Education still needs Artificial Intelligence to support Personalized Motor Skill Learning: Aikido as a case study

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Abstract. Motor skill learning is hardly considered in current AIED literature. However, there are many learning tasks that require consolidating motor tasks into memory through repetition towards accurate movements, such as learning to write, to draw, to play a musical instrument, to practice a sport technique, to dance, to use sign language or to train for surgery. The field of Artificial Intelligence (AI) needs new sap to cope with the challenges in the Educational (ED) domain aimed to support psychomotor learning. This new sap can be provided by novel interactive technologies around the Internet of the Things that deal with Quantified-self wearable devices, 3D modelling, Big Data processing, etc. The paper aims to identify opportunities and challenges for AI + ED that can be discussed during the workshop. Some of the issues raised are illustrated within a case study instantiated in the Aikido practice, a defensive martial art that involves learning skilled movements by training both the body and the mind, and which is not only part of extra-curricular activity in many schools, but has also been reported of value for teaching in STEM (Science, Technology, Engineering and Mathematics) education, in particular, some laws of mechanics.

Keywords: motor skill learning, psychomotor domain, artificial intelligence, education, Internet of the Things, personalization, Aikido, STEM.

1 Introduction

Motor skill learning can be defined as achieving the ability to perform a function acquired with practice that requires body and/or limb movement to accomplish the goal of an action or task [1]. Although it is not a new concept [2], up to my knowledge (grounded by a review of the papers published in the International Journal of Artificial Intelligence in Education (IJAIED) and which is reported elsewhere [3]), the physical aspects of learning have been hardly considered in the AIED research. Nevertheless, consolidating specific motor tasks into memory through repetition (thus, creating long-term muscle memory for a given task) is very relevant in diverse educational scenarios that support learning processes involving not only brain activity, but also physical activity, such as learning to write, to draw, to play a musical instrument, to practice a sport technique, to dance, to use sign language or to train for surgery that require long-term physical training, as reported in [3]. In these situations, learners have to train by repeating basic and very specific movements till they learn the best way to carry them out effectively without conscious effort. It has to be remarked here that learning physical skills (i.e., the proficiency of individual movements, also called sensomotor habits [4]) goes beyond mere muscle memory, but involve blending motor skills and cognitive, meta-cognitive and affective skills. In fact, psychomotor skills cannot be acquired by multiple repetitions of given motor pattern without considering the importance of feedback between cognitive processes and motor actions [5]. However, the focus of the discussion that this paper aims to bring to the workshop is mainly on how the physical part related to the psychomotor learning domain (which deals with physical movement, coordination and the use of the motor skill areas [6]) can be supported from an AIED perspective, both in 1) the modelling of the learner physical interaction, and 2) the provision of the required personalized support during the learning. In my view, this is a new dimension that is worth to be explored by combining AI + ED research. The cognitive, meta-cognitive and affective dimensions are already being widely addressed in AIED literature.

In addition, at this point in time, technology has evolved in such a way that it can monitor the movements carried out by the learners through diverse types of sensors (e.g., inertial, optical, position, electromyography, etc.) and timely feedback can be provided through diverse actuators (such as resistance, force, vibration, etc. as well as servo motors) to help the learner improve the performance of the corresponding movement. Quantified-self approaches (based on data gathered from wearable devices such as electronic bracelets and intelligent t-shirts) allow personal awareness and reflection for behavioral monitoring in many situations, such as physical exercise or affective support. Big Data allows processing real time data streams gathered from heterogeneous information sources. 3D models of real objects can be produced with low-cost scanners and printers. These technologies (among others) support the so called Internet of the Things (IoT), that is, the connection of *physical things* to the Internet, which makes possible to access remote sensor data and to control the physical world from a distance [7]. In this context, the do-it-yourself movement supports non-experts in getting familiar with these novel interaction technologies and in being able to build ad-hoc electronic components for their own needs. Thus, AIED researchers can take advantage of this supportive context so the learning curve of integrating above technologies with AI techniques can be feasible for the field.

As a result, this paper proposes to explicitly open a new research line for the AIED field where ED can benefit from AI techniques enriched with emerging novel interactive technologies around the Internet of the Things. This new research direction, framed within the psychomotor learning domain, requires a shift towards supporting physical practice (i.e., training) rather than supporting instructional teaching. This implies that the physical actions carried out while practicing need to be monitored, modelled and, when needed, corrected, to achieve successful motor skill learning (i.e., skills learning at a physical level).

2 Opportunities and Challenges

As discussed in [3], the synergy of Artificial Intelligence techniques with novel interactive technologies opens new opportunities for researching the physical (i.e., corporal) aspects of learning. For instance, it seems to be possible to provide intelligent real time feedback to scaffold physical skill learning by using sensors, actuators, 3D scanning and modelling, data streams processing, etc. And in order to improve performance, tangible scaffolding could be provided to guide motor skill learning in a personalized way through embodiment technology. A case study that illustrates some issues involved is outlined in Section 3.

In any case, by integrating novel interactive technology, the foreseen goal is that AIED researchers can produce systems that sense the learner's corporal behavior as she learns specific skilled movements, and then guide the learner on how to react in an optimal way (taking into account the learner's current performance, corporal features and the particularities of the specific movement to perform) by providing personalized feedback during the learning process (rather than just giving directions of what to do and how to do, as in traditional AIED intervention approaches). Procedural learning in terms of motor skill is usually difficult to explain by the instructor and to understand by the learner. In fact, this procedural tutoring support is of major relevance in the case of novice learners, as they might get into a wrong habit if no timely feedback is provided to them while practicing by their own and, thus, they cannot understand why the movement is not correct.

In order to build procedural learning systems that can personalize motor skill learning, both AI and ED research need to revise the application of their theoretical and methodological approaches to the particularities of the psychomotor learning domain. From the AI point of view, there is a need for modelling the individual functional and corporal features, her interaction and the accurate movement, by processing the simultaneously and continuously data streams produced by diverse and heterogeneous sensors, and then controlling the robotics to physically deliver the intervention to the learner. From the ED point of view, the focus has to be put on identifying what is the most appropriate intervention in each case (considering cognitive, meta-cognitive, affective and behavioral dimensions) and when and how it should be delivered in order to make a positive impact in the learning process.

Therefore, as discussed in [3], there exist challenges regarding 1) modelling and representing the movements of the learner by building the learner physical interaction model as well as the accurate movement model, and 2) providing the appropriate personalized physical support in the most efficient way for each learner in each training context. More specifically, regarding the modelling of movements, there seem to be challenges related to: i) detecting the physical interaction, ii) modelling the movements to be trained, iii) error diagnosing and intervention modelling, and iv) modelling the learner. In turn, regarding the provision of the appropriate personalized physical support, challenges might exist in order to: i) deciding upon adaptation, ii) evaluating the user activity, iii) visualization of movement performance, and iv) sharing progress and social learning.

3 A case study for AI + ED: supporting personalized psychomotor learning in Aikido

In order to facilitate the discussion on existing challenges for AI + ED to support personalized motor learning skill learning, a case study is presented. This case study focuses on Aikido martial art. Since it might surprise the reader the selection of this domain from an ED perspective, first some of the reasons for its selection are discussed. Then, some technological advances that can help AI to provide personalized motor skill training within the Aikido psychomotor learning domain are presented. They intend to include in the AIED research agenda ideas that can be explored.

3.1 Aikido & ED: more than just a psychomotor learning domain

Aikido is a non-aggressive Japanese martial art that consists of entering and turning movements that redirect the momentum of an opponent's attack, and a throw or joint lock that terminates the technique [8]. The word is formed by Ai (coordination, accord, harmony, blending), Ki (psychological energy, spirit, universal force) and Do (way of life, philosophy of living) [9]. It is guided by defending oneself while also protecting the attacker from injury. In fact, it is based on the principle that in order to control an attacker, the defender must meet the attack in a state of perfect balance [10]. Properly carrying out the technique requires years of training by repeating over and over the sequence of movements that makes up each Aikido technique.

Martial arts do not only involve complex manipulations of human anatomy and physiology [9], but they aim to train both the body and the mind, since training consist of improving mental disposition and motor skills (i.e., fitness and coordination) [4]. According to these authors [4], the technique of self-defense can be defined as a specific sequence of movements constituting a partial or total resolving of various dynamic situations. These movements imply eccentric and concentric muscle work, rotation of the trunk and hips, translocation of the body mass center and adequate leg work. Interplay of muscle tension and relaxation combined with accurate decisions is needed. This requires the development of skills in body movement control that combine mental balance and appropriate motor actions, where the general motor fitness is adjusted to the individual level of motor abilities (i.e., quality is more important than strength). Automation of movements occurs when mental processes are free of controlling individual movements. An ability of psycho-physical self-controls is also required to allow for efficient performance under stressful situations.

Since Aikido practice involves the execution of paired movements between the attacker (*uke*: receiver of the technique) and the defendant (*tory*: doer of the technique), it helps understanding cooperation and timing in movement [11]. Recent studies using electroencephalography and electromyography techniques have shown that the postural control training using Aikido improves psychomotor performance [10].

Nonetheless, the benefits of Aikido go beyond physical fitness and motor abilities. For instance, some studies suggest that Aikido training increases mindfulness [11]. In particular, since practitioners are taught to be mindful of the technique, breathing, balance, center of gravity and their connection to the other person, it may facilitate increasing one's awareness of body position, of others around, practitioner's emotional states and how other people's emotions may affect the Aikido practitioner's emotional states. As compiled by these authors, benefits of increased mindfulness may include better concentration, stronger awareness, improved immune system functioning and decreases in stress related physical symptoms [12, 13]. In this way, Aikido training may enhance awareness and resolution of problematical situations, as during training sessions, the practitioner learns to deal with multiple stressors concurrently, and this is learnt to do in an effective manner while remaining calm, which suggests that Aikido seem to teach practical problem solving and acceptance of circumstances [11]. In this sense, Aikido is one of the more spiritual martial arts as it studies the energy within oneself, her partner and the world through the physical principles of entering, turning and securing, and thus, focuses directly on the energy involved in dealing with one's emotions, perceptions of trust and fear, and conceptions of reality as well as the energy and demands in relating with another human being [14]. In this authors' viewpoint, Aikido can contribute to relationship encounters, conflict resolution, motivation and personal energy by an effective management of energy, improving interpersonal relationships and facilitating stress reduction. Following these ideas, studies have shown that including martial arts such as Aikido in school programs can enhance student's awareness of violence prevention and allow them to react calmly and without panic, reducing violence in schools [15].

In addition to above benefits, Aikido has also potential to be used in education, not only for physical education (i.e., development of motor abilities, mental and physical health benefits, violence reduction…) but also in STEM education (i.e., Science, Technology, Engineering and Mathematics). In this sense, there are studies where some laws of Physics are taught with Aikido practice (see [15]) that show statistically significant improvements in the scores on biomechanics (i.e., mechanics principles of human movement) tests as well as statistically significant correlations between the results in those tests and the performance of the Aikido techniques. From these works, it seems that solid-state mechanics concepts such as the law of momentum conservation, second law of motion for angular motion, centrifugal force and composition of resultant forces and moments of force, can be explained more effectively with the practice of Aikido, facilitating the understanding of how forces act on a person while in translator or rotary motion.

Since the practice of Aikido seems to improve not only motor skills, but also some cognitive abilities (i.e., acquiring the knowledge of mechanics required by the scholar curriculum), this martial art has been chosen to discuss how a psychomotor learning domain like this could benefit from an AIED procedural learning environment. In this sense, some ideas on how to provide some tangible scaffolding when needed to guide motor skill learning in a personalized way using novel interactive technology from the IoT are discussed next. The research question behind is: *How to design and implement a personalized procedural learning environment that can physically train and guide the particular way each learners' body and limbs should move in order to achieve a specific learning goal that is related to improving learners' motor skills acquisition, such as the needs identified in the Aikido practice?*

3.2 Improving AI based personalized motor skill learning in Aikido with novel interactive technologies

The goal of Aikido is to hold the *uke* (attacker) in a compromised and secured position with a minimal amount of effort [17]. To achieve this, Aikido practice involves the manipulation of various joints of the body and is based on effective anatomical principles to subdue a training partner by twisting the limbs or locking up the skeletal system. In order to better understand the body's responses and improve the proficiency of applying specific techniques, anatomical studies on cadavers that investigated the nerves, bones, muscles, tendons and tissues manipulated by each technique have been carried out in the past [9]. However, novel interactive technologies, such as those provided by quantified-self wearable devices, can be used to gather dynamic indicators while making the movement. This can help to understand how the movements are performed and improve training. For instance, the movements carried out by a person can be monitored using diverse types of sensors (inertial, optical, position, physiological, etc.) [18] for real time motion study outside the laboratory [19]. This technology is becoming less and less intrusive, to the point that sensors that allow complex movement patterns tracking are getting embedded directly into clothes [20]. The interaction data streams continuously collected by these sensors in real time need to be processed. Due to its volume, variability and speed, Big Data mining techniques need probably to be applied [21].

In addition, as introduced above, Aikido requires long-term physical training to learn how to carry out the movements in the most efficient way. Very often, the execution of the corresponding techniques involves practitioners moving along a curve and lowering one's center of gravity in order to employ the centrifugal force acting on the opponent and one's own gravity [16]. Forces applied are notably subtle and intricate, and thus, difficult to learn without the direct tutelage by an experienced *sensei* (teacher) [17]. This is not easy to put into practice without being repeatedly told what is done wrong and what should be done right. In order to be able to compare how the movement is performed, a model of the accurate movement needs to be built. In the field of virtual reality, there are works that build virtual skeletal models for videogames from the information collected using wearable technology (e.g., biomechanical or inertial sensors), which both map the movement as well as recognize gestures with AI techniques [22]. The movement controlled by sensors can also be represented in 3D models of the human body [23].

The next step is to provide some guided feedback. Since the situations where the applied techniques are never the same (e.g., the degree and direction of force is different, the position of the *tory* is not always the same, body shape and muscular structure differ from *uke* to *uke*, perception and timing change) the application of the technique must change accordingly [24]. This means that the provided feedback should be personalized to the current situation, including *uke* and *tory* body built. With respect to defining the appropriate feedback to give, an initial proposal can be to provide some tangible scaffolding through embodiment technology that corrects the learner's movements by physically controlling and guiding the movement of the learner till her ideal movements (considering the learner's own body built) are achieved. Feedback with different levels of complexity (simple verification, try again and elaborated) provided through different channels (visual, audio and haptic) [17] should be considered. For instance, in order to provide motor intervention, some works use electromyography sensors (i.e., the measure of the electrical activity produced by the skeletal muscles) to detect movement intentions and help to carry them out through exoskeletons (i.e., physical shells) moved with servo motors [25]. Resistive sensors have also been used to move body parts through vibrations [26]. Inertial sensors and vibro-tactil feedback is also used to replicate referred postures and correct those that are not alike [27]. A forced feedback system to guide fingers movement to improve motor skills when playing the piano has been implemented with a simple exoskeletal robotics [28]. The technology for 3D modelling can be used to build physical prototypes of tangible objects. As an example, combining available technologies, a 3D printed hand has been controlled with Arduino using servomotors [29].

However, guiding the learner by delivering forced haptic feedback when the movement performed does not reflect the reference movement might not be the most appropriate psycho-educational approach to achieve long-term learning, although it might help to increase motivation by contributing to short-term performance [30]. Therefore, there is a need to research the appropriate personalized support to provide. Here, the application of TORMES methodology [31] (or an extended version of it that addresses the particularities required by the psychomotor learning domain and the requirements to sense the environment and provide tangible support) can be of value to model the personalized dynamic psychomotor support to be provided in specific situations. In particular, TORMES extends the design cycle of interactive systems as defined by ISO 9241-210 with the life cycle of e-learning and the layered evaluation of adaptive systems, and combines user centered design methods (which can be applied to gather tacit knowledge from psychomotor experts as well as experienced Aikido teachers and practitioners) with (big) data mining techniques (that can be used to analysis performance indicators regarding the movements carried out gathered from Aikido training sessions, for instance, using wearable devices).

There is a commercial software (i.e., Aikido 3D[1]) that recreates with animated characters the movements of a high degree Aikido black belt using motion capture technology. The goal of this tool is to facilitate visualizing how the techniques are to be carried out, so the learner can see it from different perspectives, in slow motion, zoomed, etc. It provides a technological improvement on top of what takes place in Aikido *dojos* (i.e., training places) around the world, but the approach behind is similar: learner watches how an expert (in this case, an animated character whose behavior has been modelled with the movements of an expert) carries out the technique and then tries to reproduce (imitate) the same movements with a partner. However, an AIED support through a procedural learning environment could improve the learning experience by physically controlling and guiding the movements of the learner when appropriate, so she can correct them till she masters the movements for the technique (considering the learner's own body built and skills, as well as the context where the movement is carried out, including the opponent features). This requires the follow-

[1] https://www.aikido3d.com

ing: 1) sensing the learner's movement and the context in which this movement takes place (e.g., the physical features and abilities of the opponent), 2) comparing it against the accurate movement (e.g., how an expert in the technique would carry the movement out considering the same physical features and abilities of the learner and the opponent), 3) deciding whether it is appropriate to provide the tangible support at this moment (dealing with focusing on short term performance vs. long-term learning), and 4) if appropriate, then provide the tangible support in an effective non-intrusive way, for instance with vibro-tactil feedback through actuators sew on the *Aikidogi* (i.e., the Aikido training uniform).

4 Conclusion

There is a challenge and opportunity to take advantage of AI and ED research to develop personalized procedural systems that can support learners while acquiring psychomotor abilities. Learning and improving motor skills is of relevance in many domains, such as learning to write, to draw, to play a musical instrument, to practice a sport technique, to dance, to use sign language or to train for surgery.

In this paper, the relevance of Aikido practice and the support it can obtain from AIED based procedural learning environments has been discussed for the first time in the literature. In addition, the application of novel interaction technologies that are being used by the Internet of the Things (such as quantified-self wearable devices, big data processing and 3D modelling) to build an AIED procedural learning environment has been proposed by reporting works that partially address some of the technological issues discussed. Although the assimilation of new technologies is always costly, the do-it-yourself movement, which encourages people in creating Internet of the Things applications by their own [32], can simply their learning curve and thus, their usage should be feasible for the AIED research community, provided that many people around the world are taking advantage of them without a wide specialized technological background. In turn, non-specialized users benefit from the feeling of belonging to a community that characterizes this kind of developing culture (as well as the open source and open hardware philosophy underneath it) and receive on-line peer support both on search (i.e., looking for information with the help of web search engines or within specialized repositories) and on demand (i.e., asking in specialized forums).

In addition, it can also be noted here that most of the approaches referenced in the previous section can be controlled by an Arduino based infrastructure. Arduino is an open source electronics prototyping platform, which is based on easy to use hardware and software [33]. As reported in previous work, Arduino can be used to gather contextual information from sensors [34] and deliver ambient intelligent feedback [35].

In summary, the motivation of this paper is to propose a new research direction to the AIED field, where novel interactive technologies enrich Artificial Intelligence techniques to deal with some challenges within the Educational domain. This proposal will be discussed further during the workshop "Les Contes du Mariage: Should AI stay married to ED? A workshop examining the current and future identity of the AIED field" taking place during the 17th International Conference on Artificial Intelligence in Education (AIED 2015). Outcomes from the discussion in the workshop will be included in a paper for the IJAED Special Issue “The next 25 Years: How advanced, interactive educational technologies will change the world” [3].

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