DOI: http://dx.doi.org/10.24200/jeps.vol12iss3pp672-685

The Effect of Multi-Media Instructional Design based on Sweller's Theory on Reducing Cognitive Load and Developing Scientific Concepts among Deaf Primary Students

Aliah M. Al Atiyat*
Tabouk University, Kingdom of Saudi Arabia

Received: 20/12/2017 Accepted: 11/4/2018

Abstract: This study aimed to investigate the effect of instructional design of multi-media on reducing cognitive load and the development of scientific concepts among primary school deaf students. It combined the descriptive and quasi-experimental design using an extension of pre-test and post-test experimental-control group design with three groups: an experimental group that was taught the "solar system, stars and galaxies" modules using multimedia software based on the principles of cognitive load theory; a second experimental group was taught the same content using multimedia software but was not based on the principles of cognitive load theory; and a control group that was taught via the textbook. The study sample consisting of 48 male and female deaf students was selected from Al-Amal Institutes at Jeddah, Madinah, and Tabuk. The study used two instruments: scientific concepts test and NASA-TLX scale of cognitive load. The results revealed that the first experimental group outperformed the second and control group students on both measures. However, there was no significant difference between the second experimental and control groups. It is recommended that Sweller's theory and multimedia be used to design curriculum of science to deaf students.

Keywords: Instructional design, multimedia, cognitive load, deaf, scientific concepts.

أثر التصميم التعليمي للوسائط المتعددة استناداً إلى نظرية "سويلر" في تقليص العبء المعرفي وتنمية المفاهيم العلمية لدى الطلاب الصمّ في المرحلة الابتدائيّة

عالية العطيات*
جامعة تبوك، المملكة العربية السعودية

مستخلص: هدفت الدراسة إلى تقديم تصميم تعليمي للوسائط المتعددة وفقاً لنظرية "سويلر" واختبار أثره في تقليص العبء المعرفي وتنمية المفاهيم العلمية لدى الطلبة الصم في المرحلة الابتدائية. وقد تمت المزاوجة بين منهجي البحث الوصفي وشبه التجريبي. وتم الاعتماد على تصميم شبه تجريبي يتضمن ثلاث مجموعات إحداها مجموعة تجريبية أولى تدرس فصل "النظام الشمسي والنجوم والمجرات" باستخدام برمجية للوسائط المتعددة قائمة على مبادئ نظرية العبء المعرفي، ومجموعة تجريبية ثانية تدرس نفس المحتوى التعليمي باستخدام برمجية متعددة الوسائط غير قائمة على مبادئ النظرية، ومجموعة ضابطة تدرس بالكتاب المدرسي. وتم التطبيق على عينة قوامها ٤٨ طالباً من الصم في ثلاثة من معاهد الأمل في ثلاث محافظات: جدة، والمدينة المنورة، وتبوك؛ منهم ١٧ في المجموعة التجريبية الأولى، و ١٥ في المجموعة التجريبية الثانية، و ١٦ في المجموعة الضابطة. وتم استخدام اختبار المفاهيم العلمية، ومقياس NASA-TLX للعبء المعرفي كمتغيرات تابعة. وكشفت النتائج عن تفوق طلاب المجموعة التجريبية الأولى بشكل دال إحصائياً في تقليص العبء المعرفي وتنمية تحصيل المفاهيم العلمية مقارنةً بطلاب المجموعتين التجريبية الثانية والضابطة، بينما لم تكن هناك فروق دالة بين طلاب المجموعة التجريبية الثانية والضابطة في مستويات العبء المعرفي وتحصيل المفاهيم العلمية. وأوصت الدراسة بالاستناد إلى مبادئ نظريتي العبء المعرفي والتعلم من الوسائط المتعددة عند تصميم البرمجيات ومواقع الويب التعليمية لتعليم العلوم للصم.

الكلمات المفتاحية: التصميم التعليمي، الوسائط المتعددة، العبء المعرفي، المفاهيم العلمية، الصم.

*dr.aliahaa@gmail.com

Students with special needs represent an important population that has the right to receive the same educational opportunities as regular students. Providing opportunities for learning and acquisition of knowledge and scientific skills that would enable hearing impaired students to deal effectively and efficiently with the requirements of living in the current age.

According to Chan (2006), scientific concepts and their acquisition are critical for deaf students for the development of their scientific knowledge, enhancing their scientific skills, increasing their levels of self-esteem, and improving their self-concepts. Scientific concepts can also be viewed as the building blocks for the development of scientific thinking and science processes skills of deaf students.

Given deaf learners may encounter a varied set of problems within their learning due to their delayed language acquisition and inefficient reading comprehension skills, some researchers advocate the premise that employing multimedia would help this population understand and comprehend new knowledge as efficient as their typical counterparts (e.g. Martini, Castiglione, Bovo, Vallesi & Gabelli, 2015). Techaraungrong, Suksakulchai, Kaewprapan and Murphy (2017, p. 2) state: “Multimedia can be versatile in improving academic achievement of deaf learners." Debevc and Peljhan (2004), for instance, found that using ICTs technologies increase deaf learners' abilities to learn and understand, especially when instructional multimedia is designed in accordance with the specific needs of these learners. The desired effectiveness of employing multimedia in teaching deaf students, however, remains dependent on the efficiency of its instructional design that should take into account modern theories of learning, and adapt them to the unique characteristics and needs of these students.

In this respect, cognitive load theory developed by Sweller is one of the significant notions that would point the identification compass of the guiding principles of multimedia instructional design. When properly implemented, these guiding principles help instructional designers and teachers provide an instructional design that harness the full potential of working memory of learners, and at the same time design instruction commensurate with the nature of cognitive processing of students; thus reducing the cognitive load on their working memory and eventually improving learning (Sweller, Ayres, & Kalyuga, 2011). The theory assumes that cognitive load occurs when cognitive processing requirements exceed the capacities already available to students (Mayer & Moreno 2003). It is also presumed the existence of three sources of cognitive load: "Intrinsic cognitive load that is inherent in learning materials studied that are relevant to prior knowledge of learners, extraneous cognitive load resulting from poor instructional design, and germane cognitive load that is related to the cognitive system through the processes associated with the acquisition and automation of mental schemata or various learning activities" (Sass, 2016, p. 13).

Learning through multimedia has to be directed towards reducing the cognitive load of learners' working memory thus contributing to the achievement of better levels of learning. In this context, instructional designers would draw on several guidelines, including, for example, the methods of reducing cognitive burden proposed by many scholars concerned with cognitive load theory and its application, as well as the principles and methods stated by Mayer and Moreno (2001; 2003; 2005; 2009) for reducing cognitive load.

The literature review conducted by Techaraungrong, et al. (2017) points to the scarcity of scientific-based studies that focus on the considerations of multimedia design delivered to deaf students, while devoting their attention to the reduction of cognitive load through the process of designing these multimedia. In light of the above, the present study tries to fill this gap in literature related to employing cognitive load theory in the instructional design of multimedia used with deaf students.

Problem and Questions

As a category of special education population, learners with hearing disability have significantly different characteristics from their hearing peers. Their disability conditions pose problems that would affect their skills in linguistic, academic and social domains (Masitry, Majid, Toh & Herawan, 2013). Deaf students also suffer from obvious cognitive delay compared to their typical peers (Olson & Campbell, 2013). Specifically, numerous studies show that deaf students encounter various problems and difficulties in science education (learning) in particular (Akram, Mehboob, Ajaz & Bashir, 2013). Nevertheless, deaf students are expected to learn the curriculum following the same route of their hearing peers, they encounter problems resulting from their delayed language acquisition, that require an instructional design appropriate to their limited skills (Martini et al., 2015). The optimal solution to cope with such problems lies in instructional design commensurate with educational material delivered to deaf students. However, "Instructional design appropriate to the characteristics of deaf learners are among the most notable challenges facing their teachers" (Martini et al., 2015, p. 2).

There is a wealth of literature on cognitive load issues in the studies investigating multimedia design in general. However, "Existing literature that examines multimedia design considerations aimed at teaching deaf learners as well as how to design multimedia to support this population needs are very few in number to help draw any conclusive conclusions about these important issues" (Techaraungrong et al., 2017, p. 3). Yoon and Kim (2011) observed a paucity in studies that examine the application of cognitive load in designing multimedia delivered to deaf students.

In light of the expertise of the author in approaching the reality of deaf education in KSA, the author has observed the following: deaf students' poor acquisition of scientific concepts; the existence of negative attitudes among students towards learning science; students' suffering from problems related to the level of readability of science books; the lack of educational materials tailored to deaf students' needs; the absence of specialists in the instructional design for deaf students in general; the vast majority of multimedia related to science that can be used to enrich the education of deaf students does not consider their needs; and the fact that the few numbers of the multimedia available in sign language do not take into account the principles of good instructional design guided by contemporary learning theories such as cognitive load and multimedia learning theory.

The problem of the present study can be stated as follows: what is the effect of instructional design of multimedia aiming at reducing cognitive load on the development of scientific concepts among primary school deaf students? In order to address this main question, the study attempts to answer the following questions:

1. What are the main characteristics that must be available in multimedia in order to reduce cognitive load?
2. What is the instructional design of multimedia appropriate to reduce cognitive load of deaf students?
3. What is the effect of instructional design of multimedia according to cognitive load theory on reducing cognitive load among deaf students?
4. What is the effect of instructional design of multimedia for reducing cognitive load on the development of scientific concepts among deaf students (as a total degree and at the levels of memorizing, understanding, and applying)?

The first two questions will be answered in the course of reviewing the literature related to the subject of the study to determine the main characteristics that must be available in multimedia in order to reduce cognitive load, and the instructional design of multimedia appropriate to reduce cognitive load of deaf students. The third and fourth questions will be answered by collecting and analyzing the empirical data.

Significance

The present study can be of theoretical as well as practical significance. Theoretically, the importance of the study stems from the above cited paucity in research studies focusing on the application of cognitive load theory in designing multimedia delivered to deaf students; a field that is still in its infancy. Practically, however, the significance of the present study lies in informing science teachers of deaf students of the importance of considering cognitive load while teaching science as well as the effect of learning through cognitive load theory-based multimedia on the development of scientific concepts for this population. The study may also be beneficial for instructional designers who design learning software for deaf students. Moreover, the study devotes the attention of those in charge and policy makers in the ministry of education as well as those responsible on special education to the importance of providing learning materials commensurate with deaf students' needs that would help reduce cognitive load, thus improving their levels of scientific concepts acquisition.

Limitations

The following limits as guidelines to be adhered to in the application of the present study:

- The study is limited to the appropriate applicable principles of Mayer's multimedia learning theory and Sweller's cognitive load theory according to the characteristics of deaf students (modality effect, segmentation effect, coherence effect, signaling effect, spatial contiguity effect, temporal contiguity effect, redundancy effect, and spatial ability effect).
- Unit 8 "the solar system, stars and galaxies" of science syllabus taught to sixth-grade primary education.
- Levels of memorizing, understanding, and applying in scientific concepts achievement.
- The following dimensions of cognitive load: (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration).

Terminology

Instructional design: It is defined as a systematic process that involves analysis, design, development, application, and evaluation for the production of multimedia instructional software aimed at teaching the "solar system, stars and galaxies" module through employing cognitive load theory-based principles that are consistent with the deaf sixth graders needs

Multimedia: It is defined as a combination of texts, images, animations, charts, video clips, and some sign language clips that are specifically integrated to provide instructional content involving scientific concepts to teach deaf students.

Cognitive load: It is defined as the amount of mental effort exerted by deaf students when using multimedia learning software (provided to them). Its measurement includes the following dimensions**:** Mental Demand, Physical Demand, Temporal Demand, Performance-Effort and Frustration according to what is being measured by means of NASA-TLX scale**.**

Scientific concepts: They are defined as terms or symbols known to nominate objects, ideas or scientific elements that share a set of specific characteristics. Scientific concepts are measured via the degrees obtained by students participating in the pre- and post-administrations to scientific concepts test of the concepts involved in module 8 of sixth-grade science textbook entitled "Solar system, stars and galaxies”.

Literature Review

Deaf students encounter several difficulties in scientific concepts learning and acquisition. For instance, in comparing scientific concepts of deaf students to their hearing peers in fifth-grade, Akram et al. (2013) found that typical students were more efficient in scientific concepts compared to deaf students. It is argued that the embedded difficulties in learning scientific concepts are partially traced back to deaf characteristics, while others are due to the nature of science curriculum itself, and other difficulties are resulting from the adopted teaching methods. The lack of consistency in scientific vocabulary delivered through sign language, poor knowledge background of learners regarding scientific concepts and the existence of a significant gap in that background that makes it difficult to acquire new scientific knowledge, and the lack of scientific dialogue the students are being exposed to or involved in and the associated weakness of their vocabulary are some of the difficulties faced by deaf learners in learning science (Molander, Hallden, & Lindahl, 2010; Lang, Hupper, Monte, Brown, Babb & Scheifele, 2007).

Furthermore, deaf students encounter other difficulties in coping with science textbooks given their readability levels are far beyond deaf students' comprehension and learning abilities making it extremely difficult for them to learn effectively through these textbooks (Mastropieri, Scruggs & Graetz, 2005), in addition to the fact that "Many of the texts in science textbooks are written without taking into account the influence of presentation on cognitive processing system of learners, which may burden them with high levels of cognitive" (Haslam & Hamilton, 2010, p. 1717).

Multimedia targeting students with hearing disability encompass the same multimedia elements used with their typical counterparts with the exception of a unique element, i.e. the use of sign language as a main visual language for communication that includes body movements, facial expressions, and using hands and signs (Martini et al., 2015, p. 5).

It seems that language deficiency of deaf students hinders their capacity to access knowledge and information in different learning environments. In response, "Endeavors have been made to support them through the use of multimedia as learning materials to support their learning" (Yoon & Kim, 2011, p. 2). Several studies emphasize the importance of multimedia learning for students with hearing disability. For example, Walker, Munro and Richards (1998) found that learning materials provided to deaf students that involved texts, images, video clips, and graphic organizers that are associated with concise texts would enhance these students' achievement at levels of memorizing and understanding.

The results of many studies also revealed that employing multimedia technologies contributes to the development of science academic achievement for deaf students. The use of multimedia would provide visual stimulation that is, according to Chen (2014), "The main source of information for deaf students, since visual learning is the main learning channel for them" (p. 108). Beal-Alvarez and Cannon (2014) concluded that deaf learners fulfill numerous benefits from using multimedia in learning such as retaining the learning effect and understanding information delivered visually and verbally rather than this presented in printed form (p. 499). Moreover, Gentry, Chinn, and Moulton (2005) enumerate some of the benefits of employing multimedia in deaf education including, improving students' understanding of the subject material and developing language skills in light of providing the opportunity to access rich language experiences.

Although several studies emphasize the importance of using multimedia for deaf students, other studies point out that learning through multimedia has not achieved the desired effectiveness. For example, Delgado (2007) found that there was no significant difference in the development of verbal problem solving skills between students who studied through multimedia and those who did not. Similarly, Lin, Shen and Liu's (2015) study on employing multimedia in teaching science for Chinese fifth-grade students concluded that improper multimedia design due to the absence of CL principles would negatively affect learning.

This discrepancy in the results can be explained knowing that during the design and development of learning materials, instructional designers often fail to consider the limited working memory capacity of learners, which can be burdened with a cognitive load, compounded by the inherent burden of learning tasks (Sweller, 2005). Poorly designed learning materials that increase CL on students have negative impact on learning in light of their interference with cognitive processing and draining the limited working memory resources of students (Mayer & Moreno, 2003).

The problem is that, to give the impression of providing equal opportunities, multimedia is designed primarily for typical students and then provided with captions or video clips involving sign language after, rather than during, the production phase (Yoon & Kim, 2011, p. 9). Thus, "Adopting a systematic approach based on educational techniques and instructional design to be responsive to the needs of deaf during the development of learning materials is essential" (Yoon & Kim, 2011, p. 9).

Cognitive Load Theory:

In mid 1980s, Sweller laid the foundations of CLT. According to Paas, Tuovinen, Tabbers and Van Gerven (2003), CLT assumes that cognitive load (CL) associated with any learning task results primarily from intrinsic cognitive load (ICL) inherent in the nature of learning task and indicates the extent of its difficulty or complexity; and "Extraneous cognitive load (ECL) referring to requirements imposed on working memory that do not directly contribute to learning but rather to the structure of the task and relevant activities" (Meissner & Bogner, 2012, p. 128); in addition to a third CL, which is related to learning.

It is observed that while ICL is pertinent to the difficulty or complexity inherent in a learning task, ECL results from poor instructional design from the part of teacher/instructional designer (Meissner & Bogner, 2013). "GCL, however, refers to working memory resources the learner allocates to cope with ICL" (Sweller, 2010, p. 126).

Instructional Design in accordance with CLT

Instructional designers need to balance elements involved in multimedia to avoid the major challenge in designing multimedia, or "cognitive overload" in Mayer and Moreno's (2003) words. Marschark, Lang, and Albertini (2006) state that the materials, strategies, and learning environments designed for deaf students must take advantage of their strengths while compensating for their own needs (p. 220). They further add that "Learning materials should focus on students' visual-spatial strengths, and avoid reliance on text and reading skills requirements of these learners" (p. 210). Meissner and Bogner (2013, p. 24) state: "The purpose of CLT principles-based instructional design: (a) to provide learning tasks involving a prober level of ICL, (b) to work on minimizing ECL as possible, and (c) to activate GCL."

Before reviewing CLT applications in multimedia instructional design used with deaf students, however, Meyer's multimedia learning theory that provides an applied framework for employing CLT in instructional design will be outlined. Cognitive Theory of Multimedia Learning (CTML) developed by Meyer (2005) is based on three main assumptions derived from cognitive psychology.

The following paragraphs highlight the implications of both CLT and CTLM in multimedia instructional design in general prior to addressing the particular applications of the two theories in light of the special nature and educational needs of the deaf. Mayer and Moreno (2003, p. 46) enumerate some problems associated with multimedia learning that would increase CL levels as well as how to cope with these problems.

The following are some of the multimedia instructional design methods that address each type of CL:

- Minimizing ECL: Van Merriënboer and Sweller (2005) proposed a number of mechanisms (under the title of Redundancy effect) through which instructional designer would increase GCL through minimizing ECL. These mechanisms involve; "eliminating duplicate information sources; the sources that replicate the same content, modality effect that combines visual and verbal information simultaneously; and split attention effect that aims at avoiding distracting learner's attention in several directions by means of integrating of information sources to learner on the page" (p. 151).
- Minimizing ICL: this occurs primarily by adopting a structured method in the sequence of the learning material. To do this, Hao (2016, p. 27) summarizes three different approaches: "part-whole approach in which the sequence runs from the simplest to the most complex; whole-part approach that involves presenting the learning task as a whole and then learners focus on specific subtasks or subsections; and progressive approach involving presenting information in a gradual manner where only relevant steps or information are presented at the specific time making learners focus on learning without thinking on the full instructional structure".

Mayer (2014) has introduced many guidelines for multimedia design for learning purposes, albeit they lose their relevance when applied on deaf students. For instance, many of the principles of multimedia design consider text and sound crucial; since students, according to Mayer, learn better through words and graphs compared to learning from graphs only. For deaf students, however, who lack reading skills in comparison with their hearing peers the presumption may be difficult to apply. In addition, phrases like "the multimedia message enters the cognitive system through students' ears and eyes" (Mayer, 2014, p. 61) are irrelevant to deaf students who lack hearing completely.

Table 1
Minimizing CL through The Instructional Design Commensurate with Multimedia

Increased CL	Example	Solutions
One of the two cognitive channels is burdened with key processing requirements	Displaying an animation accompanied by an illustrative explanation	Reduce the load by omitting the text and replacing it with a narration
Both cognitive channels are burdened with processing requirements imposed on working memory	Providing an animation of a highly inherently complex narration due to its difficulty and rapid presentation of the instructional content	• Splitting (and allowing interval between shorter sections). • Delivering prior training regarding the names and characteristics of the elements included in the section
One or both channels are burdened with exogenous or contingent cognitive processes.	Providing an animation associated with narration or video clips inserted with examples	• Omitting exogenous material • Introducing prompts to help process scientific material
One or both channels are burdened with essential or situational processing (confusing presentation).	Displaying images at the top of the screen while text at the bottom.	• Alignment (placing the text near its images). • Eliminating redundancy by avoiding displaying duplicate information through writing and spelling at a time.
One or both channels are burdened with main processing (representational holding)	Narration followed by an animation.	• Synchronization: displaying narration and motion simultaneously. • Individualization: providing learners with necessary skills to construct mental representations

Visual and cognitive loads on deaf learners may easily increase in teaching and learning contexts through visual distraction or the need to divide attention between managing and coping with multiple visual sources of information such as the sign interpreter and the teacher (Cavender, Bigham, & Ladner, 2009). On the other hand, "Multimedia design for deaf students should consider the deficiency of the audio/video channel on which many theories and principles of multimedia design are based" (Techaraungrong et al., 2017, p. 3).

In light of the unique characteristics of sign language, multimedia involving the use of language would help reduce CL thus enhancing deaf learners' learning (Emmorey & Wilson, 2004). "Human working memory copes with sign language as being visual and phonological inputs that stimulate different components of cognitive system, which means that students with hearing disability handle sign language in similar way to their typical peers coping with spoken language within working memory space. Teachers of students with hearing disability are therefore obliged to adhere to the sound principles of multimedia instructional design based on the nature of their students' cognitive processes within their working memory" (Martini et al., 2015, p. 6).

In order to minimize CL on deaf students, some of Mayer's (2014) principles can be applied that include avoidance of exogenous and distracting content, using references to point to important points in instructional material, and presentation of instructional materials strategically on the screen. With regard to basic and generative processing or for CL related to learning, some recommendations made by Mayer (2014) that are relevant to deaf learners may be helpful, including splitting multimedia into sections learners can control, using human facial expressions, and employing eye movements and glances.

The results of many studies revealed that adoption of CLT in teaching science would contribute to achieve several positive outcomes such as reducing CL, increasing learning level, and the acquisition of scientific concepts (Lin et al., 2015). For example, the results of an empirical study on 23 deaf high school students in Taiwan revealed the positive impact of 3D virtual learning environments that consider CL on minimizing CL, developing spatial concepts and spatial sense among students with hearing disability (Lin, Wang, Hung & Lin, 2010).

The results of an intervention study conducted by Nikolaraizi et al. (2013) reported that CL on deaf learners can be minimized in addition to developing their reading comprehension through the use of multimedia. In this study that involved 8 deaf learners, multimedia components including e-texts, conceptual maps, images, and videos were employed along with sign language. In order to minimize CL, the following considerations were taken into account: concept maps would show the main elements and ideas included in the text; the images must be accompanied by the text and display the relationships between the different information; and the software should not allow students to access more than one particular visual component at the same time to avoid burdening the working memory with multiple sources that replicate each other.

Recently, the attempt was made in Techaraungrong's, et. al (2017) study to identify and examine the extent of effectiveness of employing CLT in teaching mathematics for seventh-grade deaf students in Thailand. Considerations targeting minimizing CL guided multimedia design used in the study. The intervention took 16 weeks in which students studied some sessions using the specifically designed multimedia. The findings related to design included characteristics like: non-basic use of text, reliance on non-symbolic objects, providing users access to control, and references to relevant instructional content. It was also found that learning through multimedia designed to minimize CL has resulted in higher scores in learning compared to teacher-led teaching.

Method

This study used an extension of quasi-experimental design; that is pre-test/post-test experimental-control groups. The adopted experimental design involved two experimental groups; the first studying "the solar system, stars, and galaxies" modules using multimedia software designed based on CLT, while the second studied using multimedia software with no consideration to CLT; and a control group that studied through the usual textbook method.

Population and sample

The study has been conducted on a population involving all male and female sixth-grade students of 6 "Al-Amal Institutes for the Deaf" at Jeddah, Madinah and Tabuk. After excluding dropouts and those who did not complete the experiment, the final sample consisted of 48 male and female students divided into three groups: 17 students for the first experimental group, 15 students for the second experimental group, and 16 students for the control group.

Instruments and intervention

Scientific concepts test: in order to develop this test to measure scientific concepts relevant to instructional content, the researcher did the following steps:

1. Determining instructional content of interest: module 8 of the 2nd semester textbook taught to sixth-grade students "the solar system, stars and galaxies".
2. Behavioral objectives have been set at three levels: memorizing, understanding, and applying.
3. A specifications table for scientific concepts test has been developed and distributed according to the relative weights of content and objectives.
4. Test items development: multiple choice format has been used, where each item has one correct answer with total number of 30 items.
5. Verifying validity of the test: Face validity has been utilized to verify validity of the test through presenting it to a set of jury members specializing in curricula and science instruction, as well as some supervisors and teachers with expertise in teaching science for deaf students in order to verify the precise of the test according to the above specifications table.
6. Determining test correction method and instructions: instructions regarding the test, its administration, and a key to correct its items have been pointed out. Each correct answer was given one point while no points was awarded for an incorrect answer, and thus the total score of the test had been 30 points.
7. Verifying the coefficients of difficulty and discrimination: difficulty coefficients have been calculated for the pilot sample and the results ranged between 0.41 to 0.61, thus difficulty level was considered acceptable according to levels determined by specialists in measurement and evaluation. Discrimination coefficients were approximately between .47 to .66 thus all test items were accepted in terms of degree of discrimination.

8. Verifying the test reliability: scientific concepts achievement test was verified to be reliable using alpha Cronbach on a pilot sample consisting of 19 students. Reliability coefficients were found to be high, ranging between 0.65 to 0.89 with overall reliability coefficient of 0.93, which means that test items enjoy a high level of reliability.

CL Scale: the short version of NASA-TLX scale[1] was utilized to measure CL. The researcher translated the scale into Arabic and then to sign language. The scale included the following dimensions: Mental demand, physical demand, temporal demand, performance, effort and frustration.

Validity of the scale within the study has been verified on a pilot sample consisting of 19 deaf students by means of calculating Pearson correlation coefficient between the degrees of each dimension and the total degree of the scale. The results ranged between 0.70 to 0.81, which indicates that all correlation coefficients between each dimension degree and the total score of the scale have been statistically significant (p 0.01), thus proving internal consistency for all sub-dimensions included in CL scale. In addition, the reliability of CL scale has been verified by calculating alpha Cronbach's; with results ranging between 0.78 and 0.88 for the scale dimensions; and 0.89 for overall reliability of the scale, which is also a high value thus affirming that the scale enjoys an appropriate degree of reliability.

Multimedia Instructional Design

The model that involves analysis, design, development, implementation, and evaluation (ADDIE) stages has been adopted to design two types of multimedia software designed to teach the "solar system, stars and galaxies" module. The first multimedia software design-that used with students of the second experimental group- followed the ADDIE model steps and the content of the module was delivered through direct instruction of content along with a video clip involving embedded sign language within the display. In the second multimedia software design, however, CLT principles as well as some proper multimedia learning principles developed by Mayer were taken into consideration. These considerations included the following:

1. Shortening written texts as much as possible.
2. spatial proximity of written texts, images and illustrations.
3. Providing hints (prompts) for key ideas in the presentation of the scientific material.
4. Reducing situations in which video clips contain sign language and written texts simultaneously, so that either sign language or written text is used.
5. Splitting the presentation into segmented sections that learners can easily learn and control.
6. Attention to make presentation speed appropriate to enable learners to control it.
7. Utilizing conceptual maps to help students make linkage between different concepts.
8. Using human facial expressions to clarify and give feedback to students.
9. Excluding instructional content irrelevant to objectives.
10. Providing students with prior training on the nominates of the main scientific concepts contained in the unit.
11. Following a sequence in the presentation of scientific material from simple to complex.

Results and Discussion

Questions 1 & 2 of the present study have been answered by reviewing literature and procedures. Based on literature review, the instructional design of multimedia used with deaf students should take into account the following principles: modality effect, segmentation effect, coherence effect, signaling effect, spatial contiguity effect, temporal contiguity effect, redundancy effect, and spatial ability effect. In what follows, the results of the remaining questions are presented.

Results of question three
To answer this question, One Way ANOVA was utilized.

[1] (available on http://jensgrubert.bplaced.net/nasa-tlx-short/TLX-English-short.html)

Results presented in table 2 indicate the existence of statistical significant differences at the level (0.01) among the three groups on the mean scores of the six dimensions and total score of CL scale. In order to detect the source of differences among mean scores of participating students, a Scheffe test was utilized.

The results indicate that there are statistical significant differences at the level (0.01) of significance between the mean scores of the first and second experimental groups in favor of the first experimental group in the total score as well as all dimensions of CL scale.

Results of question four

There are also statistical significant differences at the level (0.01) of significance between the mean scores of the first experimental group and the control group in favor of the first experimental group in the total score and all dimensions of CL scale.

Table 2
Results of Analysis Of Variance Test for the Significance of Differences among the Average Scores of the Participants in the Post-Administration of CL Scale

Dimensions	Source of variance	D F	Mean square	F value
Mental Demand	Among groups	2	40.025	34.028*
	Error (within groups)	45	1.176	
	Total	47		
Physical Demand	Between groups	2	37.033	24.652*
	Error (within groups)	45	1.502	
	Total	47		
Temporal Demand	Between groups	2	40.644	38.084*
	Error (within groups)	45	1.067	
	Total	47		
Performance	Between groups	2	49.844	39.831*
	Error (within groups)	45	1.251	
	Total	47		
Effort	Between groups	2	44.373	39.489*
	Error (within groups)	45	1.124	
	Total	47		
total	Between groups	2	38.530	29.017*
	Error (within groups)	45	1.328	
	Total	47		

* $p < 0.01$

Table 3
Sheffe Test for the Detection of Source of Differences According to the Participating Groups (i.e. First Experimental, Second Experimental, and Control Groups) in the Post-Administration of CL Scale

Scale dimensions	Group	Mean	1st experimental	2nd experimental	control
Mental Demand	1st experimental	8.765	-	-	-
	2nd experimental	6.067	2.698*	-	-
	control	6.063	2.702*	0.004	-
Physical Demand	1st experimental	8.588	-	-	-
	2nd experimental	6.133	2.455*	-	-
	control	5.875	2.713*	0.258	-
Temporal Demand	1st experimental	8.941	-	-	-
	2nd experimental	6.333	2.607*	-	-
	control	6.125	2.816*	0.208	-
Performance	1st experimental	8.941	-	-	-
	2nd experimental	6.067	2.874*	-	-
	control	5.813	3.128*	0.254	-
Effort	1st experimental	8.647	-	-	-
	2nd experimental	5.733	2.913*	-	-
	control	5.875	2.772*	0.141	-
Frustration	1st experimental	8.647	-	-	-
	2nd experimental	5.933	2.713*	-	-
	control	6.063	2.584*	0.129	-
Total	1st experimental	52.529	-	-	-
	2nd experimental	36.267	16.262*	-	-
	control	35.813	16.716*	0.454	-

* $p < 0.01$

Table 4
Results of Analysis of Variance Test for the significance of Differences among the Mean Scores of the Participants in the Post-Administration of Scientific Concepts Test

Test levels	Source of variance	DF	Mean square	F value
Memorizing	Between groups	2	69.754	22.146*
	Error (within groups)	45	3.150	
	Total	47		
Understanding	Between groups	2	29.800	23.856*
	Error (within groups)	45	1.249	
	Total	47		
Applying	Between groups	2	16.388	17.925*
	Error (within groups)	45	0.914	
	Total	47		
Total score	Between groups	2	318.934	49.987*
	Error (within groups)	45	6.380	
	Total	47		

* $p < 0.01$

Table 5
Sheffe Test for the Detection Of Source of Differences in the Mean Scores of Students in Scientific Concepts Test

Test levels	Group	Mean	1st experimental	2nd experimental	control
Memorizing	1st experimental	12.176	-	-	-
	2nd experimental	8.667	3.509*	-	-
	control	8.563	3.614*	0.104	-
Understanding	1st experimental	7.941	-	-	-
	2nd experimental	5.667	2.274*	-	-
	control	5.563	2.378*	0.104	-
Applying	1st experimental	5.824	-	-	-
	2nd experimental	4.133	1.690*	-	-
	control	4.063	1.761*	0.0708	-
Total score	1st experimental	25.941	-	-	-
	2nd experimental	18.467	7.474*	-	-
	control	18.188	7.753*	0.279	-

* $p < 0.01$

In order to answer this question, ANOVA was used.

The results of Table 4 show that there are statistical significant differences at the level (0.01) of significance among the three groups on the mean scores for the levels of memorizing, understanding and applying as well as for the total score of scientific concepts test. Sheffe test was utilized with the purpose of detecting the source of differences among mean scores of the groups.

The results presented in the table reveal the existence of statistical significant differences at the level (0.01) of significance between the mean scores of the first and second experimental groups in favor of the first experimental group in the total score and sub-levels of scientific concepts test. Statistical significant differences at the level (0.01) of significance are also found between the mean scores of the first experimental group and the control group in favor of the first experimental group the total score and sub-levels of scientific concepts test.

Discussion

From these findings, it is clear that there is a high correlation between CL and scientific concepts achievement. The lower the CL the higher achievement and acquisition of scientific concepts and vice versa; whenever CL increased, the achievement and acquisition of scientific concepts are decreased. These results are confirming the main assumptions of CLT (Sweller et al., 1998; Sweller, 2005, 2010), and emphasize, at the same time, the precise assumptions upon which CTML stands, in light of proving that CL on student's working memory is a hindering for factor learning if exceeded the required limit. Thus, instructional design of educational materials that reduces CL would enhance the effective learning of scientific concepts due to the increased knowledge resources made available to learner to cope with and learn scientific material efficiently.

The results of the present study extend the generalizability of these reached by previous related studies in terms of the positive impact of CL principles-based multimedia learning (e.g. Techaraungrong et al., 2017; Martini et al., 2015; Lin et al., 2010); specially in concluding that CLT-based instructional design would contribute to significant minimizing of CL.

The results extracted from the study regarding the positive impact of multimedia based on CLT in its instructional design on scientific concepts achievement are also in consistence with those conducted with deaf and non-deaf students (e.g. Techaraungrong et al., 2017; Martini et al., 2015;). It was found that providing multimedia for students is not sufficient for the development of scientific concepts achievement for deaf students given the poorly designed multimedia would increase CL thus hindering learning. This can be justified within the study knowing that students' learning of scientific concepts drawing on written texts accompanied by sign language had burdened the learners' working memory and drained its limited resources, which hindered learners from learning scientific concepts effectively.

Moreover, the control group students have not achieved success in learning scientific concepts because of the problem embedded in the textbook that is primarily designed for hearing students who do not encounter language problems or other knowledge delay problems facing deaf students. Thus, control group students encountered difficulties in coping with a substantial amount of texts that, besides failure to consider CLT principles, involve readability levels exceeding students' restricted language capacities, such as occasional spacing among texts, charts, and images, displaying redundant instructional content, and the inability to employ many multimedia elements effectively.

In the group taught using multimedia designed in accordance with CLT, however, several principles contributing to minimizing CL were considered thus provided further resources that fed into improving overall levels of scientific concepts acquisition. There was no redundancy (resulting from displaying the same material via two different formats), and deaf students did not have to divide attention among divergent sources. The redundant irrelevant texts were eliminated as well with focusing attention to main ideas, which contributed to more in-depth and less draining processing of the available resources.

Recommendations

Based on the results of this study, the researcher offers the following recommendations:

1. Building on CLT and CTML principles in the design of software, packages, and instructional websites targeting deaf students.
2. Working toward minimizing CL sources when teaching the deaf whether in regular classrooms or through e-learning software.
3. Assessing to what extent textbooks provided to deaf students contribute to increasing CL and striving to modify these books.
4. Examining the effect of instructional design for reducing CL on the development of other variables such as correcting misconceptions and enhancing attitudes towards science learning.
5. Conducting a diagnostic-treatment study to analyze the content of deaf curriculum in light of CL sources.
6. Investigating the relationship between CL levels associated with deaf students' learning and their alternative concepts.

References

Akram, B., Mehboob, R., Ajaz, A., & Bashir, R. (2013). Scientific Concepts of hearing and deaf students of grade VIII. *Journal of Elementary Education*, *23*(1), 1-12.

Beal-Alvarez, J., & Cannon, J. (2014). Technology intervention research with deaf and hard of hearing learners: levels of evidence. *American Annals of the Deaf, 158*(5), 486–505.

Cahn, R. (2006). *Help your children learn science with science made simple*: Retrieved from www.sciencemadesimple.com/science definition.html.

Cavender, A., Bigham, J., & Ladner, R. (2009). ClassInFocus: enabling improved visual attention strategies for deaf and hard of hearing students. In *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility*, ACM,NewYork, NY, 67–74. doi:10.1145/1639642.1639656

Chen, Y. (2014). A study to explore the effects of self-regulated learning environment for hearing-impaired students. *Journal of Computer Assisted Learning, 30*, 97–109. doi:10.1111/jcal.12023.

Debevc, M., & Peljhan, Z. (2004). The role of video technology in on-line lectures for the deaf. *Disability and Rehabilitation, 26*(17), 1048–1059.

Delgado, A. M. (2007). *The effects of multimedia technology on the learning of math story problems of elementary and middle school deaf students*. Lamar University-Beaumont.

Emmorey, K., & Wilson, M. (2004). The puzzle of working memory for sign language. *Trends in Cognitive Sciences, 8*(12), 521-523.

Gentry, M. M., Chinn, K. M., & Moulton, R. D. (2005). Effectiveness of multimedia reading materials when used with children who are deaf. *American Annals of the Deaf, 149*(5), 394-403.

Hao, S. (2016). *Effects of faded scaffolding in computer-based instruction on learners' performance, cognitive load, and test anxiety* (Order No. 10120526).

Hodson, J. L. (2016). *Measuring cognitive load: A meta-analysis of load measurement sensitivity* (Order No. 10157387).

Lin, C. Y., Wang, L. C., Hung, P. H., & Lin, C. C. (2010, August). Reducing cognitive load through virtual environments among hearing-impaired students. In *Circuits, Communications and System (PACCS), 2010 Second Pacific-Asia Conference on* (Vol. 1, pp. 183-186). IEEE.

Marschark, M., Lang, H., & Albertini, J. (2006). *Educating deaf students: From research to practice*. US: Oxford University Press.

Martini, A., Castiglione, A., Bovo, R., Vallesi, A., & Gabelli, C. (2015). Aging, cognitive load, dementia and hearing loss. *Audiology & Neurotology, 19*, 2-5.

Mayer, R. (2009). *Multimedia learning* (2nd ed.). New York: Cambridge University Press.

Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31-48). New York, NY: Cambridge University Press.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38,* 43–52.

Meissner, B., & Bogner, F. X. (2012). Science teaching based on cognitive load theory: Engaged students, but cognitive deficiencies. *Studies in Educational Evaluation*, *38*(3), 127-134.

Nikolaraizi, M., Vekiri, I., & Easterbrooks, S. R. (2013). Investigating dead students' use of visual multimedia resources in reading comprehension. *American Annals of the Deaf, 157*(5), 458-73.

Olson, A. D., & Campbell, S. E. (2013). Degree of hearing loss and working memory in adults. *University of Kentucky*.

Paas, F., G., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*(1), 63–71. From: http://dx.doi.org/10.1207/S15326985EP3801_8

Sweller, J. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 19–30). New York: Cambridge University Press.

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review, 22*, 123-138. http://dx.doi.org/10.1007/s10648-010-9128-5

Sweller, J., Ayres, P., and Kalyuga, S. (2011). *Cognitive load theory*. New York: Springer.

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

Techaraungrong, P., Suksakulchai, S., Kaewprapan, W., & Murphy, E. (2017). The design and testing of multimedia for teaching arithmetic to deaf learners. *Education and Information Technologies*, *22*(1), 215-237.

Walker, L., Munro, J., & Richards, F. W. (1998). Teaching inferential reading strategies through pictures. *Volta Review*, *100*(2), 105-20.

Yoon, J. O., & Kim, M. (2011). The effects of captions on deaf students' content comprehension, cognitive load, and motivation in online learning. *American Annals of the Deaf*, *156*(3), 283-289.