REVIEW PAPER

WORKING MEMORY & AUGMENTED REALITY'S TRAJECTORY: A LITERATURE REVIEW OF AR IN EDUCATION, ONLINE LEARNING, WORKFORCE TRAINING, AND WORKING MEMORY RESEARCH

By

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ABSTRACT

The structure of the literature review features the current trajectory of Augmented Reality in the field including the current literature detailing how Augmented Reality has been applied in educational environments; how Augmented Reality has been applied in training environments; how Augmented Reality has been used to measure cognition and the specific instruments used to measure cognitive load with AR; previous working memory testing and foundational working memory practices that might be adapted in order to measure AR's potential impact on working memory; and how AR technology might be adapted to support working memory in future studies. There is evidence in the literature to support the assertion that AR technology can impact working memory and can be adapted to longstanding testing and foundational practices measuring cognitive load, novel iterations of AR in education can also be updated to be mobile friendly, aid in enriching student feedback and provide information on the overall learning experiences of the student.

Keywords: Augmented Reality, Literature Review, Mobile Learning, e-Corsi, TLX Cognitive Load Assessment, Working Memory, Cognitive Systems.

INTRODUCTION

1. Augmented Reality's Trajectory

According to Dunleavy and Dede, (2013) AR is an instructional approach looking for the context where it will be the most effective tool amongst the collection of strategies available to educators. While AR's commercial aspects have recently become well documented with appearances of AR in popular mobile games, such as Pokémon Go - reaching a collective download user total never before seen via Apple's mobile app distribution platform iTunes (Roman Dillet, 2016). The educational affordances of Augmented Reality are still emerging in the literature as an encouraging instructional permutation for the future of learning. The use of AR allows the adaption of static objects into rich learning objects and enables movement in a physical environment with the appearance of virtual elements mixed in with the environment (Azuma, 2004). Although there has been much speculation about the potential of Augmented Reality (AR), there are very few empirical studies about AR's effectiveness in regards to online learning and conventional learning spaces. Researchers posit that while relatively few empirical studies, and development teams, are actively exploring how mobile, context-aware AR could be used to enhance teaching and learning an AR review of studies research team reported that AR implementations can result in substantial student motivation (Dunleavy and Dede, 2013). The MIT Scheller Teacher Education Program, the Augmented Reality and Interactive Storytelling (ARIS) Group at the University of Wisconsin at Madison, the immersive learning group at the Harvard Graduate School of Education, and the Radford Outdoor Augmented Reality (ROAR) project at Radford University have all used AR in some form of design-based research (DBR) approach to

explore the feasibility and practicality of using AR in an environment for teaching and learning (Dieterle, Dede, and Schrier, 2007; Squire and Klopfer, 2007; Dunleavy and Simmons, 2011; Martin, Dikkers, Squire, and Gagnon, 2013).

2. Augmented Reality in Education

AR technology in schools is an important factor to consider, because AR integration in academic environments have revealed learning experiences that are associated with directly relevant content (Bujak, Radu, Catrambone, MacIntyre, Zheng, and Golubski, 2013). Student motivation and the novelty effect of AR is a component that can also impact AR integration, if AR is effectively adapted to student learning environments by allowing slower students more time, and usually providing them with tutoring or other special assistance (Wentzel and Brophy, 2014). Researchers have striven to apply AR to classroom-based learning within subjects like chemistry, mathematics, biology, physics, astronomy, and to adopt it into augmented books and student guides (Lee, 2012). Furthermore, studies have also document that learners are highly engaged while playing mobile augmented reality learning games (Chang, Medicherla, and Morreale, 2010; Bressler and Bodzin, 2013). On the other hand, researchers estimate that AR has not been much adopted into academic settings due to limited financial support from government funding and the general lack of awareness of AR in academic settings (Shelton, 2002; Lee, 2012).

AR may help enable elaborate rehearsal of learners' related prior experiences and knowledge with superimposed information (Estapa and Nadolny, 2015). Researchers measuring the result of an Augmented Reality enhanced mathematics lesson on student achievement and motivation found that AR did capture the attention of the students to a greater degree than the website only group: The result supports prior research showing that the use of AR in classroom contexts can increase motivation (Estapa and Nadolny, 2015). Interacting with AR-based learning experiences, documented by Bujak, Radu, Catrambone, MacIntyre, Zheng, and Golubski (2013), noted that AR experiences leverage situated cognition, by allowing the student to connect to the virtual educational content by simply pointing a camera at their environment, whether inside or outside the classroom. This ease of access is highly beneficial to students, because contextually relevant information can be procured to satisfy the student's interest. Johnson, Smith, Willis, Levine, and Haywood, (2011) specified that Augmented Reality implementations have a strong potential to provide both powerful contextual, on-site learning experiences and serendipitous exploration, and discovery of the connected nature of information in the real world.

Other instances of AR applications in the education domain are the increased motivation, engagement activity of learners, and the overall cost and safety. According to Wojciechowski and Cellary, (2013), AR environments allow learning content to be presented in meaningful and concrete ways including training of practical skills. AR technology has been documented in trial and Project Based Learning environments, where complex chemical reactions and expensive materials can be substituted for simulations and image-based AR environments can be used for a broad spectrum of chemical experiments without having to make changes to the physical configuration of the installation. According Wojciechowski and Cellary, (2013) an AR application takes up much less space and costs less than a typical workbench for chemical experiments, and does not require any special chemistry laboratory infrastructure. The advantages of using Augmented Reality to improve training versus virtual reality and other web based tools, is the time and cost for developing virtual scenes is removed because the scene is a real one where content is overlaid onto the scene and the participants can see the environment around them; whereas VR removes the learner from the context and only simulates the experience (Azuma, 2004).

Furthermore, studies investigating learners' collaborative knowledge construction performances and behavior patterns in an Augmented Reality simulation systems recorded that AR has the potential to markedly increased student knowledge gains (Chang, Medicherla, and Morreale, 2010). Studies have found that the AR supported students perform with increased proficiency due to the

representation of the concept; attributing that the AR system may serve as a confirmatory tool and enable learners to respond quickly to the displayed results and support their knowledge construction processes (Lin, Duh, Li, Wang, and Tsai, 2013). The suggestion that AR can potentially increase motivation is also poignant catalyst to assist learners with elaborative rehearsal strategies and may aid in increasing working memory (Lin, Duh, Li, Wang, and Tsai, 2013).

Researchers utilizing a mixed methodology approach to Augmented Reality in science education settings found that AR may result in different affordances for science learning (Cheng and Tsai, 2013). Cheng and Tsai (2013) note that image-based AR often affords students' spatial ability, practical skills, and conceptual understanding. Furthermore, effective applications of Augmented Reality have been seen in numerous inquiry-based learning environments where the AR tool is used to unlock, investigate questions, scenarios, and complex problems by probing learning processes through the methods of interviews, observations, or videotaping analysis, on how students structure the scientific thinking and knowledge in AR-related learning activities could be better understood. According to Cheng and Tsai (2013) these qualitative methods have been commonly utilized in AR-related studies, but there is a need to apply mixed method analysis to attain in-depth understanding of the learning process.

During a mixed methods assessment of students' flow experiences during a mobile Augmented Reality science integration researchers found that while AR may be a technology lacking in extensive research for education, it was determined that its potential as a scalable design for schools was very stable (Bressler and Bodzin, 2013). That is, AR minimized player frustration and may have increased enjoyment reducing cognitive overload (Bressler and Bodzin, 2013). Lee (2012) found that Augmented Reality lowers the barrier to entry for students engaging with virtual content, as it makes use of natural interactions that allow students to interact with educational content. It is highly likely that AR can make educational environments more productive, pleasurable, and interactive than ever before. According to Lee (2012) AR not only has the power to engage a learner in a variety of interactive ways, that have never been possible before, but also can provide each individual with one's unique discovery path with rich content from computer-generated three dimensional environments and models (Lee, 2012). That is, learners can select virtual objects by pointing to them, they can reach out to touch and move objects. Since AR permits these interactions, there is a reduction in the knowledge and skills required of users, increasing the transparency of the interface between students and the educational content (Bujak, Radu, Catrambone, MacIntyre, Zheng, and Golubski, 2013).

3. Augmented Reality and Workplace Training

According to Neumann and Majoros (1998) AR can endow novices with some of the advantages enjoyed by experts: Such as an efficient retrieval of information from their working memory, regardless of the situation they may find themselves. Neumann and Majoros findings suggest that AR provides this expert status in two ways. The first is simply the basic effect of AR triggering and recalling information with little user effort, by simply aiming the device. Maintenance and manufacturing experience is filled with evidence that people favor information that is easy to access and tend to use more salient data in decision making (Neumann and Majoros, 1998). Secondly, the researchers also found that AR's composite scenes are analogous to the spatial, Graphical User Interface (GUI) that is standard with personal computer use. The interface model became the standard expression for desktop use for at least two reasons: First, through direct manipulation metaphors, the GUI eliminated users' need to control functions via arcane textual language, and second (and especially relevant to AR), its desktop metaphor presented a spatial layout to the user icons and working spaces can occupy regions (often called "real estate") of a display. As Neumann and Majoros (1998) point out the GUI allows users to associate functions with spatial locations, it aids visual recognition (e.g., "similar look and feel" of various applications), and it elicits behavior, such as dragging and interacting with buttons" (Neumann and Majoros, 1998). AR's capacity to overlay new information through a very simple GUI allows subjects to recall and order items and

integrate the meanings of multiple of items by only having a consistent spatial origin (Neumann and Majoros, 1998). Therefore, tasks that are normally guided by reference to some documentation may be excellent candidates for improvement with AR.

Tang, Owen, Biocca, and Mou, (2003), found that Augmented Reality in object assembly indicated decreased mental effort for participants that used AR, suggesting some of the mental calculation of an assembly task are offloaded while using Augmented Reality overlays. Participants reported that using Augmented Reality overlays were less mentally demanding: The findings are consistent with the model that AR may reduce the amount of mental manipulation required. Tang, et al., (2003) posit that since participants did not have to mentally transform objects, and keep a model of the relationship of the assembly object to its location in their working memory, they experienced less mental workload (Tang, et. al., 2003).

4. Working Memory

Working memory is often described, since George Miller's publication in 1956, as seven plus or minus two chunks of information (Miller, 1956). Only a limited amount of information can remain in working memory, but AR can potentially help increase this amount through 'chunking'. George Miller's principle is still appropriate today and can be applied to AR to promote efficient learning and long-term retention (Miller, 1956). It is generally believed that baseline human working memory capacity is limited (Clark, 2008). When information is first presented to an individual, it is retained almost intact for a brief period in the person's sensory store: Information is then read from the sensory store into the short-term store or working memory (Proctor and Van Zandt, 2008).

Information in the working memory decays very rapidly unless it is kept active through rehearsal or covert repetition of the items read from the sensory store (Wang and Dunston, 2006). For many tasks, precise performance requires not only that relevant information be recollected in the short-term store, but also that the information be acted upon quickly. Therefore, the limited capacity of the short-term store has implications for any task or situation in which successful achievement of a task requires the learner to encode and retain information accurately for a long period of time (Wang and Dunston, 2006). Cognitive psychology reveals that the accuracy of retention can be increased by increase actives that allow for rehearsal with new information (Kaufman, 2010). It is also recognized that the more items that are stored in working memory, the longer the time a person needs to retrieve a desired item of information. Minimizing the reliance on memory focuses the use of cognitive resources on other tasks. This is important, largely because cognitive overload can result in a significant increase in the number of errors on a given task (Kaufman, 2010).

5. Working Memory Measures

Working memory involves processes such as attending to, holding, and mentally manipulating information (Lawlor-Savage, and Goghari, 2016). Studies reporting performance based working memory gains in tasks such as digit span, Corsi block tests, and reading span, indicate that a variety of tasks have been used as measures of working memory, but some of the most widely used measures within cognitive psychology are the complex span tasks (Foster, Shipstead, Harrison, Hicks, Redick, and Engle, 2014). Using three established complex span tasks Foster, Shipstead, Harrison, Hicks, Redick, and Engle (2014) measured working memory where subjects are given a sequence of 'to be remembered items' such as a sequence of letters, while the subjects must also complete a distractor task, such as solving a math problem, between the presentations of each 'to be remembered item' in a sequence (Foster, et. al., 2014). Foster, et al., (2014) describe a number series task as sequence of numbers that follow a logical pattern (1, 2, 3, 5, 8, 13, 21), then the subject's task is to choose from five available options the next number in the sequence. Working memory task procedures require participants to remember numbers, objects, or symbols in a row often matching (Lawlor-Savage, and Goghari, 2016). In this way, working memory testing might also be applied to Augmented Reality applications, where participants are asked to aim a device viewfinder at AR triggers in a succession and report on the tagged content that is overlaid. Symbols in working memory procedures are often presented as self-paced,

and once a response is recorded the next symbol appears (Lawlor-Savage, and Goghari, 2016). In theory, this procedure could be adapted to an AR system where participants aim at the tagged content and then move on the next image in a succession.

Studies based on increased memory load during task completion, when procedures are presented on mobile screens, founded that the National Aeronautics and Space Administration's Task Load Index (TLX) evaluation instrument indicate some advantages and disadvantages of mobile devices impact on working memory, procedural task performances, and information flow among NASA technicians (Byrda and Caldwellb, 2011). Subjects in the study began the session by completing a participation consent form, and a participant pre-evaluation and demographic questionnaire (Byrda and Caldwellb, 2011). The purpose of the questionnaire was to collect general demographic information and the experimental task for the study was adapted from a task used in summer educational programs introducing K-12 students to science, technology, and engineering and mathematics experiences (Byrda and Caldwellb, 2011). Before the experiment began, a window area of a Dell desktop monitor was adjusted to simulate one of the three screen sizes mobile, tablet, and desktop (Byrda and Caldwellb, 2011). The document window size was adjusted after each task section and the screen resolution remained constant throughout the experiment; however, the procedure was specially formatted for each of the three window sizes for ease of viewing (Byrda and Caldwellb, 2011). The same monitor was used in each screen size condition, to control for preferences that might result from distinct features or characteristics of using three different small-screen devices (Byrda and Caldwellb, 2011). The National Aeronautics and Space Administration's Task Load Index test, adapted from Hart, and Staveland, (1988) was administered to measure the multi-dimensional rating procedure and to derive an overall working memory workload score based on an average rating of six subscales: mental demands, physical demands, temporal demands, own performance, effort, and frustration (Byrda and Caldwell, 2011). This study is noteworthy, because it offers a bridge that may also fit into AR research. Specifically, in AR related tasks participants often use a mobile device with limited screen size. However, this study does differ in the sense that instead of using a computer and then performing a task, participants would be aiming the mobile device's view screen while also performing a task with the device. Nevertheless, the TLX working memory procedures involved has been effectively adapted to an AR environment, as Tang, Owen, Biocca, and Mou, (2003) have illustrated.

Further studies based on span tasks and measuring working memory during task completion include the Corsi Block Test. The Corsi Block Test is now a widely-used assessment used in clinical and research contexts to measure visuospatial attention and working memory (Corsi, 1972). The Corsi Block Test requires participants to reproduce a sequence of movements by tapping blocks in the same serial order an examiner did on a board containing nine blocks at fixed, and random positions. As the test procedure progresses, the number of blocks in the sequences progressively increases. Moreover, the Corsi Test also requires participants to remember the serial order of the blocks in the sequence. Current literature indicates that there is no difference between an online e-Corsi Block Test and a traditional block test (Claessen, Van der Ham, and Van Zandvoort, 2014). Findings suggest that a computerized version of the Corsi Block Test using an Internet capable mobile device or personal computer and then comparing performance on this task to the analogous scores on the standard Corsi Task among participants. In fact, because computerization of the Corsi Task leads to a more standardized administration, as compared with the standard version: Practical advantages of the computerized Corsi Task include strict application of the presentation duration of the block sequences and automatic scoring (Claessen, Van der Ham, and Van Zandvoort, 2014). As the computer takes over both the stimulus presentation and scoring procedure that were previously carried out by an examiner, using the e-Corsi instead of the standardized version results in a shift of the researcher's role in this task: from administrator to observer (Claessen, Van der Ham, and Van Zandvoort, 2014).

5. Working Memory and AR Instrumentation

Tang, Owen, Biocca, and Mou, (2003) employed the cognitive workload measurement adapted from NASA TLX, whereby they utilized the TLX instrument to specifically measure an Augmented Reality object assembly task. By adapting the TLX instrument to object assembly and having students' rate categories to measure working memory and overall cognitive load Tang, Owen, Biocca, and Mou, (2003) were able to gather data on Augmented Reality's impact on cognitive load and its impact on working memory. According to Tang, Owen, Biocca, and Mou, (2003) working memory and cognitive load measuring instruments can be adapted and applied to AR tools allowing, in the NASA TLX example, users to self-report on their cognitive load by detailing their use with the AR enabled device, and their overall interactions in the enabled contexts. The TLX instrument measures cognitive load and the impact on effective working memory utilization (Hart, and Staveland, 1988). As Cheng and Tsai (2013) illustrate, the learning experience has only been discussed in relatively few AR-related studies, especially in image-based AR applications: Following the issues of learning experience, an investigation of learners' responses to cognitive load and working memory could be incorporated into image-based AR studies in the future.

6. Augmented Reality and Working Memory

The findings from Juan, Mendez-Lopez, Perez-Hernandez, and Albiol-Perez (2014) working with Augmented Reality illustrate that learners' pre-and posttest results with AR displayed a pronounced amount of memory improvement providing evidence to support the proposition that AR systems may improve task performance and can relieve mental workload. Outcomes demonstrated age-related spatial memory improvement when the researcher's setup boxes distributed in a circle where the different learner groups could travel to each box and point the device inside where some AR content was programmed and in others where it was not, then the learner would recount what was inside and the location after aiming the handheld AR device inside (Juan, et al., 2014). According to Juan, et al., (2014) AR systems have already proven their potential in the education field with the ability of AR enabled courses to potentially enhance learner's cognitive ability, their response to behavioral demands, and increase working memory.

Studies conducted with Augmented Reality tools to specifically measure working and spatial memory have suggested that AR enabled environments have a positive impact on participant's memory recall ability (Tang, Owen, Biocca, and Mou, 2003). Assistive devices, with the capacity to access a worldwide compendium of knowledge from the Internet indeed facilitate human's abilities to recall knowledge and aid memory by assisting and easing cognitive loads via overlaying content access with instantaneous content that can now, via a mobile device, display information visually, three-dimensionally, and with audio visual properties (Jaeggi and Buschkuehl, 2008; Cheng and Tsai, 2013). AR technology can attach required information to the learner's physical world view of a task, releasing part of the working memory to support user tasks in newly experienced or complex environments (Proctor and Zandt, 2008). An AR system can also help build up an enduring cognitive map and support a human's ability to comprehend spatial relationships (Proctor and Zandt, 2008). AR technology attaches the required information to the user's world view of the task, releasing part of the working memory occupied by the information items, and therefore facilitate efficient retrieval of information that must be obtained from memory (Proctor and Zandt, 2008). Placing virtual objects in the context of real locations makes the objects subject to particular human abilities, and one of the most critical of those abilities is according to Proctor and van Zandt, (2008) spatial cognition. By spatially relating information to physical objects and locations in the real world, AR technologies can support working memory (Proctor and Van Zandt, 2008). It is suggested that an experimental design for examining students' learning experience (e.g., working memory) by different instructional designs, either in location-based AR or in image-based AR studies, be developed in future studies (Cheng and Tsai, 2013). While the literature points to possible uses of Augmented Reality as tool for engagement, motivation, training, and working memory aid, the future for AR as an instructional platform

remains to be conducted in AR studies in the future (Cheng and Tsai, 2013).

Conclusion

Effective cognitive load reduction frees up more processing power to focus on learning tasks. While additional research is needed with Augmented Reality specific implementations in education and learning environments in general, it is possible to hypothesize that a user response to simulated AR environments and customized trigger effects may reduce cognitive load, and promote effective working memory utilization potentially positively impacting associative information processing and working memory in the process. For students to effectively adapt to procedural knowledge in near transfer, and changing knowledge scenarios in far transfer, cognitive load measurements help to shed light on Augmented Reality's impact on effective utilization of working memory. By examining students' learning experiences, working memory, and cognitive load with AR applications, future studies might measure if learners remember what they learned, if they can recognize and apply what they learned more effectively while using AR overlays in online classrooms, and if learner's utilization of AR has an impact on their working memory based on e-Corsi measurements. Grounded by a review of the literature, future AR studies could incorporate multiple methods and strategies in an attempt to elucidate what impact, if any, Augmented Reality may have on working memory utilization in higher education.

References

[1]. **Azuma, R. (2004, August).** Overview of augmented reality. In *ACM SIGGRAPH 2004 Course Notes* (p. 26). ACM. doi:10.1145/1103900.1103926

[2]. **Bressler, D. M., & Bodzin, A. M. (2013).** A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted Learning,* 29(6), 505-517. doi:10.1111/jcal.12008

[3]. **Bujak, K. R., Radu, I., Catrambone, R., Macintyre, B., Zheng, R., & Golubski, G. (2013).** A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education,* 68, 536-544. doi:10.1016/j.compedu.2013.02.017

[4]. **Byrd, K. S., & Caldwell, B. S. (2011).** Increased memory load during task completion when procedures are presented on mobile screens. *Behaviour & Information Technology,* 30(5), 643-658. doi:10.1080/0144929x.2010.529944

[5]. **Cheng, K. H., & Tsai, C. C. (2013).** Affordances of augmented reality in science learning: Suggestions for future research. *Journal of Science Education and Technology,* 22(4), 449-462. doi:10.1007/s10956-012-9405-9

[6]. **Claessen, M. H., Van Der Ham, I. J., & Van Zandvoort, M. J. (2014).** Computerization of the standard Corsi Block-tapping task affects its underlying cognitive concepts: A pilot study. *Applied Neuropsychology: Adult,* 22(3), 180-188. doi:10.1080/23279095.2014.892488

[7]. **Clark, R. C. (2008).** *Building expertise: Cognitive methods for training and performance improvement.* John Wiley & Sons.

[8]. **Corsi, P. M., & Michael, P. (1972).** *Human memory and the medial temporal region of the brain* (Vol. 34, p. 819B). Montreal: McGill University.

[9]. **Dieterle, E., Dede, C., & Schrier, K. (2007).** Neomillennial" learning styles propagated by wireless handheld devices. *Ubiquitous and pervasive knowledge and learning management: Semantics, social networking and new media to their full potential,* 35-66. doi:10.4018/978-1-60566-652-5.ch049

[10]. **Dillet, R. (2016).** Apple says Pokémon Go is the most downloaded app in a first week ever. *TechCrunch.* Retrieved from https://techcrunch.com/2016/07/22/apple-says-pokemon-go-is-the-most-downloaded-app-in-its-first-week-ever/

[11]. **Dunleavy, M., & Dede, C. (2013).** Augmented reality teaching and learning. In *Handbook of Research on Educational Communications and Technology* (pp. 735-745). Springer New York. doi:10.1007/978-1-4614-3185-5_59

[12]. **Dunleavy, M., & Simmons, B. (2011).** Assessing learning and identity in augmented reality science games. *Serious Educational Game Assessment,* 221-240. doi:10.1007/978-94-6091-329-7_14

[13]. Estapa, A., & Nadolny, L. (2015). The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. *Journal of STEM Education: Innovations and Research,* 16(3), 40.

[14]. Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2014). Shortened complex span tasks can reliably measure working memory capacity. *Memory & Cognition,* 43(2), 226-236. doi:10.3758/s13421-014-0461-7

[15]. Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in Psychology,* 52, 139-183.

[16]. Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences,* 105(19), 6829-6833.

[17]. Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K., (2011). The 2011 horizon report. Austin, Texas: The New Media Consortium. Retrieved from http://www.nmc.org/ publications/horizon-report-2011-higher-ed-edition

[18]. Juan, M. C., Mendez-Lopez, M., Perez-Hernandez, E., & Albiol-Perez, S. (2014). Augmented Reality for the Assessment of Children's Spatial Memory in Real Settings. *PloS one,* 9(12), e113751. doi:10.1371/journal.pone.0113751

[19]. Kaufman, C. (2010). *Executive Function in the Classroom: Practical Strategies for Improving Performance and Enhancing Skills for All Students.* Brookes Publishing Company. PO Box 10624, Baltimore, MD 21285.

[20]. Lawlor-Savage, L., & Goghari, V. M. (2016). Dual n-back working memory training in healthy adults: A randomized comparison to processing speed training. *PloS one,* 11(4), e0151817. doi:10.1371/journal.pone.0151817

[21]. Lee, K. (2012). Augmented Reality in Education and Training. *TechTrends,* 56(2), 13-21. doi:10.1007/s11528-012-0559-3

[22]. Lin, T. J., Duh, H. B. L., Li, N., Wang, H. Y., & Tsai, C. C. (2013). An investigation of learners' collaborative knowledge construction performances and behavior patterns in an augmented reality simulation system. *Computers & Education,* 68, 314-321. doi:10.1016/j.compedu.2013.05.011

[23]. Martin, J., Dikkers, S., Squire, K., & Gagnon, D. (2014). Participatory scaling through augmented reality learning through local games. *TechTrends,* 58(1), 35-41. doi:10.1007/s11528-013-0718-1

[24]. Medicherla, P. S., Chang, G., & Morreale, P. (2010, March). Visualization for increased understanding and learning using augmented reality. In *Proceedings of the international conference on Multimedia information retrieval* (pp. 441-444). ACM. doi:10.1145/1743384.1743462

[25]. Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. Indiana: Bobbs-Merrill. *Psychological Review,* 63(2), 8

[26]. Neumann, U., & Majoros, A. (1998, March). Cognitive, performance, and systems issues for augmented reality applications in manufacturing and maintenance. In *Virtual Reality Annual International Symposium, 1998. Proceedings., IEEE 1998* (pp. 4-11). IEEE.

[27]. Proctor, R. W., & Van Zandt, T. (2008). *Human Factors in Simple and Complex Systems.* CRC press.

[28]. Shelton, B. E. (2002). Augmented reality and education: Current projects and the potential for classroom learning. *New Horizons for Learning,* 9(1). Retrieved from http://www.newhorizons.org/strategies/technology/shelton.htm

[29]. Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *The Journal of the Learning Sciences,* 16(3), 371-413. doi:10.1080/10508400701413435

[30]. Tang, A., Owen, C., Biocca, F., & Mou, W. (2003). Performance evaluation of augmented reality for directed assembly. In *Virtual and Augmented Reality Applications in Manufacturing* (pp. 311-331). Springer London. doi:10.1007/978-1-4471-3873-0_16

[31]. Wang, X., & Dunston, P. S. (2006). Mixed Reality-Enhanced Operator Interface for Teleoperation Systems in Unstructured Environment. In *Earth & Space 2006:*

Engineering, Construction, and Operations in Challenging Environment (pp. 1-8). doi:10.1061/40830(188)93

[32]. Wentzel, K. R., & Brophy, J. E. (2014). *Motivating Students to Learn.* Routledge.

[33]. Wojciechowski, R., & Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments. *Computers & Education,* 68, 570-585. doi:10.1016/j.compedu.2013.02.014

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