Augmented Reality as a Tool for Enhancing Metacognitive Knowledge in Chemistry

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Manuscript received October 26, 2023; revised November 16, 2023; accepted December 28, 2023; published April 23, 2024

***Abstract*—This study developed a Teaching and Learning Material (TLM) with Augmented Reality (AR) to enhance the students' metacognitive knowledge, namely declarative, procedural, and conditional knowledge in General Chemistry. The developed TLM has three components: the printed learning material that contains the AR trackers; a database of tactile 3D objects and animations that served as metacognitive scaffolds; and a dedicated smartphone software application specifically created for the retrieval, display and control of AR objects. The design-based research paradigm was used in the development of the Teaching and Learning Material with Augmented Reality, while the pre-experimental single group research design was employed in the assessment of the effect of scaffolds using AR on the students' metacognitive knowledge. A Metacognitive Knowledge Test (MKT) was administered to the student participants before and after using the AR learning material system. Using the Hake factor test, the study found that the student participants achieved high learning gains for declarative and procedural metacognitive knowledge as signified by g values of 0.73 and 0.79, respectively. In terms of conditional metacognitive knowledge, the students registered a medium learning gain given by g = 0.68. It is recommended that teachers use innovative teaching and learning materials embedded with AR to enhance students' learning attributes like metacognitive knowledge.**

***Keywords*—augmented reality, chemistry education, educational technology, instructional materials development, metacognitive knowledge**

I. Introduction

Learning in chemistry is often measured through problem-solving skills where students use metacognitive knowledge in controlling their cognition. Moreover, metacognitive knowledge enhances problem-solving skills by developing the student's ability to plan, regulate, and monitor their learning process. Hence, it is the goal of chemistry teachers to enhance metacognitive knowledge among students. This could be achieved by developing instructional materials that provide metacognitive scaffolding.

Meanwhile, Augmented Reality (AR) is gaining traction in the field of educational technology. Augmented reality is defined as "a situation in which a real-world context is dynamically overlaid with coherent location or context-sensitive virtual" [1] and combines digital and physical information in real-time through different technological formats such as tablets or smartphones to create this new reality [2]. Relative to this, educators should utilize and maximize the use of technology such as handheld devices because research has shown that students benefit when handheld technology instructional approaches are used in learning [3].

Systematic reviews of AR research and applications have recognized its potential for pedagogical applications and identified advantages of the technology and research gaps about the topic. Most of the studies reviewed utilized AR as a stand-alone tool in delivering the lesson and imparting knowledge and skills among the students. There were a few studies that explored the use of augmented reality in the teaching and learning of chemistry. Most of them used innovative technology as an alternative way of presenting the structure of molecules [4, 5]. However, none of the studies investigated the use of AR as metacognitive scaffolds geared to enhance the metacognitive knowledge of learners. In relation to this, future research should focus on the creation of teaching and learning materials with embedded AR [6] and the assessment of learning that could specifically be attributed to AR [4].

From the foregoing discussion, the researcher aimed to develop a teaching and learning material that integrates augmented reality and metacognitive scaffolding to enhance the students' metacognitive knowledge in chemistry. Specifically, this study sought to:

1) Develop a Teaching and Learning Material (TLM) in general chemistry that integrates augmented reality and metacognitive scaffolding.
2) Assess the level of integration of augmented reality and metacognitive scaffolding in the developed teaching and learning material.
3) Measure the learning gain in terms of metacognitive knowledge among the student participants after being exposed to augmented reality and metacognitive scaffolding.

II. Literature Review

Augmented Reality (AR) is defined as technology that enables users to augment the visual field by using heads-up display technology [7] and which allows users to see a supplemented reality through superimposed virtual objects over the real world [8]. Since these definitions cover only the visual aspect of augmented reality, they do not describe the full capabilities of AR. As such, a more encompassing definition of AR is simply the technology that overlays virtual objects in the real world [5].

Currently, AR is a technology that is widely being adopted in the field of education. AR technology in education leads to the enhancement of learning achievement in educational settings and the adoption of positive attitudes toward AR-enhanced learning activities and concludes that AR might potentially support teaching and learning when pedagogical issues and other technical issues have been resolved [5]. Future research should attempt to develop holistic models and design principles (empirically proven) for AR environments. Additional research could also be directed toward student

doi: 10.18178/ijiet.2024.14.4.2086

satisfaction, motivation, interactions and student engagement to better understand the advantages of AR in educational settings.

Scaffolding refers to temporary support provided by the teacher, more capable peers, or computer tutors to help students solve a problem or carry out a task that they cannot accomplish independently [9, 10]. Several factors determine the effect of scaffolding on learning outcomes in innovative learning environments. These are the rationale for applying scaffolding, kind of learning activity scaffolds to meet the learning outcomes, and the design and delivery of these scaffolds [11, 12]. The method of scaffold delivery, its integration into the learning process, and the form of the scaffold message are significant in determining the effects of scaffolding. Scaffolds can be delivered to the learner by a human tutor or a virtual agent, on paper, or through tools in a computer environment. Several studies have shown that in innovative learning arrangements, students have problems regulating their learning due to a lack of metacognitive skillfulness [13].

Metacognitive scaffolding is a teaching strategy that assists learners in providing reflections on what they have learned and reflections on how they are learning. This assistance can come in many forms from simple question prompts on what learners have learned in class to more specific assistance that guides them in organizing and accessing their knowledge [14]. Metacognitive scaffolding can be in the form of problematizing and structuring scaffolds. Structuring reduces the complexity of a learning task through step-by-step examples, providing guideposts that function as part of the regulation of students while problematizing scaffolds elicits students' view on how they could finish or accomplish a learning task, constructing their own strategy. In addition, metacognitive scaffolding intends to increase students' learning abilities by means of a systematic approach [15] and by assisting students on how to think about the problem under study. This can possibly be implemented if the teacher involved understands the aspects of metacognition which include metacognitive knowledge, metacognitive judgment and monitoring, and metacognitive self-regulation and control. When metacognitive scaffolding is used by the teacher in the learning process, learners could be stimulated to activate their own heuristic learning [16].

This study was anchored on the Metacognitive Theory and Multimedia Learning Theory. In the field of chemistry education where problem-solving skills is critical in students' academic performance, metacognition plays an important role in students' deeper understanding of the concepts and development of problem-solving skills [17]. Students' learning outcomes and their problem-solving skills can be enhanced by a planned learning strategy that is carefully structured to improve knowledge and metacognitive skills [18]. The metacognitive scaffolding feature of the TLM aims to develop metacognitive knowledge among the learners.

In terms of innovative learning arrangements, scaffolds can be given by computer aids or digital assistants. In these type of innovative learning environments, it was found out that metacognitive scaffolding enhances students' learning outcomes [19]. The innovative learning arrangement in this study refers to the use of the TLM with augmented reality component. The TLM provides structuring and problematizing metacognitive scaffolds in the form of AR molecules and AR animations of chemical reactions.

The second theory that guided the development of the teaching and learning material is the multimedia learning theory, which provides potential explanations of how augmented reality may improve learning [20]. The multimedia theory explains that words and pictures help students learn better than words alone. Students have an opportunity to construct verbal and pictorial mental models and to build connections between them [21]. The TLM which features augmented reality content provides opportunities based upon this principle by combining printed text with virtual content (i.e., integrating videos into a textbook) or by augmenting physical objects with virtual objects (i.e., displaying immersive and tactile 3D molecular models on mobile gadgets when placed directly on markers located on the printed instructional material).

III. Materials and Methods

The methodology employed in this study was adapted from a combination of appropriate research designs. The development of the TLM was anchored on the design-based research paradigm while the assessment of the effect of using augmented reality as a metacognitive scaffold on students' metacognitive knowledge utilized the pre-experimental single group design which involved two learning cycles consisting of the pilot experiment and the teaching experiment. The participants of the study include one intact homogeneous Grade 11 Senior High School Science, Technology, Engineering and Technology (STEM) class, which composed of 44 students with 26 boys and 18 girls.

The teaching and learning materials covered the chemistry concepts including atomic theory, chemical bonding and valence shell electron pair repulsion (VSEPR) theory. The discussion of the atomic theory was considered as the pilot experiment where the students familiarized themselves with the use of the learning material with AR component as scaffolds for metacognitive knowledge. The discussion of the topics chemical bonding and VSEPR theory served as the teaching experiment where the metacognitive questions used in the study were drawn.

The developed TLM was assessed in terms of the level of integration of AR and metacognitive scaffolding in the TLM. Five teacher observers who are experts in the field of chemistry education were invited to validate the TLM and observe its utilization in the classroom. They were then asked to assess the integration of augmented reality and metacognitive scaffolding in the TLM through an Observation Checklist instrument.

Likewise, the effect of the TLM utilization on the metacognitive knowledge of the student participants was also assessed. A Metacognitive Knowledge Test (MKT) was developed and validated to measure the learning gains among student participants. The computed Cronbach's alpha for MKT was 0.811, signifying high internal consistency and reliability of the instrument. The MKT includes cognitive tasks and open-ended questions. The cognitive task requires the students to answer certain questions to test their understanding of the concept while the open-ended questions measure their metacognitive knowledge in terms of declarative, procedural, and conditional knowledge. The MKT pretest and posttest were administered to the students before and after using the TLM. Three chemistry teachers were then asked to rate the students' MKT responses on both tests using a scoring rubric. Based on Kendall's coefficient of concordance, W values of 0.793 and 0.759 for the MKT pretest and posttest respectively, there is good agreement between the scores of the three inter-raters. Finally, to assess the effect of AR as a metacognitive scaffold on the students' metacognitive knowledge, the Hake factor (normalized gain, g) was used.

IV. Result and Discussion

A. *Development of the Teaching and Learning Material (TLM)*

The developed TLM was composed of three components, namely the printed teaching and learning material that contains the lesson and trackers, a database of 3D AR objects like atoms, molecules, animations and different chemical simulations, and a dedicated mobile application software for the retrieval, display and manipulation of AR objects. The contents of the TLM was developed based on the standard syllabus of the Department of Education for General Chemistry 1 for senior high school curriculum. The identified learning competencies were used as basis for designing the AR models and animations. The AR component of the TLM was designed and specified by the researcher to provide structuring and problematizing metacognitive scaffolds. The AR objects were intuitive and could be zoomed in and rotated by 360o using tactile manipulations on the mobile device's screen. Specific trackers (Fig. 1) for each AR object were strategically placed in the presentation of the lesson in the TLM to ensure the seamless blending of AR objects for each topic.

Fig. 1. Specific trackers for each AR object that were printed in the TLM.

The development of AR objects and mobile application software (Fig. 2) was commissioned to a software engineer. Blender software was used in building the AR objects and animations, while Unity software was used in developing the mobile application that will retrieve and display the AR objects based on the trackers printed in the TLM. The mobile application software has a memory of 1213 MB and requires devices that run on Android 8.1 (API 27) or later. Each student participant was given a copy of the TLM and the accompanying mobile application software was installed in their respective smartphones.

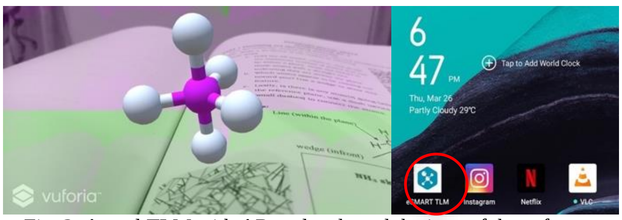

Fig. 2. Actual TLM with AR molecule and the icon of the software application as seen in the smart phone user interface.

B. *Level of Integration of AR Technology and Metacognitive Scaffolding in the TLM*

Five faculty experts in the field of chemistry observed the utilization of the TLM in the conduct of general chemistry class and assessed the level of integration of AR technology and metacognitive scaffolding in the TLM. Table 1 presents the results of their assessment

Table 1. Level of integration of AR technology and metacognitive scaffolding in the TLM

Descriptors	Mean	Interpretation
1. The AR animations used in the class enabled the teacher to provide metacognitive scaffolding.	4.00	Greatly Integrated
2. The AR animations designed for metacognitive scaffolding were dynamically integrated in the TLM.	4.00	Greatly Integrated
3. The AR animations present step-by-step tutorials that provide procedural metacognitive scaffolding.	4.00	Greatly Integrated
4. The AR animations show clear explanations of chemical concepts that provide declarative metacognitive scaffolding.	4.00	Greatly Integrated
5. The AR animations enabled the students to answer conceptual questions.	4.00	Greatly Integrated
6. The features of the TLM could help the students organize their thoughts and ideas.	4.00	Greatly Integrated
7. The AR animations facilitated students' ability to acquire problem-solving skills.	3.60	Greatly Integrated
8. The AR objects which depict chemical images are correct and accurate in terms of chemical concepts and laws.	4.00	Greatly Integrated
9. The AR objects provide a more engaging representation of atoms and molecules as compared to 2D pictures only.	4.00	Greatly Integrated
10.The AR objects blends seamlessly in the presentation of the lesson.	3.80	Greatly Integrated
Composite Mean	3.94	Greatly Integrated

The composite mean value of 3.94 (SD = 0.18) indicates that the pedagogical approaches of using AR technology and metacognitive scaffolding were greatly integrated into the developed material. Eight out of ten items/descriptors in the instrument obtained the highest possible score of 4.0, indicating a unanimous agreement among the faculty observers that these are greatly integrated into the TLM. While there are two items with 3.60 (SD = 0.55) and 3.80 (SD = 0.45), these descriptors still indicate that they are greatly integrated into the teaching and learning material.

In terms of Descriptor 1, the AR animations used in the class provided the springboard from which the researcher posed probing questions to the students that required metacognitive knowledge. One example of an AR animation that was embedded in the TLM was Rutherford's gold foil experiment (Fig. 3).

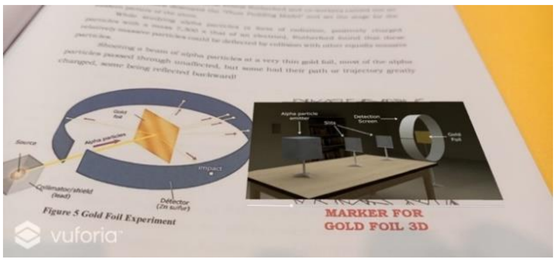

Fig. 3. Animation for gold foil experiment.

The animation showed how alpha particles were used to bombard the gold foil and how these particles did not follow the expected result of passing through the thin foil. The particles instead deflected and some of them bounced back. From this animation, probing questions were given to the students, a form of problematizing metacognitive scaffolds that bring out answers on "what could be the reason for the deflection of a massive radioactive particle" and "what is the implication of this experiment to the elucidation of the atomic structure. Problematizing scaffolds are explicitly given to students as questions to elicit their own metacognitive abilities [22].

The same thing holds true for descriptor 2 which obtained a mean score of 4.0. The teacher observers agreed that "The AR animations that were designed to provide metacognitive scaffolding were dynamically integrated into the class discussion". There are many ways in which the AR objects and animations were utilized in the class discussion. Through screen mirroring of the mobile screen that shows AR animations or objects to the wide television screen in the class, this innovative technology served as a visual aid in explaining the lesson.

Descriptor 3 which also obtained a mean score of 4.0 (SD = 0.00) states that the AR animations present step-by-step tutorials which provide a procedural metacognitive scaffold. In this case, the procedure is also a form of structural scaffold because it simplifies the learning process by reducing its complexity and clarifying the underlying components. An example of this in the TLM is the formation of covalent bonding. In the user interface of the mobile software, there are options where students can choose which step in the formation of covalent bond between hydrogen and oxygen to form water do they want to view (Fig. 4). They can go back and forth between the steps to clarify any misunderstanding and develop deeper procedural metacognitive knowledge.

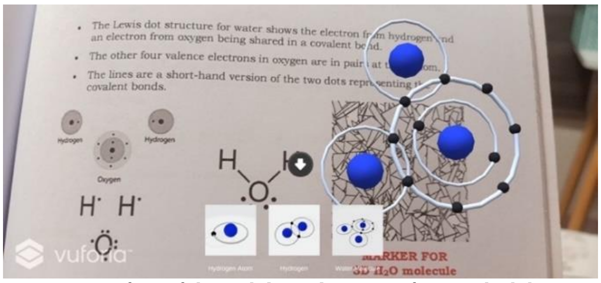

Fig. 4. User interface of the mobile application software which has options for students to choose which step in the formation of covalent bonds to view.

Descriptor 4 and 5 both obtained a mean score of 4.0, which means that it is greatly integrated in the TLM. Scaffolding through AR animations in this study falls under structuring scaffolds because it reduces the complexity of the abstract nature of chemical bonding, with the students having a tangible model that helps them develop declarative metacognitive knowledge. An example of this animation is Millikan's Oil Drop Experiment. In regular chemistry books, it is usually depicted in static pictures and is accompanied by textual explanations about the complex nature of the experiment. Since Millikan's Oil Drop Experiment also involves the application of physics principles, this topic is quite difficult for students to understand. The 3D animation of what really happened in the experiment with a focus on each step of the experiment really reduced the complexity of the lesson and enabled the students to answer conceptual questions that require metacognitive knowledge.

For descriptor 6, the development of the TLM was built around the goal of enhancing metacognitive knowledge using AR technology. The AR animations of complex lessons and step-by-step procedures like the formation of chemical bonds are the features of the developed TLM that served as structural scaffolds that guided the students in organizing their thoughts and ideas. These features were clearly noted by the teacher observers based on the result of this study.

Descriptor 7 with a mean score of 3.60 reports that "The AR animations facilitated students' ability to acquire problem-solving skills." Just like the written step-by-step example, there are also AR animations in the TLM that helped the students concretize the vague and abstract nature of chemistry like atomic theory. The elucidation of the subatomic particles through AR animation and visually relating how they dictate the physical and chemical properties of elements provide the necessary scaffold for students to solve problems relating to atomic theory.

Descriptor 8 with a mean score of 4.00 relates to the accuracy of AR objects integrated in the TLM. The accurate depiction of atoms and molecules in a general chemistry course is important because it is the basis of how students will form their understanding of the microscopic nature of matter. It is important for students to develop the ability to navigate between the three levels of chemical representation which are the macroscopic, submicroscopic and symbolic representations. The 3D AR objects in the TLM provide the students a model that accurately shows the submicroscopic level of matter.

Descriptor 9 also got a mean score of 4.0. Fig. 5 shows students' engagement by viewing the 3D animation of how a covalent bond is formed between hydrogen and oxygen atoms to form water molecules. From the mobile software that accompanied the TLM, students can choose which molecule to view in this particular animation. They can start with hydrogen or oxygen only, showing their respective atomic orbitals. Then they can click from the options to view how the atomic orbitals of hydrogen and oxygen atoms overlap with each other to form the molecular orbital and how the shared electrons continue to move around the molecular orbital. Now when students navigate the AR objects and there are visual, aural and tactile stimulation, there is direct interaction with the surroundings. This is a "solid" experience that makes lasting neural connections because the brain processes 3D images in significantly different ways to how it processes 2D images, thus creating authentic learning experience [23].


Fig. 5. Students viewing the 3D animation for covalent bonding.

Lastly, Descriptor 10 obtained a mean score of 3.8 (SD = 0.45) asserts that the AR objects blend seamlessly in the presentation of the lesson in the class. While the students can individually use their mobile phones to access the AR content during the class discussion, the teacher can also use the AR model as a visual aid in explaining the concepts through screen mirroring of the mobile phone to the smart TV. Fig. 6 shows how the AR content blends seamlessly into the presentation of the lesson. As seen below, the researcher explains the concept of the Billiard Ball Model of the Atom using the AR object displayed on the smart TV monitor which was actually a mirrored image from the mobile phone being manipulated by the student.

Fig. 6. Seamless blending of AR in the class discussion.

C. *Effect of AR as Metacognitive Scaffolds on Students' Metacognitive Knowledge*

Metacognitive knowledge was categorized into declarative, procedural and conditional. Table 2 shows the average normalized gains obtained from the pretest and posttest scores of the students in these three categories.

Table 2. Average normalized gains for metacognitive knowledge of student participants

Knowledge Area	Pretest	Posttest	Hake Factor	SD	Interpretation
Declarative	53.02	87.36	0.73	0.15	High Gain
Procedural	53.29	90.29	0.79	0.16	High Gain
Conditional	50.64	84.01	0.68	0.15	Medium Gain

As can be observed from the table, there are high average normalized gains for declarative and procedural metacognitive knowledge as given by the g value of 0.73 (SD = 0.15) and 0.79 (SD = 0.16) respectively. On the other hand, there is only medium average normalized gain for conditional knowledge, as given by the g value of 0.68 (SD = 0.15).

From these values, it can be said that the use of AR and metacognitive scaffolding in the TLM to enhance metacognitive knowledge has greater effect on declarative and procedural knowledge as compared to conditional knowledge. The structuring and problematizing metacognitive scaffolds integrated in the TLM helped the students understand the nature of the learning activity, the resources and steps necessary to solve the problem and the nature of the task, which are characteristics of the declarative knowledge. Likewise, the scaffolds have the same effect on the procedural knowledge which is about learner's capacity of how to do something and strategies related in doing it. It can be recalled that these scaffolds in the TLM were in the form of AR objects and animations that vividly demonstrates the experiments and simulations, and provide step-by-step examples to incite students' deeper analysis of the learning process. These scaffolds were more related to both declarative and procedural as compared to conditional knowledge, which is actually knowing when and why to use declarative and procedural. From this, it is only logical that there will be higher gains in declarative and procedural knowledge since conditional knowledge depends on these two.

This result is consistent with the idea that students generally have a repertoire of metacognitive strategies, including declarative and procedural knowledge but may lack the knowledge of knowing under which circumstances it is best to apply a strategy that constitutes conditional knowledge [24]. Likewise, it also provided metacognitive scaffolding in an innovative learning environment through a 3D virtual agent embedded in a computerized learning environment [22]. Metacognitive scaffolding could be applied to increase metacognitive knowledge as an alternative method of training metacognition because of its positive influence on the latter.

V. Conclusion

The study concludes that the integration of augmented reality (AR) as metacognitive scaffolds in the TLM can significantly contribute to learning gains on metacognitive knowledge of the learners, specifically on declarative and procedural knowledge. With the innovative technology offering a rich learning environment with accurate AR objects that provided metacognitive structuring and problematizing scaffolds, the purpose of developing this new hybrid of teaching and learning material was achieved in this study. The development of the TLM with AR component showcases the potential of creating high-quality, innovative resources to raise the profile and importance of the role of TLMs to facilitate meaningful teaching and learning inside the classroom. Furthermore, the inclusion of a dedicated, custom mobile application software in TLM highlights the integration of mobile technology in education.

From these findings, it is recommended that educators should consider creating TLM with Augmented Reality as scaffolds to enhance students' metacognitive knowledge across various subjects. Likewise, schools and educational institutions might consider investing in such technologies and providing training for educators to integrate them effectively into their teaching practices.

Conflict of Interest

The authors declare no conflict of interest.

Funding

This study was funded by the Commission on Higher Education as part of the K to 12 Transition Program Graduate Education Scholarship (Local) with grant number 2017a-040716.

Acknowledgment

The author wishes to thank Batangas State University and the Commission on Higher Education for the opportunity to conduct this study and Dr. Rebecca C. Nueva España for her invaluable input in completing the study.

References

[1] E. Klopfer and K. Squire, "Environmental detectives—the development of an augmented reality platform for environmental simulations," *Educational Technology Research and Development*, vol. 56, no. 2, pp. 203–228, 2002.

[2] J. Fombona, C. Vazquez, and M. Valle, "Analysis of geolocation and augmented reality on mobile devices, social and educational proposals related to the environment and field trips," *Journal of Curriculum and Teacher Training*, vol. 22, pp. 197–222, 2018.

[3] D. Kiger, "Bring your own device: Parental Guidance (PG) suggested." *Association of Educational Communications and Technology*, pp. 51–61, 2015.

[4] J. Garzon and J. Acevedo, "A meta-analysis of the impact of augmented reality on students' learning effectiveness," *Educational Research Review*, vol. 27, pp. 244–260, 2019.

[5] M. Akçayir and G. Akçayir, "Advantages and challenges associated with augmented reality for education: A systematic review of the literature," *Educational Research Review*, vol. 20, pp. 1–11, 2017.

[6] J. Almenara, J. M. Fernández-Batanero, and Barroso-Osuna, "Adoption of augmented reality technology by university students," *Heliyon*, vol. 5, no. 5, May 2019.

[7] T. P. Caudell and D. W. Mizell, "Augmented reality: An application of heads-up display technology to manual manufacturing processes," in *Proc. the Twenty- Fifth Hawaii International Conference on System Sciences*, vol. 2, 1992, pp. 659–669.

[8] R. Azuma, "A survey of augmented reality," *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, pp. 355–385, 1997.

[9] L. Vygotsky, *Mind and Society: The Development of Higher Mental Processes*, Cambridge, MA: Harvard University Press, 1978.

[10] D. Wood, J. Bruner, and G. Ross, "The role of tutoring in problem solving," *Journal of Child Psychiatry and Psycohology*, vol. 17, pp. 89–100, 1976.

[11] R. Azevedo and A. Hadwin, "Scaffolding self-regulated learning and metacognition—implications for the design of computer-based scaffolds," *Instructional Science*, vol. 33, no. 5, pp. 367–379. 2005.

[12] R. Luckin *et al*., "Using mobile technology to create flexible learning contexts," *Journal of Interactive Media Education*, vol. 2005, no. 2, 2005.

[13] M. Veenman, B. Hout-Wolters, and P. Afflerbach, "Metacognition and learning: conceptual and methodological considerations," *Metacognition Learning*, vol. 1, no. 1, pp. 3–14, 2006.

[14] J. Way and L. Rowe, "The role of scaffolding in the design of multimedia learning objects," in *Proc. 11th International Congress of Mathematical Education*, 2008, pp. 1–7.

[15] M. Bannert, M. Hildebrand, and C. Mengelkamp, "Effects of a metacognitive support device in learning environments," *Computers in Human Behavior*, vol. 25, no. 4, pp. 829–835, 2009.

[16] M. Bannert and C. Mengelkamp, "Assessment of metacognitive skills by means of instruction to think aloud and reflect when prompted. Does the verbalization method affect learning?" *Metacognition and Learning*, vo. 3, no.1, pp. 39–58, 2008.

[17] E. Cook, E. Kennedy, and S. Y. McGuire, "Effect of teaching metacognitive learning strategies on performance in general chemistry courses," *Journal of Chemical Education*, vol. 90, no. 8, pp 961–967. 2013.

[18] M. L. Delvechhio, "Students' use of metacognitive skills while problem solving in chemistry," M.S. thesis, Queen's University, Canada, 2011.

[19] R. Azevedo, D. C. Moos, and J. A. Greene, F. I. Winters, and J. G. Cromley, "Why is externally facilitated regulated learning more effective than self-regulated learning with hypermedia?" *Educational Technology Research and Development*, vol. 56, no. 1, pp. 45–72, 2008.

[20] T. H. Chiang, S. J. Yang, and G. J. Hwang, "An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities," *Journal of Educational Technology and Society*, vol. 17, no. 4, pp. 352–365, 2014.

[21] R. E. Mayer, "Multimedia learning," *Psychology of learning and motivation*, vol. 41, pp. 85-139, 2002.

[22] I. Molenaar, C. Boxtel, and P. Sleegers, "Metacognitive scaffolding in an innovative learning arrangement," *Instr Sci*, vol. 39, pp. 785–803, 2011.

[23] D. Prigge, "Ways to promote brain-based teaching and learning," *Intervention in School and Clinic*, vol. 37, pp. 237–241, 2002.

[24] A. Gutierrez. (2014). Comprehension Monitoring: The role of conditional knowledge. [Online]. Available: https://www.improvewithmetacognition.com/comprehension-monitoring-the-role-of-conditional-knowledge/