Cognitive Theories of Learning on Virtual Science Laboratories

Hasan Ozgur Kapici
Yildiz Technical University, Turkey

Hakan Akcay
Yildiz Technical University, Turkey

Introduction

Inquiry based science learning has been used in science education since it enables students to build their own knowledge that is scientific and which can be used to predict and explain what they observe around them (van Joolingen, de Jong, & Dimitrakopoulou, 2007). In such a learning environment, it is expected that students determine problems, gather and analyze data, make inferences and assess their own progressive process (van Joolingen & Zacharia, 2009). In other words, it is supposed that students acts as scientists so as to gain scientific knowledge (Zacharia et al., 2015).

Although there are many different ways to use inquiry based science learning at schools, many researcher advocate that computer supported learning environments are one of the best appropriate modalities because it is suitable for using multiple representations, available to provide instant and individual feedback, and may provide scaffolding with respect to students' needs (Furtak, Seidel, Iverson, & Briggs, 2012; Gerjets, Scheiter, & Schuh, 2008; van der Meij & de Jong, 2006). In particular, computer simulations help students to recall their prior knowledge (e.g. through developing hypothesis) and enable them to reconstitute knowledge effectively (e.g. the data gathered from experiments or other sources is not consistent with the hypothesis) (de Jong, 2011). In the study done by van Joolingen, de Jong and Dimitrakopoulou (2007), they drew up several ways which show the appropriateness of computer simulations to create inquiry learning environments. One of them is stated as computer simulation makes easier to design experiment about wide scale phenomena into a simplified version. This situation is, for example, usually valid for astronomy topics which cannot be investigated without computer simulations in classes. Another convenience between computer simulations and inquiry learning is claimed as computer simulations provide several scaffolding tools such as hypothesis scratchpad, conclusion tool or data viewer, which enable students to manage their own learning process. The other way is advocated as computer simulations are proper to support collaborative learning among students to share and discuss data and results about the knowledge. The last point that they emphasized in their study is that computer supported environments might enable students to create their own models based on their theories. In this way, students' possible misconceptions might be revealed.

Because unguided discovery learning gives worse results for students' conceptual understanding than even direct instruction (Lazonder, 2014), computer supported inquiry learning requires guidance for students. For example, some studies (e.g. de Jong & Van Joolingen, 1998; Mulder, Lazonder, & de Jong, 2011) show that students have trouble while developing hypothesis, designing experiment and collecting data. There are also recent meta-synthesis studies (e.g. Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Furtak et al., 2012; Minner, Levy, & Century, 2010; Lazonder & Harmsen, 2016) which show that guided inquiry learning is more effective than unguided inquiry learning and direct instruction (de Jong & Lazonder, 2014). However, there is a discussion about amount of guidance and when it should be given to students (Lazonder, 2014). One of the two main perspectives claims that students should have all relevant knowledge and skills before designing and implementing their own experiments by themselves (Kirschner, Sweller, & Clark, 2006). The other view advocates that information (support) should be provided *just-in-time* or *on-demand basis* while students are in inquiry based learning process (Hmelo-Silver, Duncan, & Chinn, 2007). The help served for students may be into form of cognitive tools or scaffolds for computer supported learning environments (van Joolingen et al., 2007). De Jong and Lazonder (2014) categorize the types of support into six different forms. One of the support forms is called as *process constraints*, which aims that to diminish the complexity of the learning environment by limiting the number of options for students to deal (de Jong & Lazonder, 2014). This type of guidance can be used when students have fundamental inquiry skills and able to apply those through the investigations but have insufficient experience to use them for more demanding circumstances (de Jong & Lazonder, 2014). Another form of support is called as *performance dashboard*, which provides data about students' learning process' progress for students and also gives data about gained knowledge by students (de Jong & Lazonder, 2014). This type of support enables students to understand about their own learning process and learning outcomes. The other guidance type is *prompts*, which act as reminder for students to fulfill the learning task (de Jong & Lazonder, 2014). It is mainly used when students have related skills but may not use them by themselves. *Heuristics* are another type of guidance in computer supported learning environments. It is similar to prompts but more specific since they provide suggestions about how to perform particular action (de Jong & Lazonder, 2014). They are used when students have no knowledge about when and how to continue their task. Another support type is known as *scaffolds*. They act as components of learning process and are used when the task is so complicated or when students lack of competence to handle with the learning process (de Jong & Lazonder, 2014). Last type of support defined by de Jong and Lazonder (2014) is that *direct presentation of information*. Although this type of support contradicts with nature of inquiry based learning, it is used when students have lack of prior knowledge or they are unable to do the main task (de Jong & Lazonder, 2014).

There is no certain conclusion about the relation between types of guidance and students' level or age. In other words, it has been discussing that effectiveness of guidance types in inquiry based learning environment with respect to education and age levels. Based on the literature, de Jong and Lazonder (2014) advocate that more open types of guidance are more suitable for older students.

Another topic about guidance types is that whether supportive tools might be used in a combination form such as prompts and scaffolds together or they should be used alone. There are also contradictive results about this issue in the related literature. Some studies (e.g. Fund, 2007; Zhang, Chen, Sun, & Reid, 2004) concluded that the more guidance students received the higher scores in their posttest scores (de Jong & Lazonder, 2014). Some other studies (e.g. Eckhardt, Urhahne, Conrad, & Harms, 2013) reached totally opposite results, in which the group who received the combined guidance types had lower posttest scores (de Jong & Lazonder, 2014).

As a conclusion, it can be said that guided inquiry learning is more effective than unguided one but there is still uncertainty about the amount and types of guidance in order to support students. These (amount and types of guidance) might be different based on the students' age and education level.

Go-Lab as an Inquiry-Based Learning Environment

Go-Lab is a research project funded by the European Commission and provides online science laboratories for inquiry learning. Go-Lab platform consists of three main parts, which are online laboratories, applications, and inquiry learning spaces. Firstly, there are two kinds of online laboratories in the platform, one of which is remote laboratories and the other one is virtual laboratories. In remote laboratories, students are able to reach real laboratory setup, real location and materials from their own places. In the virtual laboratories, laboratories are simulated versions of real laboratories. There are more than 750 remote and virtual laboratories in the platform about physics, chemistry, biology, astronomy, technology, engineering, environmental education, astronomy, earth sciences, and mathematics. For example, in the Figure 1, some views of the virtual electrical circuit laboratory are shown. Students are able to create their own circuits and can do measurements on it. The virtual laboratory involves resistors, bulbs, power supplies and batteries and switches. In addition to these, it is possible to add ammeter, voltmeter and ohmmeter into the circuits.

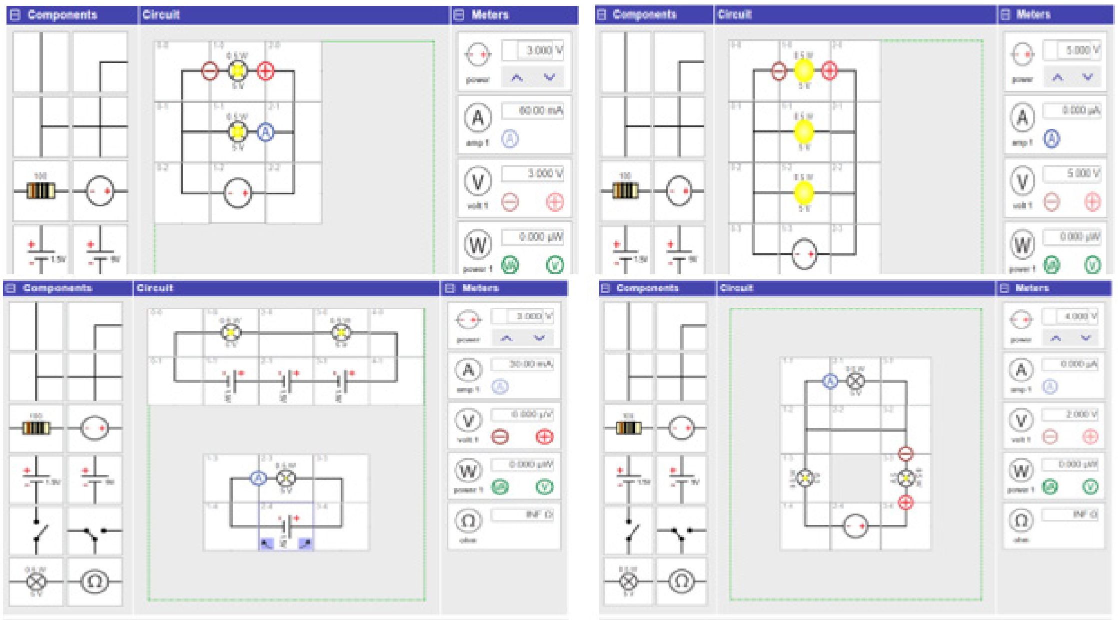

Figure 1. Some Views from the Virtual Electrical Circuit Laboratory

Another example is about remote laboratories. In the Figure 2, some views from Archimedes' principle are shown. It's a kind of remote laboratory and aims to teach students about the principle of objects floating and sinking in liquids with respect to Archimedes' principle.

Younger students (10-12 years old) can do observations for floating and sinking objects but older students (16-18 years old) can design their own experiments and determine the density of the object.

Secondly, there are web based software applications in the platform. These applications can be added into the inquiry learning space together with online laboratories. Some examples of the applications can be hypothesis scratchpad, experiment design tool, reflection tool, conclusion tool, concept mapper and data viewer. These applications act as scaffolding tools in computer supported inquiry based learning environments.

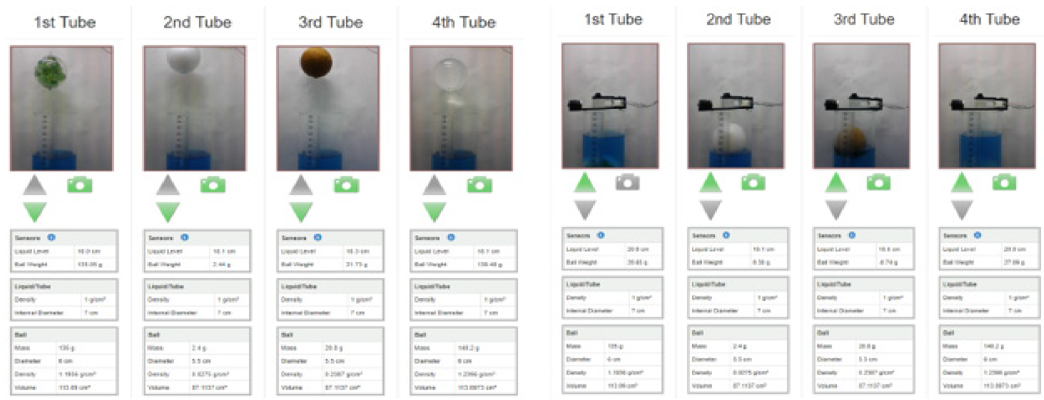

Figure 2. Some Views from the Archimedes' Principle Remote Laboratory

One of them, for example, is hypothesis scratchpad which helps students to create hypothesis. In the tool, predefined concepts are presented to students and then students compose hypothesis through drag and drop. And they can also add their own concepts by using 'type your own' box. Figure 3 shows an example of hypothesis scratchpad.

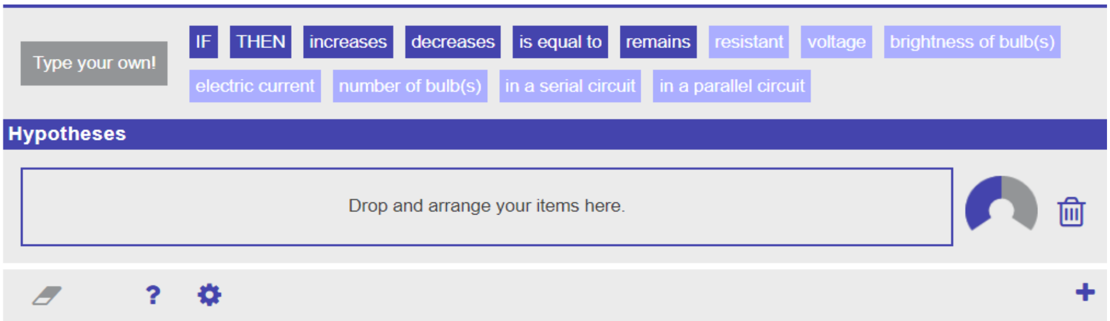

Figure 3. Hypothesis Scratchpad

The observation tool is another scaffolding tool provided by the Go-Lab platform and enables students to take notes based on their observations while preparing, conducting and analyzing experiments. Figure 4 shows the observation tool as an example.

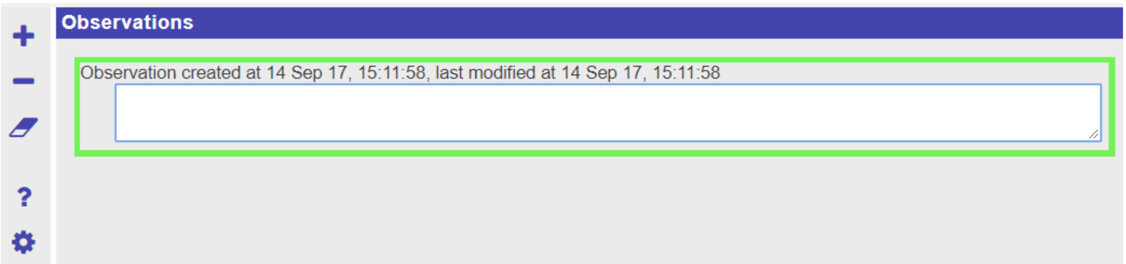

Figure 4. Observation Tool

Conclusion tool is also useful tool which is used commonly in ILSs. The tool allows students to check whether the results of experiments are compatible with the hypothesis created at the beginning of investigation. It is possible to reach hypothesis and observation notes via the tool. Figure 5 shows some examples of the conclusion tool.

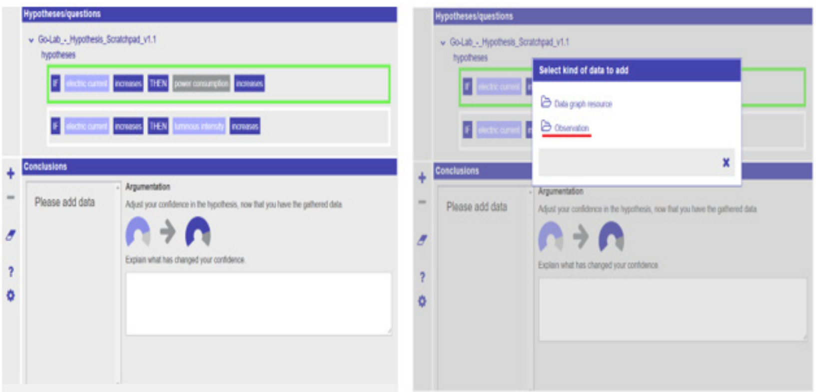

Figure 5. Conclusion Tool Enables Students to See Their Hypothesis and provides Observation Notes Taken by the Student

The third part of the platform is inquiry learning space, which is a learning environment that can contains online laboratories, applications like hypothesis scratchpad and other learning sources such as pictures, texts or videos. The learning space involves five main steps, which are orientation, conceptualization, investigation, conclusion and discussion (see Figure 6). Teachers produce inquiry learning spaces for their students and are able to share with other teachers through the system.

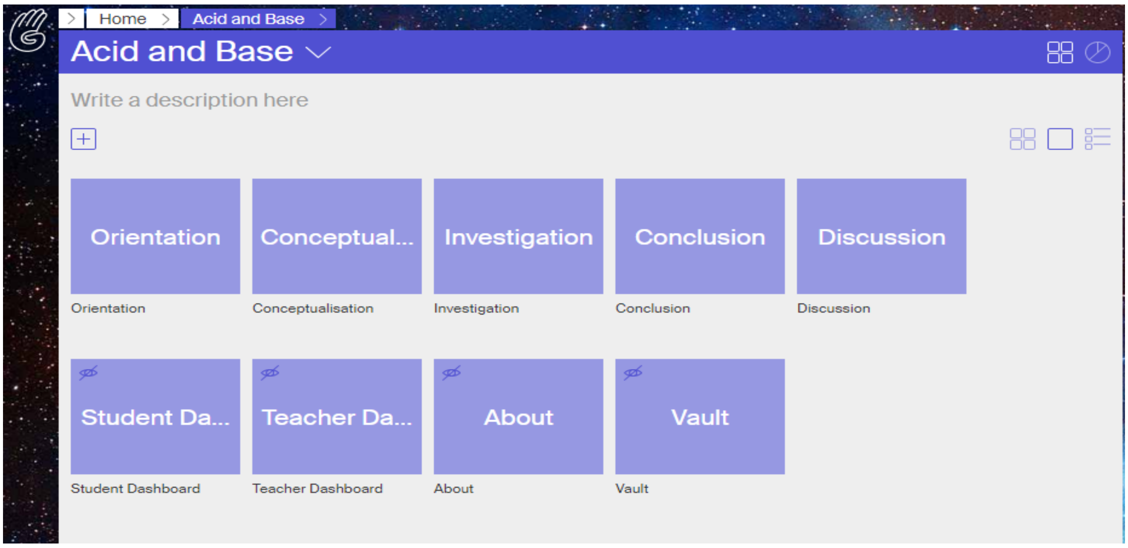

Figure 6. Main steps in an ILS

ILSs are appeared by students as Figure 7. They can move among the phases, watch videos or read texts, if exists, then they can design and implement their investigations via virtual or remote laboratories to gather data, take notes through observation tool and reach a conclusion by conclusion tool.

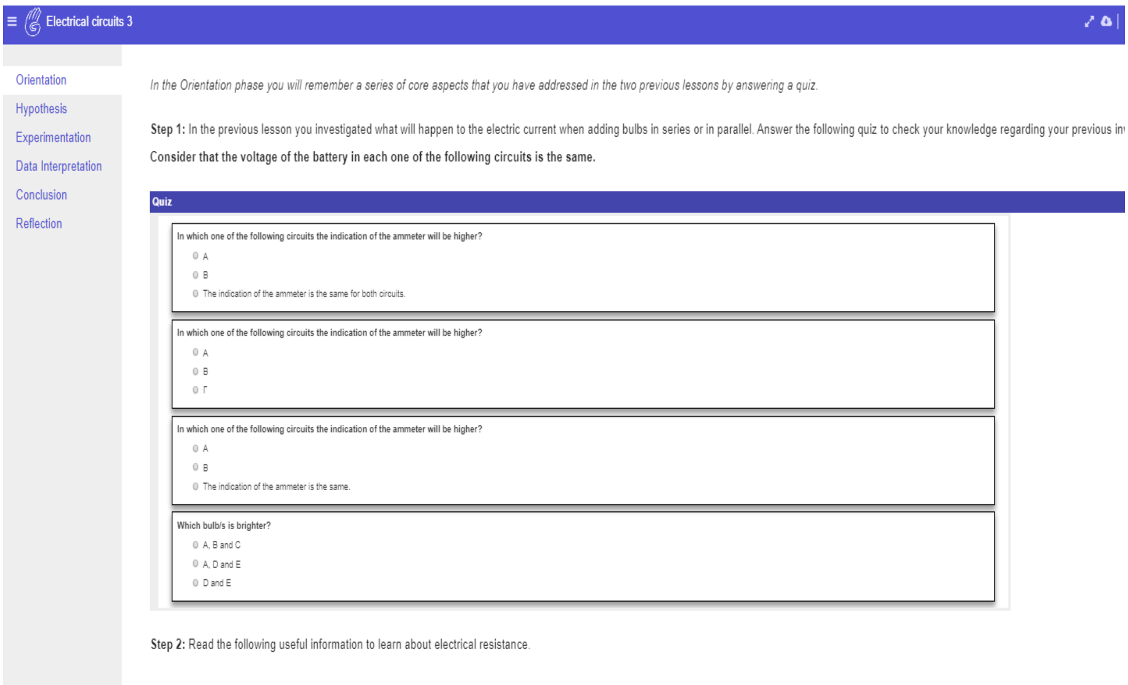

Figure 7. A View from an ILS in Terms of a Student's View

As discussed above, inquiry learning gives better outcomes if it is supported with guidance. Go-Lab platform has sufficient and useful tools to encourage students through learning process.

In addition, some cognitive learning theories also support the view that if the load on working memory decreases, then learning occurs better. In the next steps of the chapter, cognitive load theory, multimedia learning principles and importance of physicality in school science laboratories are discussed.

Cognitive Load Theory

The reason why guidance is important in inquiry based learning environment can be explained that appropriate support may help students in order to cope with the limitations of working memory and enable them to store new knowledge into long-term memory (de Jong & Lazonder, 2014). Working memory is responsible for the processing of information (de Jong, 2010, p.105). It is comprised of partially independent processors which are related to different sensory channels (Hollender, Hofmann, Deneke, & Schmitz, 2010, p.1279). There are two main deficiencies of working memory, which are holding limited amount of information and content knowledge in working memory are lost in very short duration without reiteration (Sweller, 2005). That's why; instructional designs should take in consideration these limitations.

Furthermore, there are relations between working memory and long-term memory. Long-term memory is a kind of storage, in which information is held. Cognitive activities, such as learning, done by a human are driven by information held in long-term memory (Sweller, 2005). One of the efficient ways in order to deal with the limitations of working memory while learning a new information is that using stored knowledge held in long-term memory (Sweller, 2005). In other words, understanding a concept may be explained based on the relations between working memory and long-term memory (Marcus, Cooper, & Sweller, 1996). Sweller (2005) states that schemas held in long-term memory direct the information processed in working memory in order to be organized. In other cases, for example, if there is no schema or organized information about new knowledge, then random generation based on the tests of effectiveness is followed (Sweller, 2005). Out of randomly organizing information and then testing for effectiveness, schemas held by other people can be used to organize the information (Sweller, 2005, p. 26). On the other hand, many instructional designs, like all inquiry based instructions, prefer to involve random generation followed by testing, instead of other people's knowledge (Sweller, 2005). Based on these facts, cognitive load theory was developed mainly by Paas, Renkl and Sweller (2005), Sweller (1994; 2005) and Sweller and Chandler (1991). Sweller (2005) defines cognitive load theory as an instructional theory based on our knowledge of human cognitive architecture that specifically addresses the limitations of working memory (p. 28). There are three basic categories of the theory, which are: extraneous, intrinsic and germane cognitive load.

Extraneous cognitive load is caused by improper instructional designs which ignore the limitations of working memory and does not directly promote learning (de Jong, 2010; Sweller, 2005). Because of this, instructional designers want to minimize extraneous cognitive load. There are several principles such as worked example, split-attention, redundancy, expertise-reversal effect and modality effect to minimize extraneous cognitive load. A worked example, for example, decreases extraneous cognitive load by eliminating search (Sweller, 2005). Another principle, which is split-attention, claims that learner's attention shouldn't be divided in multiple sources of information; instead, different sources of information should be integrated temporally and physically (Ayres & Sweller, 2014) if all the sources required for understanding (Hollender et al., 2010). Redundancy is the other type of principle and it also deals with multiple sources of information. Sweller (2005) explains that if there are multiple sources and both of the sources present the same information in different forms, then one of the sources is enough for understanding and the other source is unnecessary. Eliminating the second source may reduce the extraneous cognitive load. This is called as redundancy. The expertise-reversal effect is another reason for extraneous cognitive load. Detailed and exhaustive information might be useful for novice learners but not for experts because although the information is necessary for novice learners, it is redundant for expert individuals (Kalyuga, Ayres, Chandler, & Sweller, 2003; Sweller, 2005). Last but not least, modality effect has an important role to decrease for extraneous cognitive load. It advocates that instead of integrating different sources of information physically, verbal material should be presented in spoken form rather than written form (Sweller, 2005). All these principles are vital for reducing the extraneous cognitive load, which is not directly relevant for learning and learners should not spend their time and resources for the processes that cause extraneous cognitive load (de Jong, 2010).

Intrinsic cognitive load is another cornerstone for cognitive load theory. It is relevant the complexity of information and the interactivity of the elements (Sweller, 2005). In other words, material that contains a large number of interactive elements is regarded as more difficult than material with a smaller number of elements and/or with a low interactivity (de Jong, 2010, p. 106). Whereas low interactivity material refers to simple and single elements like word or number, high interactivity means that combination of single or simple elements such as sentence or adding/abstracting numbers (Sweller, 1994). Because of the fact that intrinsic cognitive load is related with the materials, instructional treatments have no impact on it (de Jong, 2010). Furthermore, it cannot be changed (Hasler, Kersten, & Sweller, 2007). In related literature, there are some ways to reduce intrinsic cognitive load such as simple to complex approach (van Merriënboer, Kirschner, & Kester, 2003) and whole-part approach (van Merriënboer, Kester, & Paas, 2006). These approaches are seen suitable with cognitive load theory because both of the approaches start with few elements and the complexity increases step by step (van Merriënboer & Sweller, 2005). As a consequence, intrinsic cognitive load tries to explain why some types of materials are more difficult than others and how this may influence the load on memory (de Jong, 2010, p.107).

The third type of cognitive load is germane cognitive load. Cognitive load theory advocates that learning occurs through construction and automation of schemas (Sweller, van Merriënboer, & Paas, 1998). Within this respect, germane cognitive load is a kind of cognitive load caused by effortful learning resulting in schema construction and automation (Sweller, 2005, p.27. Mayer (2002) states that organization of information, interpreting and classifying it, inferring and exemplifying are some required process for constructing schema, which are important constructions due to the fact that they help to reduce the load on working memory (Anglin, Vaez, & Cunningham, 2004). Instructional designs help students to expose these processes in order to engage schema construction and automation and in this way, germane cognitive load increases (de Jong, 2010). To sum up, it stems from schema construction, which is useful for teaching (Hollender et al., 2010).

These three types of cognitive load are additive (Sweller, 2005, p.27). Sweller (2005) claims that in order to provide learning better, extraneous cognitive load should be decreased through proper instructional procedure. In this way, free capacity in working memory increases. This capacity may be used by germane cognitive load, which is helpful for learning. Besides if complexity of information is low, that is lower intrinsic cognitive load, then the capacity for germane cognitive load may increase even with high levels of extraneous cognitive load since low intrinsic cognitive load gives rise to low cognitive load (Sweller, 2005). As a conclusion, the relations among these three types of cognitive load are asymmetrical and in a loop shaped (Kılıç Çakmak, 2007). Kılıç Çakmak (2007) says that reducing the extraneous cognitive load via efficient instructional designs will provide extra capacity for germane cognitive load on working memory and then schemas will be constructed more easily. After schemas are constructed, then intrinsic cognitive load will decrease at the next step.

Multimedia Learning

The theory of multimedia learning was mainly developed by Richard E. Mayer and other cognitive psychology researchers. The researcher claims that multimedia instruction encourages the way that human brain learns (Sorden, 2012, p.155). The theory benefits from cognitive load theory for developing proper multimedia based learning environment (Mayer & Moreno, 2002). The main principle of multimedia learning is individuals learn better when words and pictures presented together, instead of using them alone (Mayer, 2005). Mayer (2005) defines words as spoken or written text and defines pictures as graphs, illustrations, maps and photos in a static form or animations and videos in a dynamic form.

The theory of multimedia instruction also focuses on working memory (Mayer, 2005) similar to cognitive load theory. In his study, Mayer (2005) introduces the cognitive structure of the theory as on Figure 8.

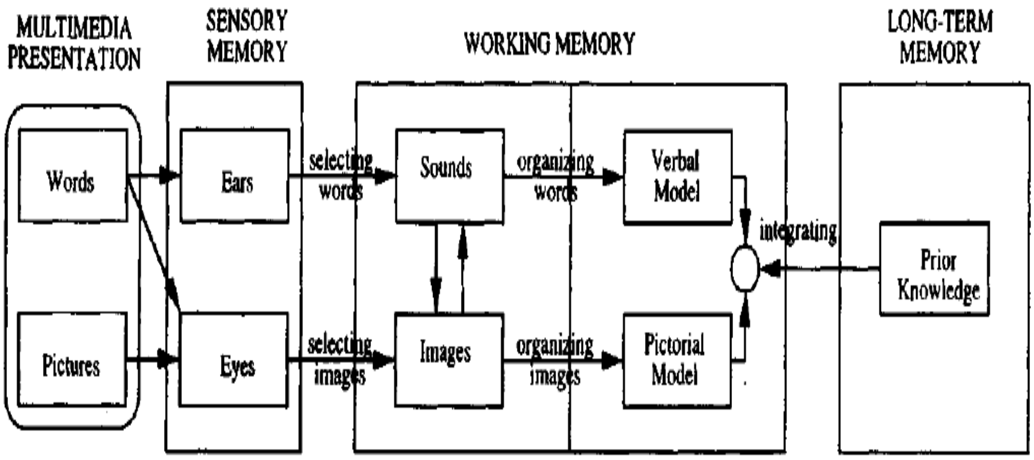

Figure 8. Cognitive Theory of Multimedia Learning

Mayer (2005) explains that structure of a human cognitive comprised of three main parts, which are sensory memory, working memory and long-term memory. Stimulus in the form of verbal and non-verbal structures receives to the sensory memory through ears and eyes. Pictures and written form of texts are held as exact visual images for a very short duration in visual sensory memory. Similarly, speech form of words and other sounds are held as exact audial images for a very short time in auditory sensory memory. The arrow from word to ears mentions the registered form of spoken text in ears and the arrow from words to eyes emphasizes the registered form of written/drawn text in eyes. The arrow from pictures to eyes represents the registered picture in the eyes. Mayer (2005) claims that working memory composes of two parts and whereas visual images of pictures and sound images of words come into working memory as raw materials to the left side, which are visual and audial modalities. In the right side of the working memory, knowledge construction occurs through verbal and pictorial models and the transfer between them. The arrow from sounds to images means that the conversion from spoken form to visual from. For example, when an individual heard the word 'dog', s/he forms the mental model of dog. The arrow from images to sound represents opposite form the process like when some sees a dog, s/he can mentally hear the word of dog. There is also long-term memory on the right side of the figure. After organizing the material into coherent form in working memory, related prior knowledge from long-term memory is brought and integrated to the organized material. The arrow from long-term memory to working memory indicates this process.

The major cognitive processes in multimedia learning are represented with the arrows labeled as selecting words, selecting images, organizing words, organizing images and integrating (Mayer, 2005). He (2005) divides sensory memory and working memory into two channels, one of which is interested in audial and verbal from of the materials and the other channel deals with visual images and non-verbal form of the materials. Due to the fact that the capacity of working memory is limited, just a few images can be held in the visual channel of working memory and just a few sounds can be held in the auditory channel of working memory (p. 45). Mayer (2005) explains that selecting words and images from sensory memory to working memory, organizing words and images in working memory and integrating the prior knowledge from long-term memory with the organized material in working memory enable an individual to be active during these processes, which is vital for meaningful learning.

The framework mentioned above was developed by three assumptions which were put forwarded by Mayer (2005). He (2005) defines these assumptions as dual channels, limited capacity and active processing. For dual channels assumption, he (2005) says that human cognitive has two channels in order to process the information. When someone is received information through eyes, then the information started to process in the visual channel. Similarly, when the information is received in the form of sound or non-verbal from, then it goes to the auditory channel. Indeed, this assumption is mainly based on Paivio's dual coding theory (Paivio, 1990) and Baddeley's working memory model (Baddeley, 1986; 1992). Furthermore, although the information is received through one channel, an individual may convert the representation from one channel to the other (Mayer, 2005).

Limited capacity assumption is related with the limited capacity of each channel at one time (Mayer, 2005). He (2005) clarifies the assumption as when an illustration or animation is presented, the learner can hold only a few items in his/her working memory at any time. These held items represent pieces of the presented material. Similarly, when an individual exposes to an expression, the learner can just hold a few words in his/her working memory at any one time. The roots of limited capacity assumption based on Sweller's cognitive load theory and Baddeley's working memory model.

The next assumption is active-processing assumption, which means that human actively engage in cognitive processing to construct a coherent mental representation of their experiences (Mayer, 2005, p.50). These cognitive processes includes being interested in the material, selecting and organizing the incoming information and integrating it with the knowledge from long-term memory (Mayer, 2005).

Out of these three assumptions introduced for cognitive theory of multimedia learning, Mayer (2005) advocates that learners should engage in five cognitive processes, which were also mentioned on Figure 1 that shows cognitive structure of multimedia learning, in order to expose meaningful learning. He (2005) collocates these processes as (i) *selecting relevant words for processing in verbal working memory*, (ii) *selecting relevant images for processing in visual working memory*, (iii) *organizing selected words into a verbal mental model*, (iv) *organizing selected images into a visual mental model* and (v) *integrating verbal and visual representations as well as prior knowledge* (p. 54). For the processes selecting words and images are required because the limited capacity of working memory. Each channel, that is verbal and visual, has capacity limitations, so selected part(s) of the information pass through sensory memory. After receiving the selected verbal and/or visual information, another cognitive process, which is organizing them, starts. Whereas verbal knowledge structure process occurs in auditory channel, visual knowledge structure process takes place in visual channel. Learners try to build connections among pieces of information that they received. Yet, due to the limitations of working memory, it is not possible to connect all the relations among pieces of information, so simple constructions have priority. For the last process, Mayer (2005) states that the most crucial step, in which word-based and visual-based representations integrate with each other and also with the prior knowledge called from long-term memory. Integration process happens in both visual and verbal channel and includes the coordination between them. This step might be inflictor for learners because it requires influential use of cognitive capacity. Learners should focus on the underlying structure of the visual and verbal representations and be able to use prior knowledge, stored on long-term memory, when they need (Mayer, 2005, p.57).

Mayer and Moreno (2002) state that in multimedia learning, individuals gain deeper learning since they receive multi medium presentations, instead of single medium one. They claim that multimedia works better but not always. In order to investigate when multimedia works efficiently, they examined four different conditions for computer-based multimedia learning, which are contiguity aids, coherence aids, modality aids and redundancy aids. For example, in contiguity aids, visual and verbal representations are presented to students simultaneously. When learners expose to such a condition, they performed better than the group, who received the representations successively (Mayer & Moreno, 2002). This finding is compatible with the cognitive theory of multimedia learning because when the representations are presented successively, then learners expose the full information twice which contradicts with the limited capacity of working memory. Mayer and Moreno (2002) also examined the coherence aids, which means that presenting information whether with some extra information or background music or not. When they compared the two groups, the one who received a concise narrated animation in which basic visual and verbal information presented simultaneously reached better score than the other group who exposed the same presentations with extra words and sounds. This result also supports the view of multimedia learning's cognitive structure because of the limited capacity of working memory. Modality aids were also investigated by Mayer and Moreno (2002). The aim of modality aids is to reduce the load on working memory by directing the information into the different channels, which are auditory and visual. In the study done by Mayer and Moreno (2002), they compared the learning outcomes of students who were taught through animation and narration with the group who learnt from animation and text. They concluded that students in animation and narration group outperformed than their counterparts. This result is appropriate with cognitive structure of multimedia learning. Redundancy aids are another type of aids in computer-supported multimedia learning. The aid examines that whether presenting animation, narration and on-screen text is beneficial for students' learning or not. Mayer and Moreno (2002) compared two groups in their study. One of groups received instruction based on animation and narration; the other group were taught with animation, narration and text. The result showed that animation and narration group reached better score. Mayer and Moreno (2002) state the reason of this result as adding on-screen text may cause a split-attention effect and may give rise to overload on working memory. All these types of aids focus on the same critical point, which is limited capacity of working memory. In order to deal with the problem, several aids as mentioned above were emphasized in related literature review.

The Advantages of Physicality in a Hands-on Laboratory Environment

Out of cognitive processes of learning, the other important issue in a virtual laboratory environment is physicality. Physicality refers to actual, active and intentional tactile actions done by someone in order to realize an object's hardness, temperature, surface shape or weight and so on (Loomis & Lederman, 1986). In a hands-on laboratory environment, touch sensory input is provided by directly touching the physical materials and apparatus (Zacharia, 2015). Yet, it is difficult to provide such kind of physicality in a virtual laboratory environment because all materials are on screen and there is no direct touching to the materials. In order to handle with this situation, haptic devices added to the virtual laboratory environment. Based on these facts, there is no certain conclusion about the topic whether physicality is prerequisite for learning in science education. There are some studies (e.g. Kontra, Lyons, Fischer, & Beilock, 2015) which found that students in hands-on laboratory environments, in which physicality is available, gained more knowledge than virtual laboratory environments without touch sensory input or haptic devices. On the other hand, there are also studies (e.g. Zacharia, Olympiou, & Papaevripidou, 2008) which concluded that virtual laboratory environment is more beneficial for students than hands-on laboratory environment. There are also studies (e.g. Zacharia & Olympiou, 2011) that reached each type of laboratory environment is equally effective for students' conceptual understanding. With respect to these studies, Zacharia (2015) states that physicality is not necessary for learning because students reached better scores in some studies, in which there is no physically touching or haptic devices, than their counterparts, who were taught in a hands-on laboratory environment, where touch sensory input was active. Zacharia (2015) and some other researcher (e.g. Triona & Klahr, 2003) advocate that manipulation is more important process for learning rather than physicality. Manipulation requires the learner to intentionally interact with the material and apparatus in a skillful manner and does not necessarily require touching the materials (Zacharia, 2015, p.117). In other respect, physicality might be required for developing certain motor skills especially on younger learners.

There are two main theoretical perspective about tactual manipulative, which are embodied cognition and additional (touch) sensory channel (Zacharia, 2015, p.118). According to the embodied cognition theory, learning (or thinking) necessitate s actual and dynamic activations of sensory and motor systems (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Fischer & Zwaan, 2008; Niedenthal, 2007). Sensorimotor experiences drawn from embodied cognition help for meaningful learning (Zacharia, 2015). Kontra et al. (2015) explains that when the content, which will be taught, connected with physical activities, ensuing activation of sensory and motor systems might promote learners' reasoning ability. Within the context of science education, usage of touchable manipulative encourages to perform physical sensorimotor actions which cause to construct motor schemas that can help students to have conceptual metaphors about certain science concepts (Zacharia, 2015).

Another theory about the importance of physicality on learning is the additional (touch) sensory channel theory. McNeil and Jarvin (2007) state that providing additional touching opportunity for students, then they receive more knowledge about the manipulative included in the experiment such as physical structure, temperature and so on. Adding tactile experience of a physical phenomenon with visual and audial modalities may have an impact on learning more complex concepts (Bivall, Ainsworth, & Tibell, 2011) because each modality has its own processing channel (Burton & Sinclair, 2000). In other words, the information might be divided into multiple processing channels which give rise to decrease cognitive load (Chan & Black, 2006). Zacharia and Olmypiou (2011) explain two ways about how activating touching sensory channel effects learning through science experimentation. For the first way, they (2011) say that if the same type of information that travels through the visual or the auditory channels is transferred through the sensory channel of touch, the cognitive load on the visual and auditory storage systems are abridged (p. 119), which causes idle capacity in central working memory to sustain the processing for complex understanding. The second approach offered by Zacharia and Olympiou (2011) is that if different type but complementary information carried via visual or auditory channels to the touching sensory channel, then learning would be enhanced since amount of information received to the learner's working memory increases without augmentation the cognitive load for each individual channel.

These two theories reveal the importance of touching through learning process but Zacharia (2015) states that there is no research about combining touching sensory channel modality with visual or auditory modalities in order to investigate how compounding affects an individual's cognitive load.

Conclusion

Fundamental cognitive theories of learning about multimedia-based learning discussed in this chapter focus on the specific working system of human brain. In order to encourage an individual to have permanent learning, each theory proposes definite ways to decrease cognitive load on working memory. Besides, it is seen that theories are interrelated and compatible with each other. Based on the facts derived from the theories, firstly, it is suggested that researchers should provide more data about the conditions for meaning learning by using the theories. Secondly, teachers should take consider the ways discussed in cognitive learning theories while organizing their teaching approach and environments. Thirdly, multimedia developers should pay attention to the theories in their products.

References

Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology, 103*(1), 1-18.

Anglin, G. J., Vaez, H., & Cunningham, K. L. (2004). Visual Representations and Learning: The Role of Static and Animated Graphics. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (Vol. 2, pp. 865-916). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Ayres, P., & Sweller, J. (2014). The Split-Attention Principle in Multimedia Learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd Edition ed., Vol. 2, pp. 135-146). Cambridge, MA: Cambridge University Press.

Baddeley, A. (1986). *Working memory*. Oxford: Clarendon Press.

Baddeley, A. (1992). Working memory. *Science, 255*(5044), 556-559.

Barsalou, L. W., Kyle Simmons, W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences, 7*(2), 84-91.

Bivall, P., Ainsworth, S., & Tibell, L. A. E. (2011). Do haptic representations help complex molecular learning? *Science Education, 95*(4), 700-719.

Burton, H., & Sinclair, R. J. (2000). Attending to and remembering tactile stimuli: A review of brain imaging data and single-neuron responses. *Journal of Clinical Neurophysiology, 17*(6), 575-591.

Chan, M. S., & Black, J. B. (2006). *Direct-Manipulation Animation: Incorporating the Haptic Channel in the Learning Process to Support Middle School Students in Science Learning and Mental Model Acquisition*. Paper presented at the International Conference on Learning sciences, Bloomington, Indiana.

De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. *Instructional Science, 38*(2), 105-134.

De Jong, T. (2011). Instruction based on computer simulations. In P. A. Alexander & R. E. Mayer (Eds.), *Handbook of research on learning and instruction* (pp. 446-466). New York, NY: Routledge.

De Jong, T., & Lazonder, A. W. (2014). The guided discovery principle in multimedia learning. In R. E. Mayer, J. J. G. Merriënboer, W. Schnotz, & J. Elen (Eds.), *The Cambridge handbook of multimedia learning* (pp. 2015-228). Cambridge: Cambridge University Press.

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations? *Instructional Science, 41*(1), 105-124.

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology, 61*(6), 825-850.

Fund, Z. (2007). The Effects of scaffolded computerized science problem-solving on achievement outcomes: A comparative study of support programs. *Journal of Computer Assisted Learning, 23*(5), 410-424.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching:A meta-analysis. *Review of Educational Research, 82*(3), 300-329.

Gerjets, P., Scheiter, K., & Schuh, J. (2008). Information comparisons in example-based hypermedia environments: Supporting learners with processing prompts and an interactive comparison tool. *Educational Technology Research and Development, 56*(1), 73-92.

Hasler, B. S., Kersten, B., & Sweller, J. (2007). Learner control, cognitive load and instructional animation. *Applied Cognitive Psychology, 21*(6), 713-729.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99-107.

Hollender, N., Hofmann, C., Deneke, M., & Schmitz, B. (2010). Integrating cognitive load theory and concepts of human–computer interaction. *Computers in Human Behavior, 26*(6), 1278-1288.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23-31.

Kılıç Çakmak, E. (2007). Çoklu ortamlarda dar boğaz: Aşırı bilişsel yüklenme [The bottle neck in multimedia: Cognitive overload]. *Gazi Eğitim Fakültesi Dergisi, 27*(2), 1-24.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75-86.

Kontra, C., Lyons, D. J., Fischer, S. M., & Beilock, S. L. (2015). Physical experience enhances science learning. *Psychological Science, 26*(6), 737-749.

Lazonder, A. W. (2014). Inquiry learning. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (pp. 453-464). New York, NY: Springer.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*(3), 681-718.

Loomis, J. M., & Lederman, S. J. (1986). Tactual perception. In K. R. Boff, L. Kaufmann, & J. P. Thomas (Eds.), *Handbook of perception and performance* (pp. 1-41). New York: Wiley.

Marcus, N., Cooper, M., & Sweller, J. (1996). Understanding instructions. *Journal of Educational Psychology, 88*(1), 49-63.

Mayer, R. E. (2002). Multimedia learning. *Psychology of Learning and Motivation, 41*, 85-139.

Mayer, R. E. (2005). Introduction to multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 1-18). Cambridge: Cambridge University Press.

Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational Psychology Review, 14*(1), 87-99.

McNeil, N., & Jarvin, L. (2007). when theories don't add up: disentangling he manipulatives debate. *Theory Into Practice, 46*(4), 309-316.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Mulder, Y. G., Lazonder, A. W., & de Jong, T. (2011). Comparing two types of model progression in an inquiry learning environment with modelling facilities. *Learning and Instruction, 21*(5), 614-624.

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*(5827), 1002-1005.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Paivio, A. (1990). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Sorden, S. D. (2012). The cognitive theory of multimedia learning. In B. J. Irby, G. Brown,

R. Lara-Alecio, & S. Jackson (Eds.), *The handbook of educational theories* (pp. 155-168). Charlotte: NC: Information Age Publishing.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 19-30). Cambridge, MA: Cambridge University Press.

Sweller, J., & Chandler, P. (1991). Evidence for cognitive load theory. *Cognition and Instruction, 8*(4), 351-362.

Triona, L. M., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction, 21*(2), 149-173.

Van der Meij, J., & de Jong, T. (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction, 16*(3), 199-212.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Van Joolingen, W. R., de Jong, T., & Dimitrakopoulou, A. (2007). Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning, 23*(2), 111-119.

Van Joolingen, W. R., & Zacharia, Z. C. (2009). Developments in inquiry learning. In N. Balacheff, S. Ludvigsen, T. de Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-enhanced learning: Principles and products* (pp. 21-37). Dordrecht, the Netherlands: Springer.

Van Merriënboer, J. J. G., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology, 20*(3), 343-352.

Van Merriënboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist, 38*(1), 5-13.

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: recent developments and future directions. *Educational Psychology Review, 17*(2), 147-177.

Zacharia, Z. C. (2015). Examining whether touch sensory feedback is necessary for science learning through experimentation: A literature review of two different lines of research across K-16. *Educational Research Review, 16*, 116-137.

Zacharia, Z. C., Manoli, C., Xenofontos, N., de Jong, T., Pedaste, M., van Riesen, S. A. N., Kamp, E. T., Maëots, M., Siiman, L., & Tsourlidaki, E. (2015). Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: A literature review. *Educational Technology Research and Development, 63*(2), 257-302.

Zhang, J., Chen, Q., Sun, Y., & Reid, D. J. (2004). Triple scheme of learning support design for scientific discovery learning based on computer simulation: Experimental research. *Journal of Computer Assisted Learning, 20*(4), 269-282.

Zacharia, Z. C., & Olympiou, G. (2011). Physical versus virtual manipulative experimentation in physics learning. *Learning and Instruction, 21*(3), 317-331.

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2008). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. *Journal of Research in Science Teaching, 45*(9), 1021-1035.

Citation:
Kapici, H.O. & Akcay, H. (2019). Cognitive theories of learning on virtual science laboratories. In M. Shelley & S.A. Kiray (Ed.). *Education Research Highlights in Mathematics, Science and Technology 2019* (pp. 107-126). ISRES Publishing, ISBN:978-605-698540-9.