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REFLECTING A... "BIT". WHAT RELATIONSHIP BETWEEN METACOGNITION AND ICT?

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Using Information and Communication Technologies (ICT) in educational environments has become widespread in latest years. Since research underlined the important role played by metacognition and self-regulation abilities in fostering learning outcomes, the relationship between these aspects appears to be particularly worthy of investigation. In this review, we present 14 studies that have deepened the relationship between ICT, metacognitive skills and learning outcomes by identifying two main categories. Some articles investigated the effects of ICT environments combined with metacognitive aspects of learning outcomes, while others investigated the reciprocal relationship between ICT and metacognition. In general, from our review, the interaction between ICT and metacognition in producing better learning outcomes appears well established and the results highlight a bi-directional relationship between metacognition and ICT, but also allow to draw attention to gaps requiring further research.

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1 Introduction

1.1 What is metacognition?

The latest research on educational psychology has highlighted the importance of knowing how to think and how to learn rather than just 'knowing' and underlined the advantage of focusing on the characteristics of the learning process, rather than on its content elements (Bjork & Yan, 2014). This has stimulated a reflection on the thinking process, on the construction of knowledge and on the systems with which people know and regulate their own learning. The attention of those who design learning environments has thus progressively shifted towards the awareness of one's learning processes and needs. This allowed to identify available opportunities to overcome obstacles in learning, by developing and promoting a strategic and positive emotional-motivational attitude towards the acquisition of learning strategies and methods (Battistelli *et al.*, 2009). All these skills fall into metacognition as a superordinate category concerning cognitive processes. Metacognition can be defined as the individual's knowledge regarding cognitive functioning (Flavell, 1979) - i.e. what one knows about how his/her and other people's minds function. It also refers to the different forms of control that can be implemented before, during and after the execution of a task (Brown, 1987) - i.e. the activities that guide and monitor one's cognitive processes. The main components of the regulation of cognition are planning, monitoring, and evaluating (Manning, Glasner, & Smith, 1996). Planning involves the selection of appropriate strategies and the allocation of personal resources. It includes goal setting, activating relevant background knowledge, and budgeting time. Monitoring refers to self-testing skills necessary to control learning. Evaluation refers to appraising the products and regulatory processes of one's learning. Metacognition generates interest because it enables individuals to monitor their own knowledge and skill levels, to allocate a limited amount of learning resources efficiently, and to evaluate their learning outcomes, ultimately favouring learning (Lee & Stankov, 2013).

Fiore and Vogel-Walcutt (2010) state that students with metacognitive skills can foresee problems that may arise during the learning experience and are able to better allocate their cognitive resources for learning and determine the information they understand or they need. Students with better self-regulation skills typically learn more, with less effort, and report higher levels of academic satisfaction (Barak, 2010).

1.2 Characteristics of the ICT learning environments

If the literature analysing the factors involved in scholastic success has widely shown the key role played by metacognition in supporting effective study,

less is known on the role of transversal skills in smart learning environments. However, these environments are particularly interesting because there they are increasingly pervasive in students' lives. New Information and Communication Technologies (ICT) provide new approaches to design learning environments, where many factors can influence learning: materials, activities, motivation, students' learning styles and self-regulation (Ligorio *et al.*, 2010). Importantly, although educational environments are characterized by an increasing presence of ICT (Al-Samarraie, Teo, & Abbas, 2013), this did not (yet) translate into a critical theory on technological education (Whitworth, 2007). The growth of ICT does not always correspond to the ability of researchers to better define and structure their use in different environments. This can cause negative consequences at the level of learning processes (Thomas *et al.*, 2016).

Technological tools can play a crucial role and determine a significant impact on metacognition and self-regulation. For instance, Zimmerman (2008) argues that high-tech learning environments can assist students in using self-regulated learning strategies. Azevedo, Cromley, and Seibert (2004) suggest that learning in a high-tech environment requires self-regulatory skills to organise, navigate, and combine information into feasible mental models. This review aims to answer this and other questions from an empirical perspective: is ICT more (or solely) effective when it includes metacognitive components; is there a relation between metacognition and ICT, and if yes in which direction?

2 Analysing the relationship between metacognition and ICT

We consulted PsychINFO, using the query strings: "ICT" AND ("metacognition" OR "metacognitive"); "e-learning" AND ("metacognitive" OR "metacognition"); "blended" AND ("metacognition" OR "metacognitive"). The search produced 108 results (54 after removing duplicates), that we searched with respect to the relationship between metacognition and ICT. We screened 34 records and excluded 6 by reading the abstract because they were not pertinent to the topic. We then excluded 14 more articles because they did not fit our investigation topic. The articles that met these our criteria and were, therefore, eligible for the review are 14.

The analysis allowed to distinguish two broad categories. Some articles (N = 5) investigated the effects of ICT environments combined with metacognitive aspects on learning outcomes. Other studies tested the relationship between ICT and metacognition, with the majority of studies hypothesizing a direction from ICT to metacognition (N = 8) rather than from metacognition to ICT (N = 1).

Table 1
STUDIES TESTING THE JOINT ROLE OF ICT AND METACOGNITION ON LEARNING (N = 5 studies)

Authors (year)	Type of ICT	Sample	Outcomes investigated	Metacognition measures	Main results
Cacciamani, S., Cesareni, D., Martini, F., Ferrini, T., & Fujita, N. (2012)	Blended learning	67 undergraduate students from Italy	Epistemic agency	Ad-hoc scale	Metacognitive reflection during the online course fostered student's Advanced Epistemic Agency.
Hsu, Y.S., & Lin, S.S. (2017)	Visualisation tool in e-learning	74 11th-graders from Taipei city	Decision-making skills	Ad-hoc scale	Decision-making skills were improved by metacognitive guidance in an e-learning environment.
Kramarski, B., & Gutman, M. (2006)	E-learning	65 9th-graders from Israel	Mathematical problem-solving and self-regulated learning	Improve method (Mevarech & Kramarski 1997; Kramarski & Mevarech 2003)	Students exposed to a metacognitive questioning in E-learning (EL+) outperformed EL students in problem-solving and mathematical explanations.
Sáiz Manzanares, M.C., Marticorena Sánchez, R., García Osorio, C.I., & Díez-Pastor, J.F. (2017)	E-learning (MOODLE)	129 undergraduate students from blended courses	Learning outcomes	Scale of learning strategies (Román & Poggioli, 2013)	A correlation between learning outcomes and metacognitive responses was found in Supplemental blend, but not in Replacement blend courses.
Zhang, W.X., Hsu, Y.S., Wang, C.Y., & Ho, Y.T. (2015)	E-learning (Inquiry-based Online Learning Module)	51 9th-graders from southern Taiwan	Students' inquiry practices	Ad-hoc Questionnaire of Metacognition	Cognitive and metacognitive prompting in e-learning enhanced the students' inquiry practices.

2.1 Metacognition and ICT jointly influencing outcomes in learning

We found 5 studies examining whether taking into account metacognition in ICT educational environments relates to learning outcomes (Table 1).

The experimental study carried out by Kramarski and Gutman (2006)

compared a "basic" e-learning environment with one associated with a self-metacognition training and revealed how structuring e-learning activities combined with activities on metacognition led to better mathematical problem-solving in Israelian high-school students, especially with respect to the use of self-monitoring strategies during problem-solving.

Similarly, a recent study with 11th graders (Hsu & Lin, 2017) tested decision-making (DM) skills of students of socio-scientific subjects. Students were divided into two groups: the first group was only provided with a visualisation tool in e-learning (control group), while the second also learned with a DM module that included metacognitive guidance to support understanding, planning, and monitoring (experimental group). A comparison between the two groups indicated that the two versions of the DM learning modules had similar effects on the improvement of students' DM skills, but the experimental group overcome the control group in overall skills in DM and in monitoring (in terms of self-evaluation of DM skills). Results in the same direction were found with respect to the relationship between scientific inquiry and metacognition in high-school students (Zhang *et al.*, 2015). Specifically, an inquiry-based e-learning environment together with cognitive and metacognitive prompts was associated with greater tendencies towards inquiry practices among students, concerning especially their planning and analyzing abilities.

A study on epistemic agency (when students negotiate their ideas with one another, instead of relying on teachers) with undergraduate students (Cacciamani *et al.*, 2012) suggested that opportunities for metacognitive reflection on the students' own participation strategies during an online course were amongst the best practices for fostering epistemic agency, therefore evidencing the important role that metacognition can have in allowing positive effects of ICT.

Sáiz Manzanares *et al.* (2017) further showed the benefits of combining e-learning with metacognition. The authors focused on the special benefits that metacognition can have when framed in a e-learning context, investigating the relation of metacognitive strategies with the type of learning pattern in Learning Management Systems (LMS). In a sample of 129 university students, the authors found a positive correlation between metacognitive responses and learning outcomes when using a supplemental blend (that is combined with face-to-face feedback), but not when using a replacement blend (that is when the feedback is given only on the platform).

2.2 Metacognition and "ICT": Unidirectional or bi-directional relationship?

We identified only one study that tested the relationship from metacognition to ICT (Table 2).

Table 2
STUDIES TESTING THE RELATIONSHIP BETWEEN ICT AND METACOGNITION (N = 9 studies)

Authors (year)	Type of ICT	Sample	Outcomes investigated	Metacognition measures	Main results
Al-Samarraie, H., Theo, T., Abbas, M. (2013)	E-learning	245 undergraduate students from southern Malaysia	Understanding a research article	Sub-scale of Thinking skills (Bernard, Brauer, Abrami, and Surkes, 2004)	Structured information (i.e. title, introduction,...) influenced learners' metacognitive activity and their understanding of research articles.
Hsu L.L., & Hsieh S.I. (2011)	Blended learning	99 undergraduate nursing students from Taiwan	Learning outcomes	Metacognition scale (Hsu, 2010)	Blended learning improved learning outcomes by facilitating metacognition and self-regulation.
Hsu L.L., & Hsieh S.I. (2011)	Blended learning	223 undergraduate nursing students from China	Learning outcomes	Metacognition scale (Hsu, 2010)	No differences were found on a Metacognition Scale between students in traditional and blended classes.
Klein, H.J., Noe, R.A., & Wang, C. (2006)	Blended learning	600 undergraduate students enrolled in either classroom or blended learning courses	Motivation to learn and course outcomes	Metacognition scale (Ford et al., 1998)	Motivation to learn was related to course satisfaction, metacognition, and course grades. It also mediated the relationships between delivery mode and metacognition.
Lee Y.H., & Wu J.Y. (2013)	Online reading activities	87.735 high-school students across 15 regions (PISA 2009)	Reading literacy	Ad-hoc scale	The positive effect of online activities on reading was mediated by metacognitive strategies.

Ramirez Arellano, A., Bory-Reyes, J., & Hernandez-Simon, L.M. (2019)	E-learning (MOODLE)	137 undergraduate biology students from a blended course	Learning outcomes (overall grade)	Motivated Strategies for Learning Questionnaire (Pintrich & De Groot, 1990)	Metacognitive self-regulation and organization predicted students' performance in blended learning.
van Vliet, E. A., Winnips, J.C., & Brouwer N. (2015)	Flipped classroom	170 undergraduate psychobiology students from Amsterdam	Motivated Strategies for Learning Questionnaire (Pintrich & De Groot, 1990)	Motivated Strategies for Learning Questionnaire (Pintrich & De Groot, 1990)	The flipped-classroom enhanced critical thinking, task value, and peer learning. However, the effects did not persist in a retention-test five months later.
Yang, Y.F. (2012)	Blended learning	108 undergraduate technology students with English reading difficulties from Taiwan.	Reading skills	Web-based functionalities, (dialogue box, forum, chat room, and annotation tool)	Students in blended learning outperformed the control group in reading by fostering the use of metacognition.
Zhao, H., & Chen, L. (2016)	E-learning	289 university distance learners from Mainland China and Hong Kong.	Self-regulated learning (SRL)	Ad-hoc scale	Self-regulation in e-learning environments was influenced by information quality, communication quality, and user satisfaction.

Ramirez-Arellano, Bory-Reyes, and Hernandez-Simon (2019) conducted a study with 137 Mexican university students, testing the predictiveness of 19 variables (with respect to emotions, motivation, cognitive and metacognitive strategies, and behaviour) on the overall students' performance. Six of these predictors, explaining the 67% of the variance were found to be significant. Among these predictors, metacognition and self-regulation abilities explained the 5% of variance. The authors therefore showed that metacognition and self-regulation play an important role in defining students' performance, and they are an actual predictor of positive learning outcomes in blended learning.

Instead, scholars have largely hypothesized the opposite direction, from ICT to metacognition (8 studies; Table 2). Among these, the study carried out by Al-Samarraie, Theo, and Abbas (2013) revealed that the degree of attention, motivation and interaction in an e-learning educational environment was associated with higher levels of metacognition which, in turn, predicted

better learning performances in university students. This study therefore highlights the benefit of online learning, if this is characterized by motivational components. Similarly, the study by Hsu and Hsieh (2011a) on a sample of 99 senior undergraduate nursing students revealed that blended learning courses contributed to learners' learning outcomes by facilitating their metacognitive development and self-regulatory skills. In a study by Klein, Noe, and Wang (2006), students enrolled in blended learning condition, showed a higher motivation to learn compared with their peers involved in the traditional classroom. Also in this case, motivation to learn was, in turn, related to students' metacognition. Furthermore, motivation to learn partially mediated the relationship between delivery mode and metacognition.

In the study by Zhao and Chen (2016), a sample of distance learners showed how user satisfaction, information and communication quality influence self-regulation in the e-learning environment. Predicably, self-regulation learning dimension was also influenced by the time (in years) spent using the e-learning mode. Learners who attended distance learning for less than 1 year and between 1-3 years were found to be better than those who attended distance learning for 4-6 years in the self-regulated dimension.

In a study by van Vliet, Winnips, and Brouwer (2015), significant differences were found between students of flipped classes and traditional lecture learners. Participants showed differences in their levels of metacognition and learning outcomes in relation to the teaching method employed. The flipped-classroom pedagogy had positive effects on critical thinking, task value, and peer learning of students. However, the effects of flipped classes were not sustained in a 5-months follow-up.

Lee and Wu (2013) compared two different activities of online reading (social entertainment and information-seeking), conducted by students aged 15 from 15 different regions of the PISA (Program for International Student Assessment) 2009 dataset. The results showed that only information-seeking activities were associated with better understanding of metacognitive strategies which, in turn, were associated to better reading literacy. Therefore, benefits on metacognition are dependent upon ICT environments that stimulate individuals to be active actors in the online activity.

A study also took into account the benefits that ICT could produce with respect to special populations. Yang (2012) considered university learners with English reading difficulties as participants, in order to understand how such special sample could benefit to a greater extent of the learning environment. The online interface system employed in the blended learning supported the use of metacognition, monitoring and regulation of one's own learning through four functions: dialogue box, discussion forum, chat room, and annotation tool. This led to better results in learning outcomes in students who used the

blended modality compared to those assigned to the control group (with on-site instruction only).

Taken together, the results hereby presented suggest a positive relation between the use of ICT and learning outcomes. Note however that some study did not find evidence for a relation between ICT and metacognition (Hsu & Hsieh, 2011b), highlighting the need of further research that helps clarify the relation between the two constructs.

3 Discussion

Our results showed that e-learning environments can have beneficial effects on learning outcomes, and this effect is greatly favoured when they are structured in a way to take advantage of metacognition. Second, they show that ICT can also foster metacognition and better learning outcomes *per se*, without metacognitive prompts. To understand why this may happen, we can rely on the further results of our analysis.

The studies presented highlight that ICT and metacognition are likely in a bi-directional relationship. Indeed, we found studies showing that ICT can foster metacognition, and that therefore help explain why online activities may have an effect on learning outcomes (i.e. they stimulate metacognition). There are several explanations as to why this may happen. For instance, they can foster greater motivation to learn, which in turn relates to the importance of adopting metacognitive strategies (Klein *et al.*, 2006). Consider that, in some cases, ICT allows to record the actions performed by the individual and offer him/her feedback regarding the operations he/she has performed. This feedback is extremely important so that the person becomes aware of his/her own mental mechanisms and learns how to control his/her own learning strategies. Often, ICT explicitly requires students to reflect on the choices to be made and therefore invite them to ask themselves about the mental processes that are activated in order to identify the most suitable paths. Other times, ICT "force" learners to scan their thoughts in stages or sequences, thereby facilitating the awareness of the mental operations that are put in place in carrying out a task. These represent an optimal use of ICT, that can act on mental processes and therefore may even have wider beneficial effects on unrelated field (although this is yet to be tested, we argue that is an interesting avenue for future research). Also, metacognitive reflection develops thanks to social interaction and these tools can actually encourage and support cooperation, favouring "shared" metacognition, to the extent that the e-learning environment is interactive (Cacciamani *et al.*, 2012). The possibility of online collaboration via ICT has led to the transformation of the communication processes themselves. This re-modulation presents an interesting potential in terms of transformation in a

metacognitive sense of distance learning processes (De Beni, Meneghetti, & Pezzullo, 2010).

On the one hand, although ICT can promote a more metacognitive individual, our analysis also revealed evidence for the reverse pattern, that is basic self-regulatory skills are needed to take advantage of web-based training (Ramirez-Arellano *et al.*, 2019). Also, metacognition appears to moderate the relationship between ICT and learning outcomes, that is ICT produces better learning outcomes only for those students with better metacognition or provided with metacognitive training (e.g., Lee & Wu, 2013). The implication of this conclusion is that individuals should be equipped with metacognitive skills, otherwise they would not be able to benefit of the ICT revolution. Given that many individuals may lack sufficient metacognitive skills, we recommend to measure metacognitive skills even in the context of web-based learning to obtain information about the tasks to be implemented. For instance, it is possible to structure web-based activities to foster the acquisition of those skills that can be improved, develop new strategies by which to promote the process of assimilation of concepts during the learning processes, increase the learner's confidence, planning the study in a more efficient manner in order to achieve specific learning objectives (Sanchez-Alonso & Vovides, 2007).

These results allows several conclusions. First, the scarce number of studies investigating the relation between ICT and metacognition calls for the need of research. Second, we prefer avoiding trivial conclusions on the fact that, simply, ICT has beneficial effects on metacognition and learning. In fact, since the relation between the two constructs may be more complex than previously thought, it is important to understand the condition that favour the different outcomes. In other words, it would be irrealistic and too simplistic to merely argue that ICT favours learning. Instead, ICT requires a set of (meta)cognitive abilities that should be taken into account when designing web-based course. Unfortunately, the advantages offered by web-based learning and ICT are often accompanied by a lack of critical theory on technological education (Whitworth, 2007) and do not always correspond to the ability of researchers to better define and structure the use of ICT in different environments. This discrepancy can possibly cause negative repercussions both at the level of learning and at the level of individual psychological processes (Thomas *et al.*, 2016). The structuring of web-based environments must include not only the technological characteristics and the individuals' characteristics, but also take into consideration learning processes, metacognition (Kramarski & Gutman 2006) as well as cognitive (Klein *et al.*, 2006) and motivational aspects (Ramirez-Arellano *et al.*, 2018).

Conclusion

Our analysis reveals that the relationship between metacognition and ICT is (at least) three-folded. On the one hand, working in technology-mediated contexts supports the development of metacognitive skills which, in turn, lead to better learning outcomes. On the other hand, metacognitive skills are necessary to take advantage of web-based training. In general, the relationship between these two variables appears to be tight and partly circular: while better metacognition allows learners to efficiently access the use of ICT, technological tools and web-based learning can foster monitoring and self-regulation processes. But there is a "third" hand, supporting the combined use of e-learning and metacognition to produce the best learning outcomes. Specifically, it appears important that ICT are accessed by learners in a metacognitive way, that is that they are not passive receivers of information, but they are facilitated by the characteristics of these tools (e.g., (a)synchronic communication, monitoring features) and metacognitive prompts.

The use of ICT can contribute to the creation of powerful learning environments (Smeets, 2015), but their use requires a critical reflection that must take into account different aspects related to students, to teachers and their approach to ICT, and to how to structure learning mediated by ICT in a way that metacognitive and self-regulation abilities are empowered and together contribute to facilitate learning.

According to Siemens and Baker at the International Conference on Learning Analysis and Knowledge in 2012, Learning Analytics consists in measuring, collecting, analyzing and reporting data concerning learners and the contexts where they learn, with the aim of optimizing learning. Our findings allow to advance this definition, to the extent that the context of learners is not only physical, but determined by their set of knowledge, skills and individual differences, that may be expressed differently based on the object of learning and to the specific settings where this occurs. In particular, by highlighting the deep interplay between metacognition and ICT, our analysis points to the need of taking into account motivational and metacognitive factors in interpreting learning outcomes, therefore qualifying these factors as key to benefit from ICT. Although they are partly determined at the level of individual, they are also highly contextual, since individuals' skills and motivation can be contextually activated and determine the whole set of psychological processes allowing learners to analyze data and productively use them to take maximal benefits of new technologies. A future challenge for ICT consists in our opinion in understanding how psychological processes can be contextually activated and influence the different learning stages.

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