, l'articolo propone che l'acquisizione delle conoscenze sulle neuroscienze educative, da parte degli educatori in servizio e in formazione, possa quindi basarsi sulle fasi di sviluppo e sugli assi identificati. Lo scopo è quello di incoraggiare gli educatori a sviluppare le conoscenze e le competenze necessarie ad integrare i principi e le scoperte delle neuroscienze educative nella progettazione, nell'insegnamento e nella valutazione.

PAROLE CHIAVE Neuroscienze Educative; Fasi di Sviluppo; Sviluppo Professionale degli Educatori.

1. INTRODUCTION

In recent decades, a significant number of research activities and interventions have been recorded, which aim to improve the educational process, as well as to enhance students' learning by providing differentiated support according to their needs (Smale-Jacobse, Meijer, Helms-Lorenz, & Maulana, 2019). One of the most promising fields of research with the potential to improve teaching and learning is educational neuroscience. Since 2002, the Organisation for Economic Co-operation and Development (OECD), has attempted to facilitate relevant discussions and highlight the importance of educational neuroscience as well as associated technologies, such as non-invasive technologies for neurophysiological measurements, in developing innovative approaches to understanding student learning (OECD, 2002; OECD, 2007). In the last decade, non-invasive portable and wearable technologies for neurophysiological measurements have allowed cognitive activation observations to be made in the brain, providing new insights into behaviours and neural correlations that seem to form the basis of learning (Lin, Parsons & Cockerham, 2019). These new technologies have led to a dynamic shift in the field of educational neuroscience and have brought to the fore the importance of transitioning research in this area from the laboratory environment to the physical or online classroom environment (Doukakis, Sfyris, Niari, & Alexopoulos, 2021).

Despite researchers' efforts to prepare in-service educators to utilize principles of educational neuroscience and debunk neuromyths, there are still educators who are not aware of this scientific field and others who, despite knowing it, are not able to use it in their teaching practice (Howard-Jones, Jay, & Galeano, 2020). Therefore, a theoretical training framework is important in order to integrate the principles of educational neuroscience in educators' teaching practice. The aim of the present study is to contribute to the discussion concerning the preparedness of educators to work according to the educational neuroscience principles by identifying some of the difficulties of integrating neuroeducational interventions into the classroom and proposing a model for improving this integration.

In the following sections, the need for educators' development in this field is highlighted, as a means to developing their perspective concerning educational neuroscience and their competency to use non-invasive portable and wearable technologies for neurophysiological measurements in teaching. Moreover, a teacher education framework based on five developmental stages proposed by Niess et al. (2009) is presented as a roadmap to supporting teacher learning.

2. EDUCATORS PROFESSIONAL DEVELOPMENT

Research development in the field of educational neuroscience is particularly useful, as it provides the opportunity to recognize the mental status of the learners, their development over the years, and their learning difficulties. At the same time, it provides a theoretical framework with the potential to support educators' planning and teaching pedagogy. However, a number of questions remain related to the effective use of neuroscience principles in the classroom, their impact on student learning outcomes, and the ethical implications associated with the use of non-invasive portable and wearable technologies for neurophysiological measurements in teaching and learning (Horvath & Donoghue, 2016).

Towards this end, researchers have begun to design professional development programs rooted in learning sciences and educational neuroscience that support teacher learning (Privitera, 2021). A primary goal of these programs is to debunk popular neuromyths in education, such as the neuromyth of learning styles (Yfanti & Doukakis, 2021), and help educators apply neuroscience principles in teaching and learning, through the design of teaching interventions, their application in the classroom and the evaluation of results in student learning development (Howard-Jones, Jay, & Galeano, 2020; Chang, Schwartz, Hinesley, & Dubinsk, 2021; Tan & Amiel, 2022). The key objective of this work is to support research efforts carried out in physical classrooms and in schools with the use of non-invasive portable and wearable technologies for neurophysiological measurements that are traditionally used only in laboratories, such as electroencephalography (EEG), heart rate monitor, eye-trackers, electrodermal activity (EDA), and face recognition devices (Williamson, 2020; Jarodzka, Skuballa, & Gruber, 2021).

Despite increasing research efforts, however, the application of educational neuroscience has had a particularly limited impact on both educator training and classroom practice. The limitations of non-invasive portable and wearable technologies for neurophysiological measurements (Janssen et al., 2021), the lack of professional development programs for in-service educators and undergraduate courses for pre-service educators (Howard-Jones, Jay, & Galeano, 2020), and the impact of misinformation regarding neuroscience (Dekker, Lee, Howard-Jones, & Jolles, 2012) have all contributed to the limited application of neuroscience principles in practice. In the next section, we identify some of the difficulties of integrating neuroeducational interventions into the classroom and we propose a model for improving such integration.

3. PROPOSED KNOWLEDGE TRANSFORMATION FRAMEWORK

Research in the field of educational neuroscience indicates a lack of appropriate translation frameworks for transitioning from structured laboratory research to the complex daily operation of the classroom (Jarodzka, Skuballa, & Gruber, 2021). Thus, a key question that emerges is concerned with the ways in which researchers can support this shift and facilitate the use of neuroscience principles in authentic classroom settings. Towards this end, educators must transform their knowledge in relation to educational neuroscience and build their skills in using non-invasive portable and wearable technologies for neurophysiological measurements, which are key to neuroscience research. The challenge lies in the fact that many educators have structured a specific professional identity, based on acquired scientific and professional knowledge, which highlights an established perspective. The *transition* from their established perspective to another social example (van Gennep, 1960) requires a process of knowledge transformation. Through this process, educators' experiences or perceptions are redefined, so that they can be activated and, through learning processes, record signs of "transformation".

The concept of transformation is linked to both experience and perspective. On the one hand, the transformation of experience refers to the creation of new knowledge, with the aim of empowering educators to act. In turn, action will result in development and change both individually and socially (Cranton, 2016). On the other hand, the transformation of perspective concerns change in educators' viewpoint, or the way in which the individual perceives the world around her/him and approaches her/his experiences.

Along those lines, Niess et al. (2009) proposed a five-stage developmental framework focusing on the transformation of teacher knowledge in the field of technological pedagogical content knowledge (TPACK). The framework (see Figure 1) has been used to examine the development of TPACK in both in-service and pre-service educators as they accept, adapt, explore and advance with the integration of digital educational technologies in mathematics, language, art, science (Niess et al., 2009; Srisawasdi, Pondee, & Bunterm, 2018), with assessment (Akyuz, 2018) and with special education students (Kaplon-Schilis, & Lyublinskaya, 2020).

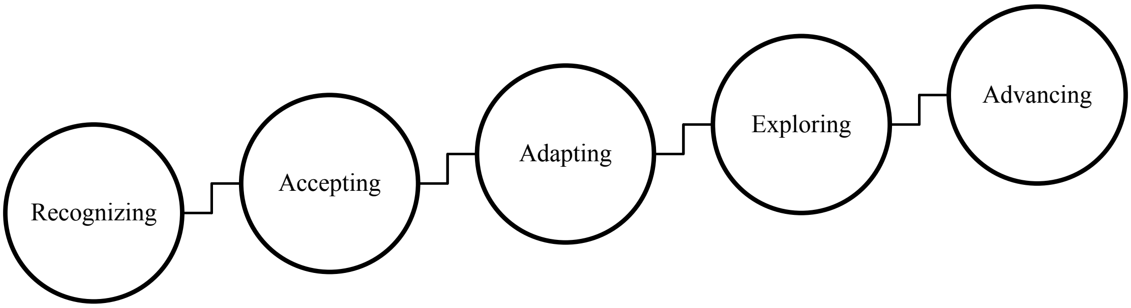

Figure 1. Five-stage developmental model.

In this work, we propose adapting the framework by Niess et al. (2009), in relation to educational neuroscience and associated non-invasive neuroimaging portable and wearable neuroimaging technologies as described below:

1) *Recognizing:* educators recognize the existence of educational neuroscience and associated technologies, and realize that findings from this field may affect the way they organize their classroom work. However, at this stage, they do not seek to integrate educational neuroscience and associated technologies into their educational practice.
2) *Accepting:* educators accept that they can use findings from educational neuroscience and associated technologies in their educational practice, as part of a process that helps them determine for themselves whether they will acquire a positive or negative attitude towards the use of these findings.
3) *Adapting:* educators adapt the daily operation of their classrooms by developing activities in which learners are taught and evaluated in accordance with the findings of educational neuroscience and with the use of associated technologies.
4) *Exploring:* educators explore and apply findings of educational neuroscience, incorporating them into teaching, assessment and learning using associated technologies.
5) *Advancing:* educators advance and assess the results of their decision to integrate findings of educational neuroscience and associated technologies into teaching, assessment and learning and to collaborate, discuss and attempt further modifications to their educational practices, enhancing educational research.

Advancing through the stages, in order to transform the experience and perspective of educators, requires a coherent professional development framework. The Association of Mathematics Teacher Educators Technology Committee (2006) framed educators' professional development in four axes: Curriculum and Assessment, Learning, Teaching, and Access. Although Curriculum and Assessment are closely linked, many educational systems treating these two axes separately (Jacobs, 1997; Khasawneh, 2022). In the present study, the discrete approach of the two axes was chosen. According to the above, a coherent professional development framework that will strengthen educators' knowledge and skills is required in the following five axes:

1) curriculum implementation,
2) student assessment,
3) learning,
4) teaching and
5) use of non-invasive portable and wearable technologies for neurophysiological measurements.

Table 1 describes these five axes in relation to the knowledge transformation framework presented above.

	RECOGNIZING	ACCEPTING	ADAPTING	EXPLORING	ADVANCING
Curriculum	Educators know that curricula and associated technologies have been developed according to educational neuroscience principles	Educators are persuaded or not to use curricular materials & associated technologies developed according to educational neuroscience principles	Educators engage learners with curricular materials & associated technologies which are developed according to educational neuroscience principles	Educators actively integrate curricular materials & associated technologies which are developed according to educational neuroscience	Educators evaluate the results of the decision to integrate curricular materials & associated technologies which are developed according to educational neuroscience
Assessment	Educators know that there are assessment approaches according to educational neuroscience principles	Educators are persuaded or not to use assessment approaches according to educational neuroscience principles	Educators engage their students with assessment activities which are developed according to educational neuroscience principles	Educators actively integrate assessment approaches according to educational neuroscience	Educators evaluate the results of the decision to integrate assessment approaches according to educational neuroscience
Learning	Educators know that student learning happens thanks to educational neuroscience principles	Educators are persuaded or not to use educational neuroscience approaches in order to help students learn	Educators help students learn according to educational neuroscience principles	Educators actively help students learn according to educational neuroscience principles	Educators evaluate the results of the decision to help students learn according to educational neuroscience principles
Teaching	Educators know that teaching can be improved using educational neuroscience principles	Educators are persuaded or not to use educational neuroscience approaches in their teaching	Educators engage their students in teaching approaches which are designed according to educational neuroscience principles	Educators actively integrate teaching approaches according to educational neuroscience principles	Educators evaluate the results of the decision to implement teaching approaches according to educational neuroscience principles
Access to non-invasive portable and wearable technologies for neurophysiological measurements	Educators know that there are portable and wearable technologies that can be used to gather neuroeducational data	Educators are persuaded or not to use portable and wearable technologies that can be used to gather neuroeducational data	Educators engage their students in approaches with portable and wearable technologies in order to realize the importance of the neuroeducational data	Educators actively integrate portable and wearable technologies that can be used to gather neuroeducational data	Educators evaluate the results of the decision to integrate portable and wearable technologies that can be used to gather neuroeducational data

Table 1. Five stages of teacher development along five axes.

3.1. *Transformation areas*

The five axes of the proposed framework described above have been studied by researchers, psychologists and educators so as to correlate with findings from the field of educational neuroscience. Regarding *curriculum*, the work of Watagodakumbura (2017) is of particular interest, as it identifies certain principles in relation to curriculum design. Specifically, Watagodakumbura describes the need for curriculum design based on the concepts of educational neuroscience which has the potential to contribute to learners' development. Issues related to educational neuroscience in the context of curriculum design include a) content, b) assessment processes, c) approaches that lead to discovery and independence skills, d) educational gap reduction, e) characteristics of people with special learning needs, and f) a focus on how the human brain works in order to favour inclusive practices. First and foremost, it is important that the curriculum enhances human brain development in ways that lead to lifelong learning. In other words, it is anticipated that through the expected learning outcomes the curriculum will favour the preservation of new memories and neural connections, so that they will be useful in multiple ways at an interdisciplinary level in the future. The achievement of the above can be enhanced by curricula which include a high level of generalized concepts or knowledge. Neuroscience findings show that high-level or more generalized concepts / knowledge are retained as permanent semantic memories, as opposed to episodic memories (Duff, Covington, Hilverman, & Cohen, 2020). In addition, curricula which incorporate high-level generalized concepts or knowledge, lead learners to a cognitive readiness and at the same time enhance students' ability to learn in one situation and then use that learning, possibly modified, in other situations (McPhail, 2021). In this way, it will be possible to transition from the acquisition of new knowledge through formal assessment processes, to the preservation of useful concepts at a high level in memory.

At the same time, since curricula also include *assessment* processes, it is important that these processes will be based on the principles of educational neuroscience. According to existing research, using non-threatening diagnostic, formative and final assessment procedures play a significant role in the construction, consolidation, storage and recall of new knowledge (Hwang & Chang, 2011; Jamaludin, Henik, & Hale, 2019). By using assessment procedures, educators can either identify the pre-existing perceptions of the students, or identify whether the students have the prerequisite knowledge, or monitor their progress. Research has already revealed, for instance, that results from such assessments must be used formatively for both educators and students (Wiliam, 2006). Educators can use these results in order to redesign the teaching approach based on students' learning obstacles. Similarly, students can use them as a metacognitive tool to perceive their cognitive awareness, and properly adjust their individual learning pathway.

Regarding *learning* and *teaching*, which are the core of educators' interventions and actions, two issues are discussed in the literature. The first concerns the use of learning barriers that the learners meet. The awareness of one's level of conceptual understanding constitutes a first step towards alleviating any misconceptions (Chi, 2008). As Versteeg, Wijnen-Meijer and Steendijk (2019) state "*when students remain unaware of their lack of knowledge or misconceptions and subsequently add new information to their current mental structures, this may result in inconsistent thinking (Chi et al., 2012; Posner, Strike, Hewson, & Gertzog, 1982)*". Thus, it is important for educators to provide learners opportunities to re-examine learning barriers (either their own or others') both individually and collaboratively, in order to eliminate possible misunderstandings and achieve the expected learning results (Moser, Schroder, Heeter, Moran, & Lee, 2011).

When educators in their teaching approach utilize the learning barriers that learners encounter and the cases of not achieving the expected learning outcomes, both, learners and educators can develop awareness about one's thinking and potential knowledge gaps or misconceptions (Versteeg & Steendijk, 2019; Sparck, Bjork E. L., & Bjork R. A., 2016). According to recent research, learners' work on teaching and learning barriers offers an orchestration of many areas of the brain which are associated with a wide range of knowledge and perform a variety of cognitive processes. Studies show significant activation of specific areas of the brain -namely, the Dorsolateral Prefrontal Cortex (DLPFC), Ventrolateral Prefrontal Cortex (VLPFC), Anterior Cingulate Cortex (ACC), upper parietal lobe, and optic cortex- for related error detection work, visuospatial processing, and visual attention (Vaughn, Brown, & Johnson, 2020).

Moreover, a decisive parameter of learning is related to the opportunities given to learners to examine an idea or concept using a multidimensional approach. For example, it is interesting to provide learners an opportunity to work with a problem by solving it

1) with operations;
2) diagrammatically;
3) algorithmically (coding); or
4) by producing a story, image or object about this problem (Doukakis et al., 2021).

In this case, synapses and neural circuits are developed and different areas of the brain are activated, depending on the activity and the way students perform the activity. According to educational neuroscience, multiple representations constitute an essential component of learning as they provide alternative ways for learners to acquire new knowledge by overcoming cognitive obstacles and applying this practice at daily life (Newton & Miah, 2017).

Another essential component related to learning and teaching is the *learning environment*. Information which enters the brain is first being processed in the parietal system of the brain –which is the neuroanatomical background for the expression and perception of emotional states, mobilization, and as well the emotional part of the memory process. After information enters the brain, the cognitive processing begins to take place. Long-term memory and learning are significantly affected by this system (Sidiropoulou, 2015). Thus, stress and threat in the context of learning have clear negative effects on learners. To this end, a learning environment which includes positive emotional experiences and connections for learners contributes to learning (Taylor, 2001). In this context, enhancing collaboration between learners also plays a key role (Saltz & Heckman, 2020). Collaboration among learners is important for two reasons:

a. it allows them to share their concerns, ideas and successfully study the problem given to them; and
b. it helps them understand and recognize how other people work.

Findings in the field of neuroscience show that when people work together, the medial orbitofrontal cortex and frontoparietal network are activated, thus enhancing the development of executive functions (Lu, Xue, Nozawa, & Hao, 2019). This is the reason why these areas of the brain are also referred to as the “social brain” and demonstrate the value of a sociocultural approach to learning and the need to provide students with opportunities for collaboration (Steffe & Gale, 1995).

The fifth axis is *access to non-invasive portable and wearable technologies for neurophysiological measurements* and educators’ ability to both use them and to analyse and interpret data from these technologies. Today, non-invasive portable and wearable devices can provide multi-task vital signs measurements. Portable and wearable systems, which include micro-sensors can be found into textiles (smart clothing), belts, smartwatches, glasses and devices which are worn on various parts of the body. With the use of these devices, it is possible to measure brain activity, pulse, body temperature, heart rate, oxygenation, respiration, electrodermal activity (EDA), electromyography (EMG), electrocardiogram (ECG), electroencephalogram (EEG) and measurements related with eyes and face (eye-tracker, face recognition).

All five axes are foundational to educators’ knowledge transformation. To move through the five stages of knowledge transformation, educators should not only change their perspective concerning educational neuroscience, but they should also integrate educational neuroscience principles and non-invasive portable and wearable technologies for neurophysiological measurements in their school practice. This shall lead them to progress through the five-stage developmental process.

4. DISCUSSION

In recent years, research in the field of educational neuroscience has developed to a great extent and a rich set of biological and behavioural data has been collected and interpreted in the context of laboratory studies. Nonetheless, it is important to consider these data and interpret them in the context of authentic educational settings. At the same time, educational research has produced significant results and contributed to the development of more effective learning contexts. These results also need to be part of neuroscientific research. In order to achieve two-way communication between researchers and educators, as well as support the involvement of educators in neuroeducational interventions, it is important to utilize the five-stage developmental framework proposed in this work. Regarding this framework, it is initially important to communicate the value of educational neuroscience to educators, so as to recognize its importance for teaching and learning. Next, it is crucial that they accept through specific interventions the integration of the principles of educational neuroscience as well as the value of non-invasive portable and wearable technologies for neurophysiological measurements in the teaching and learning process. Subsequently, it is important that they adopt research-based interventions in the field of educational neuroscience in their teaching. In continuation of these three stages (recognizing, accepting and adopting), which educators usually "reach" when they participate in properly designed six-month or annual professional development programs (Doukakis, 2012), educators need to fully integrate the principles of educational neuroscience and non-invasive portable and wearable technologies for neurophysiological measurements in the teaching and learning process (*exploring*). Moreover, they need to be able to evaluate the results of their decision to integrate these principles and technologies in the teaching and learning process (*advancing*).

At the same time, the axes in which it is important to see this development are in curriculum implementation, in student assessment, in learning, in teaching and in access to non-invasive portable and wearable technologies for neurophysiological measurements. This approach will enable the transition from the laboratory environment to the physical or online classroom, resulting in the use of portable technologies and the principles of educational neuroscience in authentic educational settings.

This approach may impact decisively teaching, learning, individual's well-being, the collective economy and the society. When curricula, student assessment and teaching are based on the principles of educational neuroscience and use of non-invasive portable and wearable technologies for neurophysiological measurements (e.g., brain activity, digital biomarkers, electrodermal activity, facial recognition and eye movement), educators can develop a more complete understanding of learners and the contexts in which learning is taking place. More specifically, collecting neurophysiological data provides educators the opportunity to observe and understand individual's needs concerning learning. It also offers the possibility of studying the effects of learning on the neural circuits of the brain. With educational mining and data analytics, the opportunity to analyse unique and ever-increasing data that come from the utilization of the above non-invasive portable and wearable technologies for neurophysiological measurements, is promising. In this way, via the use of special software, the profile of each learner can be created. Further, by utilizing machine learning and artificial intelligence, the data and the creation of the profile will not only provide the opportunity for neuroeducational understanding of each individual, but also for neuroeducational prediction of how individuals work and how they cope with learning. Subsequently, such findings could be used to develop neuroeducational interventions through the creation of appropriate learning paths. Since educators will be able to observe students in real time through non-invasive portable and wearable technologies, however, issues such as how they will utilize the data in order to support students in situ (Plerou, Vlamos, & Triantafillidis,

2017) as well as ethical issues associated with the collection and use of such data will arise.

While non-invasive portable and wearable technologies for neurophysiological measurements have a high cost and require specialized knowledge, an effort is being made worldwide to strengthen their application in educational practice given their promise. McCandliss and Toomarian's for instance report on a study of 11,000 third grade children who completed an extensive brain scanning protocol in multiple cities across the country (USA). These scans will be repeated every two years as students' progress through elementary, middle, and high school, "*providing the largest brain development study ever carried out and enabling researchers to follow changes in the structure and functions of specific neural circuits and fully explore the diversity of paths that children's brain development takes*" (McCandliss & Toomarian, 2020).

Alongside the ambitious efforts of non-invasive portable and wearable technologies for neurophysiological measurements, however, it is also critical that we consider ethical issues associated with the use of such tools. Issues such as informed consent, privacy, confidentiality, data security and data protection, as well as participants anonymization and elimination of discrimination, must be taken into account when employing digital technologies in teaching or research, and therefore appropriate training or guidance is needed. In attempting to provide an accessible method for ethical design, Mason R., Mason, F. and Culnan (1995; as cited in Harris, Jennings, Pullinger, Rogerson, & Duquenoy, 2008) propose that we researchers and educators consider four fundamental questions:

- "*Who is the agent?*" (including their motives, interests and character),
- *"What action was taken or is being contemplated?",*
- *"What are the results or consequences of that action?",*
- *"Are those results fair or just?*".

In the same vein, guidelines regarding ethical issues such as: consent and anonymity of research participants or the parents/guardians of the learners, possibility of research participants to discontinue their participation, protection of research participants from exposure to possible physical or psychological danger need to be identified. Finally, issues of accuracy and accountability in the use and exacerbation of inequalities are pressing challenges towards the generalized use of portable and wearable technologies for neurophysiological measurements in teaching.

5. CONCLUSION

The opportunities and limitations of using non-invasive portable and wearable technologies for neurophysiological measurements in education is an issue which needs to be introduced in the educational agenda and future educational policy. The framework proposed in this work, constitutes a theoretical training approach; thus, there is a need to be examine it in practice. For this purpose, the design of professional development programs is required, which will help strengthen the knowledge of educators in educational neuroscience and in the use of portable and wearable technologies for neurophysiological measurements. These programs will be an excellent opportunity for classroom education to effectively communicate with researchers in educational neuroscience and affect teaching practices.

Provided that it will be successfully implemented, educators will be given the opportunity to go beyond traditional practical assessments of educational performance to identify effective, documented and functional teaching practices for learners. Empirical work could help determine whether teaching and learning practices rooted in neuroscience principles and the inclusion of portable and wearable technologies for neurophysiological measurements make it possible to delve into how the human brain learns and interacts in relation to other human aspects such as education, mental health, innovation, productivity, poverty, and inequality.

6. REFERENCES

Akyuz, D. (2018). Measuring technological pedagogical content knowledge (TPACK) through performance assessment. *Computers & Education*, *125*, 212-225. doi: 10.17471/2499-4324/1268

Association of Mathematics Teacher Educators. (2006, January). *Preparing teachers to use technology to enhance the learning of mathematics*. Retrieved from https://amte.net/news/2006/01/position-preparing-teachers-use-technology-enhance-learning-mathematics

Chang, Z., Schwartz, M. S., Hinesley, V., & Dubinsky, J. M. (2021, August 11). Neuroscience concepts changed teachers' views of pedagogy and students. *Frontiers in Psychology*, 3264. doi: 10.3389/fpsyg.2021.685856

Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *Handbook of research on conceptual change* (pp. 61-82). Hillsdale, NJ, US: Erlbaum.

Cranton, P. (2016). *Understanding and promoting transformative learning: A guide to theory and practice*. Sterling, VA, US: Stylus Publishing, LLC.

Dekker, S., Lee, N. C., Howard-Jones, P., & Jolles, J. (2012, October 18). Neuromyths in education: Prevalence and predictors of misconceptions among teachers. *Frontiers in Psychology*, 429. doi: 10.3389/fpsyg.2012.00429

Doukakis, S. (2012). *Exploring undergraduate students' transformation of technological pedagogical knowledge in Mathematics as prospective teachers and as teachers in their school action*. [PhD Thesis] University of the Aegean.

Doukakis, S., Sfyris, P., Niari, M., & Alexopoulos, E. (2021). Exploring educational practices in emergency remote teaching. The role of educational neuroscience. In *2021 IEEE Global Engineering Education Conference - EDUCON* (Vienna, Austria, 21st-23rd April 2021) (pp. 1026-1034). IEEE. doi: 10.1109/EDUCON46332.2021.9454143

Duff, M. C., Covington, N. V., Hilverman, C., & Cohen, N. J. (2020, January 24). Semantic memory and the hippocampus: Revisiting, reaffirming, and extending the reach of their critical relationship. *Frontiers in Human Neuroscience*, *13*, 471. doi: 10.3389/fnhum.2019.00471

Harris, I., Jennings, R., Pullinger, D., Rogerson, S., & Duquenoy, P. (2008). Helping ICT professionals to assess ethical issues in new and emerging technologies. In *MINAmI workshop on ambient intelligence and ethics* (Vol. 15). *British Computer Society.* Retrieved from https://www.academia.edu/322949/Helping_ICT_Professionals_to_Assess_Ethical_Issues_In_New_and_Emerging_Technologies

Horvath, J. C., & Donoghue, G. M. (2016, March 16). A bridge too far–revisited: reframing Bruer's neuroeducation argument for modern science of learning practitioners. *Frontiers in Psychology*, *7*, 377. doi: 10.3389/fpsyg.2016.00377

Howard-Jones, P., Jay, T., & Galeano, L. (2020). Professional development on the science of learning and teachers' performative thinking—a pilot study. *Mind, Brain, and Education, 14*(3), 267-278. doi: 10.1111/mbe.12254

Hwang, G. J., & Chang, H. F. (2011). A formative assessment-based mobile learning approach to improving the learning attitudes and achievements of students. *Computers & Education*, *56*(4), 1023-1031. doi: 10.1016/j.compedu.2010.12.002

Jacobs, H. H. (1997). *Mapping the Big Picture. Integrating Curriculum & Assessment K-12*. Alexandria, VA, US: Association for Supervision and Curriculum Development.

Jamaludin, A., Henik, A., & Hale, J. B. (2019). Educational neuroscience: Bridging theory and practice. *Learning: Research and Practice*, *5*(2), 93-98. doi: 10.1080/23735082.2019.1685027

Janssen, T. W., Grammer, J. K., Bleichner, M. G., Bulgarelli, C., Davidesco, I., Dikker, S., ... & van Atteveldt, N. (2021). Opportunities and limitations of mobile neuroimaging technologies in educational neuroscience. *Mind, Brain, and Education*, *15*(4), 354-370. doi: 10.1111/mbe.12302

Jarodzka, H., Skuballa, I., & Gruber, H. (2021). Eye-tracking in educational practice: Investigating visual perception underlying teaching and learning in the classroom. *Educational Psychology Review*, *33*(1), 1-10. doi: 10.1007/s10648-020-09565-7

Kaplon-Schilis, A., & Lyublinskaya, I. (2020). Analysis of relationship between five domains of TPACK framework: TK, PK, CK math, CK science, and TPACK of pre-service special education teachers. *Technology, Knowledge and Learning*, *25*(1), 25-43. doi: 10.1007/s10758-019-09404-x

Khasawneh, M. (2022). The relationship of curriculum, teaching methods, assessment methods, and school and home environment with learning difficulties in English language from the students' perspectives. *Journal of Innovation in Educational and Cultural Research*, *3*(1), 41-48. doi: 10.46843/jiecr.v3i1.51

Lin, L., Parsons, T.D., & Cockerham, D. (2019). Rethinking learning in the rapid developments of neuroscience, learning technologies, and learning sciences. In T. Parsons, L. Lin, & D. Cockerham (Eds.), *Mind, Brain and Technology. Educational Communications and Technology: Issues and Innovations* (pp. 3-16). Cham, CH: Springer. doi: 10.1007/978-3-030-02631-8_1

Lu, K., Xue, H., Nozawa, T., & Hao, N. (2019). Cooperation makes a group be more creative. *Cerebral Cortex*, *29*(8), 3457-3470. doi: 10.1093/cercor/bhy215

Mason, R., Mason, F., & Culnan, M. (1995). *Ethics of information management*. Thousend Oaks, CA, US: Sage.

McCandliss, B., & Toomarian, E. (2020, April 13). Putting neuroscience in the classroom: How the brain changes as we learn. *Trend.* Retrieved from https://www.pewtrusts.org/en/trend/archive/spring-2020/putting-neuroscience-in-the-classroom-how-the-brain-changes-as-we-learn

McPhail, G. (2021). The search for deep learning: A curriculum coherence model. *Journal of Curriculum Studies*, *53*(4), 420-434. doi: 10.1080/00220272.2020.1748231

Moser, J. S., Schroder, H. S., Heeter, C., Moran, T. P., & Lee, Y. H. (2011). Mind your errors: Evidence for a neural mechanism linking growth mind-set to adaptive posterior adjustments. *Psychological Science*, *22*(12), 1484-1489. doi: 10.1177/0956797611419520

Newton, P. M., & Miah, M. (2017, March 27). Evidence-based higher education – Is the learning styles 'myth' important?. *Frontiers in Psychology*, *8*, 444. doi: 10.3389/fpsyg.2017.00444

Niess, M. L., Ronau, R. N., Shafer, K. G., Driskell, S. O., Harper, S. R., Johnston, C., ... & Kersaint, G. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 4-24.

Organisation for Economic Co-operation and Development. (2002). *Understanding the brain: Towards a new learning science*. OECD Publishing.

Organisation for Economic Co-operation and Development. (2007). *Understanding the brain: The birth of a learning science.* OECD Publishing.

Plerou, A., Vlamos, P., & Triantafillidis, C. (2017). the effectiveness of neurofeedback training in algorithmic thinking skills enhancement. In P. Vlamos (Ed.), *GeNeDis 2016. Advances in Experimental Medicine and Biology*, 988. Cham, CH: Springer. doi: 10.1007/978-3-319-56246-9_14

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.

Privitera, A. J. (2021). A scoping review of research on neuroscience training for teachers. *Trends in Neuroscience and Education*, *24*, 100157. doi: 10.1016/j.tine.2021.100157

Saltz, J., & Heckman, R. (2020). Using structured pair activities in a distributed online breakout room. *Online Learning*, *24*(1), 227-244. doi: 10.24059/olj.v24i1.1632

Sidiropoulou, K. (2015). *Basic principles for the functioning of nervous system*. Athens, GR: Kallipos, Open Academic Editions.

Smale-Jacobse, A. E., Meijer, A., Helms-Lorenz, M., & Maulana, R. (2019, November 22). Differentiated instruction in secondary education: A systematic review of research evidence. *Frontiers in Psychology*, *10*. doi: 10.3389/fpsyg.2019.02366

Sparck, E. M., Bjork, E. L., & Bjork, R. A. (2016). On the learning benefits of confidence-weighted testing. *Cognitive research: Principles and implications*, *1*(1), 1-10. doi: 10.1186/s41235-016-0003-x

Srisawasdi, N., Pondee, P., & Bunterm, T. (2018). Preparing pre-service teachers to integrate mobile technology into science laboratory learning: an evaluation of technology-integrated pedagogy module. *International Journal of Mobile Learning and Organisation*, *12*(1), 1-17. doi: 10.1504/IJMLO.2018.089239

Steffe, L. P., & Gale, J. E. (Eds.). (1995). *Constructivism in education*. Psychology Press.

Tan, Y. S. M., & Amiel, J. J. (2022). Teachers learning to apply neuroscience to classroom instruction: case of professional development in British Columbia. *Professional Development in Education*, *48*(1), 70-87. doi: 10.1080/19415257.2019.1689522

Taylor, E. W. (2001). Transformative learning theory: A neurobiological perspective of the role of emotions and unconscious ways of knowing. *International Journal of lifelong education*, *20*(3), 218-236. doi: 10.1080/02601370110036064

van Gennep, A. (1960). *The rites of passage (2nd Ed.)*. Chicago, IL, US: The University of Chicago Press.

Vaughn, A. R., Brown, R. D., & Johnson, M. L. (2020). Understanding conceptual change and science learning through educational neuroscience. *Mind, Brain, and Education*, *14*(2), 82-93. doi: 10.1111/mbe.12237

Versteeg, M., & Steendijk, P. (2019). Putting post-decision wagering to the test: a measure of self-perceived knowledge in basic sciences? *Perspectives on Medical Education, 8*(1), 9-16. doi: 10.1007/s40037-019-0495-4

Versteeg, M., Wijnen-Meijer, M., & Steendijk, P. (2019). Informing the uninformed: a multitier approach to uncover students' misconceptions on cardiovascular physiology. *Advances in Physiology Education, 43*(1), 7-14. doi: 10.1152/advan.00130.2018

Watagodakumbura, C. (2017). Principles of Curriculum Design and Construction Based on the Concepts of Educational Neuroscience. *Journal of Education and Learning*, *6*(3), 54-69. doi: 10.5539/jel.v6n3p54

Wiliam, D. (2006). Formative assessment: Getting the focus right. *Educational Assessment*, *11*(3-4), 283-289. doi: 10.1080/10627197.2006.9652993

Williamson, B. J. (2020). New digital laboratories of experimental knowledge production: Artificial intelligence and education research. *London Review of Education*. doi: 10.14324/LRE.18.2.05

Yfanti, A., & Doukakis, S. (2021). Debunking the neuromyth of learning style. In P. Vlamos (Ed.), *GeNeDis 2020*. *Advances in Experimental Medicine and Biology* (pp. 145-153). Cham, CH: Springer. doi: 10.1007/978-3-030-78775-2_17