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INVESTIGATING THE EFFECTIVENESS OF VIDEOS DESIGNED USING COGNITIVE LOAD THEORY ON BIOLOGY STUDENTS' ACADEMIC ACHIEVEMENT

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ABSTRACT

This study seeks to investigate the effect of videos designed based on cognitive load theory on students' academic performance. A one-group pre-test-post-test design was employed, with 25 lower sixth Biology students from one of the sixth form centres in Brunei as participants of the study, conveniently selected (non-random sampling). Twelve cycles of lessons on 12 different biology topics were conducted; for each cycle, a pretest was administered before students watched the videos (self-learning), followed by a posttest after the videos were watched. This study found a significant increase in test scores after students watched the videos for all of the cycles, with a large effect size ranging from .76 to .93 according to Cohen's interpretation. The study shows how the cognitive load theory can help instructional designers create better learning content to encourage student learning. It can therefore be concluded that carefully curated videos are able to help reduce students' extrinsic load. Thus, this finding has implications for the importance of theory-based video creation in helping students' learning that most technologically innovative pedagogies seem to leverage on. One recommendation for future study worth delving into would be to directly measure students' comparative cognitive load to investigate how their cognitive load changes before and after watching videos.

Keywords: academic achievement; cognitive load theory; video

INTRODUCTION

Technological advances over the past decade have especially changed the way we teach, with educators having attempted several ways to innovate traditional teaching. Pedagogical approaches such as the flipped classroom is one example of such innovation that has incorporated technology into learning. To date, the use of videos appears to be the most common / popular strategy for content delivery, as reported in flipped classroom research (van Alten et al., 2019). In a review of the flipped classroom by van Alten, et al. (2019), of the 114 papers included in their review, 95% of the studies used videos to deliver content outside of class. Therefore, to date, the use of videos appears to be the most common strategy for content delivery in flipped classroom research. Considering this, it has been recommended that future researchers investigate how video features affect learning in the flipped classroom (Turan & Goktas, 2016).

This study seeks to investigate the effect of videos designed based on cognitive load theory on students' academic performance. A meta-analysis of the effect of technology in classrooms has shown the benefits of using technology to support active learning (Schmid et al., 2014). For instance, Stockwell et al. (2015) specifically investigated the use of videos in science education. The authors reported improved student satisfaction and attendance of those learning from videos compared to those who learned traditionally. The authors concluded that using videos to deliver the groundwork before active learning in class is more efficacious than traditional methods, specifically for science teaching.

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In a review of the use of videos in education by Kay (2014), several benefits of using videos were reported in the literature, including the ability to prepare for class, the flexibility of learning in terms of time, pace and location, and students' ability to watch the recorded lectures if they were absent from class. It was also reported that students were able to take notes and understand fundamental concepts before class, thus improving face-to-face learning. It is compelling to note that these benefits were reported even before the rapid surge of flipped classroom research. A study by Gouia & Gunn (2016) investigated students' type of video preference to help provide recommendations for preparing self-made videos. The authors investigated the length of the videos and the depth of explanations given (i.e. concise and brief explanations versus detailed descriptions). They also explored presentation styles, such as whether the teacher was visible or not, and whether the video used an electronic screen or used handwritten notes with narration. However, the study failed to find any specific preferences for videos. This shows that, even though the available literature has shown that students enjoy videos, the research on instructional video preference and—better yet—the production of videos are still in their infancy. Nevertheless, theories such as the cognitive load theory can inform the production of videos. The theory can be used as the theoretical lens as it is an instructional design theory that considers learners' cognitive architecture, thus maximizing student learning. Fyfield et al. (2019a) suggested that researchers adopt a theoretical lens to understand and develop educational approaches that comprise the use of videos. In another paper, Fyfield et al. (2019b) outlined 25 principles for designing instructional videos curated based on the cognitive theory of multimedia learning, which is based on the cognitive load theory. The authors stated that the principles laid out could be used as the first step in designing videos that consider learners' cognitive architecture.

A recent study demonstrated the efficacy of using cognitive load theory principles to design online lectures (Hadie et al., 2021). They found increased student understanding of content and increased self-perceived learning. A specific measurement of students' cognitive load revealed a reduction of intrinsic and extrinsic load, predicted to be induced by the effects of cognitive load theory. Thus, this study leverages on the cognitive load theory as the basis of designing videos to support students' learning in biology and to determine the effectiveness of the videos on students' academic achievement.

Cognitive load theory was introduced as an instructional design theory (Sweller, 1988). The 1988 model of the theory initially ascertains three forms of cognitive load: intrinsic, extraneous and germane load. The 1988 model, however, was revised recently, whereby the germane load is no longer part of the equation for the total cognitive load (Sweller et al., 2019; Skulmowski & Xu, 2021); Skulmowski & Xu (2021) calls this revised model the 2019 model. The intrinsic load relates to the inherent difficulty of the content to be learned. Good instructional sequencing can manage the intrinsic load, where the content elements are introduced in a simple-to-complex sequencing (Van Merriënboer et al., 2003). However, some researchers argue that instructional design cannot alter the intrinsic load because it is related to the characteristic complexity of the content (De Jong, 2010). On the other hand, extrinsic load refers to the load caused by the instructional strategy used to teach it. Accordingly, the total cognitive load relates to the total amount of information an individual can hold in their working memory at any given time. De Jong (2010) states that "learning is hampered when working memory capacity is exceeded in a learning task" (p. 106). Therefore, educators should focus on the extrinsic cognitive load, which can be manipulated and reduced using sound instructional design.

An excellent instructional design for novice learners seeks to provide a concise and structured content presentation (Mancinetti et al., 2019). Hence, the extrinsic load should be minimized during learning to aid schema acquisition; below are some factors that affect this extrinsic load that are relevant to this study. The current study contributes to the flipped classroom literature, accentuating the significance of producing well-designed videos with a sound underpinning of instructional design theory.

In a study by Sweller & Cooper (1985), students studying worked examples outperformed those who learned by problem-solving. The worked example group solved similar problems more rapidly than students required to solve problems themselves. The evidence that learning may be decelerated by problem-solving substantiated that learning from worked examples may be a good alternative in order to improve student learning. In addition to that, the worked example group was also better able to apply what they had learned to transfer problems. Consequently, the concept of the worked example effect was born.

Research has pointed out that problem-solving becomes superior to studying worked examples when students have developed their own schemata (Bokosmaty et al., 2015). In other words, studying from worked examples becomes redundant once expertise is achieved and can even harm their learning; this is called the expertise reversal effect (Pachman et al., 2013).

Sweller and colleagues continued to revise the cognitive load theory, noting that a particular format of worked examples can be ineffective. The split-attention format likely increases element interactivity, diverting learners' attention away from schema construction (Sweller et al., 2011a). Therefore, "if written text is used, it must be positioned next to its referents, or in the case of spoken text, it must be synchronized with the visual representation" to avoid loss of learning (Sweller et al., 2011a, p. 128).

The modality effect was derived from the split-attention effect. This instructional approach uses two learning modalities, the visual and auditory modalities, which can reduce the extrinsic load and enhance learning (Talip et al., 2021).The redundancy effect occurs when multiple sources are used to provide similar information, leading to an increase in extrinsic cognitive load (Kalyuga et al., 1998). Delivering complex concepts in their fully interactive form has been shown to increase intrinsic cognitive load, hampering novices' learning (Sweller et al., 2011b). The isolated-interacting elements—otherwise known simply as the isolated elements effect—occurs when learning is aided by providing complex information sequentially in isolation to reduce element interactivity and hence reduce the intrinsic cognitive load. According to the theory, isolating elements during an early stage of learning helps students acquire difficult concepts (Sweller et al., 2011b).

The instructional implication suggests presenting elements in isolation to reduce intrinsic cognitive load and subsequently lead to better learning. Once concepts are learned in isolation and stored in long-term memory, learners would then just have to learn how to integrate all the isolated elements and understand the content as a whole (Sweller et al., 2019). The same results were obtained by Ayres (2006), indicating that the isolated element effect was only seen in students with low prior knowledge. On the other hand, students with high expertise benefited more from studying elements with high interactivity rather than in isolation. Learning from worked examples has been shown to reduce the extrinsic load and benefit novice learners. However, once learners gain expertise, the intrinsic load should be increased to encourage transfer skills. This can be done by introducing a variety of examples, which then leads to the variability effect (Sweller et al., 2011b).

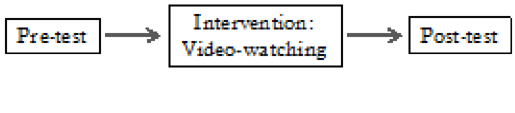
The self-explanation effect is practical when coupled with the use of worked examples. Students must explain how to derive the solutions to problems while ensuring the worked examples are carefully studied (Sweller et al., 2019). According to Sweller et al. (2011b), expert learners may benefit from self-explanation more than novice learners as they already have the prior knowledge in their long-term memory. This means that the self-explanation effect can only be seen if the learner has prior knowledge.

The collective working memory effect is one of the newer effects added to the cognitive load theory, first described by Kirschner et al. (2009). Upon viewing collaborative learning from a cognitive load theory perspective, learning collaboratively is only advantageous if the group task is complex. Students in a group can combine each individual's limited working memory and be considered as a single information processing system (Sweller et al., 2019). However, Kirschner et al. (2009) stated that the additional cognitive effort due to coordination and communicating with peers needs to be considered. They call this the 'transaction cost'. If the transaction cost exceeds the benefits of distributing the high intrinsic load of the learning task among group members, then learning would not be as efficient.

The transient information effect is another cognitive load effect in its infancy. Sweller et al. (2011c) defined the transient information effect as "a loss of learning due to information disappearing before the learner has time to adequately process it or link it with new information" (p. 220). Examples of this would be spoken texts and the use of animations. Information with low element interactivity would not be affected by the transient information effect as the transient information can be held easily in working memory. In contrast, the transient information effect would be evident when information learnt is complex with high element interactivity, leading to cognitive overload. This is especially evident when complex information is delivered as a lengthy spoken text.

METHODS

The participants were 25 lower sixth students from one of the sixth form centers in Brunei. The study adopted a one-group pre-test-post-test design, and the participants were conveniently selected (non-random sampling).



Only convenience sampling was possible because the researcher had access to only two biology classrooms during the data collection phase. All students gave their consent to participate in the study. Prior to the study, all participants had previous experience of learning through asynchronous videos from home-based learning due to the first wave of the COVID-19 pandemic in Brunei Darussalam. All of the data from the student participants in this study were collected after the first wave and before the start of the second wave (June 2020 – October 2020).

The study adopted a one-group pre-test-post-test design, which included the collection of pre-test scores before students watched the video. The posttest was administered the next day after students watched the video. The type of educational video was a lecture screencast, with audio narrations accompanying a visual PowerPoint presentation. All pretests and posttests used in the study were gathered from Cambridge's 9700 Biology past year papers. Past year papers were used to ensure construct validity: the extent to which the tests accurately assess what they are intended to measure. The assessment format includes short and long answers to test students' knowledge on a specific concept and reflect their higher-order thinking. To assess the validity of the test questions used in the research, the questions were shown to a biology teacher in one of the sixth form centers for face validity. This ensured that the content of the tests represented what it was aimed to measure (Heale & Twycross, 2015).

Since the sample size of this study is small (N=25), determining the distribution of differences in test scores (between posttest and pretest, delayed posttest and posttest, and delayed posttest and pretest) was essential for choosing an appropriate statistical method. Hence, a Shapiro-Wilk test was performed. Numerically, the Shapiro-Wilk test conducted on SPSS showed that most of the differences in test scores were not normally distributed. This was also confirmed graphically by looking at the distribution of differences in test scores on histograms.

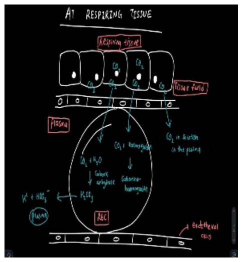
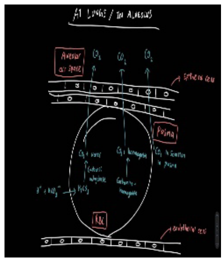
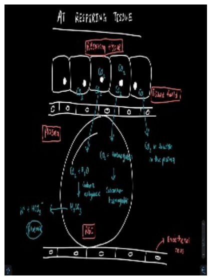
Shapiro-Wilk tests showed that none of the differences in test scores for cycle 7 were normally distributed. In cycles 3, 5 and 11, the differences in test scores between delayed posttest and pretest and delayed posttest and posttest were also not normally distributed. However, the differences in test scores between posttest and pretest were indeed normally distributed. Meanwhile, for cycle 8, the differences in test scores between delayed posttest and posttest as well as posttest and pretest were not normally distributed, while the differences in scores between delayed posttest and pretest were normally distributed. For cycles 1, 2, 6, 10 and 12, the differences in test scores between delayed posttest and posttest were not normally distributed, in contrast to the differences in test scores between posttest and pretest in addition to delayed posttest and pretest, which were normally distributed. For cycle 4 and 9, all the differences in test scores were normally distributed. Even though some of the differences in test scores were normal, this study will be using the nonparametric test as most of the cycles had violated the parametric test assumptions. The Friedman test with Wilcoxon signed-rank post hoc tests was performed on the data, and pairwise exclusion was used when analyzing the data. The following sections present the findings of the Friedman test with Wilcoxon signed-rank post hoc for each of the 12 flipped classroom cycles.

The researcher recorded all of the lecture videos on an iPad using the Zoom application to capture the PowerPoint presentation shown on the screen. The researcher annotated using the pen annotation feature on Microsoft PowerPoint to aid teaching. The pre-recorded videos were then uploaded to YouTube, which students could access and learn from at their own pace – a form of asynchronous learning. A total of 12 pre-recorded videos were developed to address some of the most fundamental concepts/learning objectives in the Cambridge Biology Advanced Subsidiary (AS) syllabus.

The selected topics chosen for the flipped classroom intervention were topics on prokaryotes, cell surface membrane, endocytosis and exocytosis, mitosis, DNA replication, protein synthesis, apoplastic and symplastic pathway, loading of sucrose, initiation of heartbeat, role of haemoglobin in carrying oxygen and carbon dioxide, modes of action of B and T-lymphocytes and the production of monoclonal antibodies. These selected topics are complex and challenging for learners to understand, due to the abstract nature of the concepts.

All of the 12 pre-recorded videos were kept concise with only the fundamental concepts included to reduce the extrinsic cognitive load. Below is an illustration of how the content of the video was designed in accordance with cognitive load theory.

Table 1. Video Design Consideration in Accordance with Cognitive Load Theory

Main cognitive considerations	Strategies for managing cognitive load	Example of reference in the video (selected frames from the pre-recorded video)
Modality effect	The selected frame shown is a self-drawn diagram summarising the highly complex concept of the role of haemoglobin in transporting carbon dioxide. The aim is to obtain a modality effect here by allowing participants to learn from visuals supplemented with narration (no lengthy texts except for short annotations). Using audio and visual modalities increases working memory capacity by reducing extrinsic load.	
Split-attention effect	The aim is to reduce the split-attention effect. All text annotations were integrated with the diagram to reduce cognitive load, therefore eliminating learners' need to split their attention between text and diagrams.	
Redundancy effect	The aim is to reduce the redundancy effect by removing unnecessary text on the slide (except for short annotations), as narrating paragraphs of text would be redundant. Using a single self-explanatory diagram is appropriate for use in a plenary at the end of the lecture.	

RESULTS AND DISCUSSION

A Wilcoxon signed rank test was conducted on the students' pre-test and post-test scores for each cycle as the data was not normally distributed. Below is the summary of the findings.

Table 2. Results of Students' Academic Achievement for the 12 Topics

Topic	Median of Pre-test score	Median of Post-test score	P-value	Effect size, w
1	4	9	P < .001	.92
2	4	11		.85
3	3	8		.92
4	2	6		.91
5	1	9		.88
6	1	8		.89
7	2	9		.93
8	1	7		.91
9	1	8		.87
10	2.5	7		.79
11	0	2		.76
12	3	7		.85

As indicated by the table above, there was a statistically significant difference in the gain score of the students from pretest to posttest for all cycles with large effect size according to Cohen's d interpretations. Descriptive statistics also showed an increase in the median scores from the pretest to posttest for all cycles.

In biology, novel content commonly includes new concepts, theories, and scientific jargon made up of many elements. Often, all of these fundamental and interrelated concepts need to be processed concurrently in the working memory, leading to a high cognitive load experienced by the learner. The increased test scores can be attributed to how the videos had been designed, adhering to the cognitive load theory. These findings are similar to a recent study that showed improved post-test scores after learning from online lectures designed according to the same theory (Hadie et al., 2021). The authors contended that the improvements might have resulted from the cognitive load effects. For example, the cognitive load theory suggests removing redundant information such as multiple visuals that explain the same concept in videos and slides to reduce the redundancy effect. Included among the other effects mentioned in their study are the modality and isolated elements effects, which were also considered in the production of videos in the current study.

Producing 'own' videos ensures a better fit with the learning objectives, syllabus, and lecture notes. Making sure that the videos align with the learning objectives is essential in order to achieve conciseness. Cognitive load theory is a series of instructional recommendations built upon the knowledge of how humans learn; in the current study, it was used to inform the impediments to learning and improve the instructional strategy. As novices have yet to acquire the appropriate schemas for understanding the material when learning new content, processing new content can often overload the working memory of inexperienced learners. Carefully curated instructional guidance to deliver the content therefore becomes vital to help construct the relevant schemas. Brame (2016) also provided guidelines for making compelling educational videos for biology. In line with the guidelines, signalling was also used throughout the 12 topics in this study by providing cues such as highlighting the essential keywords. The signalling cues used included: i) bolding, ii) using different coloured fonts, and iii) organizing content into bullet points. This format also reduces the extraneous cognitive load throughout the content.

Providing pre-recorded videos as preparation before class can reduce cognitive load (Seery & Donnelly, 2012). This is supported by a study by Jensen et al. (2018), where the video lecture strategy significantly outperformed other strategies such as text-book style readings, as seen in students' summative assessments. In the Bruneian context, one of the earlier studies of the flipped classroom in Brunei aimed to investigate its challenges, benefits and potential use in Geography classes (Nawi et al., 2015). Although the study had reported the learning improvements associated with the flipped classroom, a limitation is that it did not quantitatively report the extent of the improvement as addressed by the present study. Though there were other local studies that investigated the effect of the flipped classroom on students' academic achievement quantitatively Latif et al., 2017; Seng Toh et al., 2017), these were in the area of social studies—not science subjects—and the participants from these studies were relatively small compared to the present study. Additionally, the participants of the former were at secondary level whereas the students in this study are at pre-university level.

Furthermore, several other researchers such as Bokosmaty et al. (2019), Mooring et al. (2016) and Seery & Donnelly (2012) had applied the cognitive load theory to the flipped classroom model and found improved academic achievement, similar to the present study. Mooring et al. (2016) believed that the flipped learning format, which makes preparation before class possible, including the ability to pause and rewind videos as well as free up time for in-class active learning, was the underlying mechanism for reducing cognitive load. This was also echoed by Bokosmaty et al. (2019), who contended that the structure of the flipped model, which allows for self-paced learning, leads to better learning achievement. Therefore, the flipped classroom design (allowing students to prepare before class) and the carefully curated videos disseminated for pre-class learning lead to a reduced cognitive load and improved learning. As Torío (2019) noted, watching videos before class made students feel better prepared and also encouraged their participation during the in-class active learning activity. Still, despite the widespread use of videos for online learning, research on what constitutes a compelling video is still lacking (Ou et al., 2016). This study has presented how instructional videos can be designed and implemented to increase their effectiveness.

CONCLUSION

Instructional design that minimizes extrinsic load helps to optimize the working memory. The videos produced for this study were carefully curated according to the cognitive load theory, as poorly designed instructions may overload the working memory and make learning less effective. The results show that simply making technology available does not necessarily ensure better learning. Instead, we must be informed about properly integrating technology into our instructions. As instructional designers, the aim is to reduce the extraneous cognitive load. The current study therefore implies the importance of theory-based video creation in helping students' learning, a point that most technologically innovative pedagogies seem to leverage on, including with regard to the flipped classroom. Video-watching before class was also found to be imperative to the success of the flipped classroom implementation. Students were better prepared for class as they then had prior knowledge and could use class time to enhance their understanding of the videos. One research area worth delving into would be to directly measure students' comparative cognitive load to investigate how their cognitive load changes before watching and after watching the videos. This study used test scores to indirectly measure the effectiveness of the videos to determine whether cognitive load had been managed effectively. In addition, investigating the students' processes while watching the videos is another area worth exploring to add more insight to the field of research on cognitive load theory.

REFERENCES

Ayres, P. (2006). Impact of reducing intrinsic cognitive load on learning in a mathematical domain. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *20*(3), 287-298.

Bokosmaty, R., Bridgeman, A., & Muir, M. (2019). Using a Partially Flipped Learning Model to Teach First Year Undergraduate Chemistry. *Journal of Chemical Education*, *96*(4), 629–639.

Bokosmaty, S., Sweller, J., & Kalyuga, S. (2015). Learning Geometry Problem Solving by Studying Worked Examples: Effects of Learner Guidance and Expertise. *American Educational Research Journal*, *52*(2), 307–333.

Brame, C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE Life Sciences Education*, *15*(4).

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

Fyfield, M., Henderson, M., Heinrich, E., & Redmond, P. (2019). Videos in higher education: Making the most of a good thing. *Australasian Journal of Educational Technology*, *35*(5), 1–7.

Fyfield, M., Henderson, M., & Phillips, M. (2019). 25 Principles for effective instructional video design. *ASCILITE 2019 - Conference Proceedings - 36th International Conference of Innovation, Practice and Research in the Use of Educational Technologies in Tertiary Education: Personalised Learning. Diverse Goals. One Heart.*, 418–423.

Gouia, R., & Gunn, C. (2016). Making mathematics meaningful for freshmen students: investigating students' preferences of pre-class videos. *Research and Practice in Technology Enhanced Learning*, *11*(1).

Hadie, S. N. H., Tan, V. P. S., Omar, N., Nik Mohd Alwi, N. A., Lim, H. L., & Ku Marsilla, K. I. (2021). COVID-19 disruptions in health professional education: use of cognitive load theory on students' comprehension, cognitive load, engagement, and motivation. *Frontiers in Medicine*, *8*, 739238.

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-based nursing*, *18*(3), 66-67.

Jensen, J. L., Holt, E. A., Sowards, J. B., Heath Ogden, T., & West, R. E. (2018). Investigating Strategies for Pre-Class Content Learning in a Flipped Classroom. *Journal of Science Education and Technology*, *27*(6), 523–535.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human Factors*, *40*(1), 1–17.

Kay, R. H. (2014). Developing a framework for creating EffectiveInstructional Video Podcasts. *International Journal of Emerging Technologies in Learning*, *9*(1), 22–30.

Kirschner, F., Paas, F., & Kirschner, P. A. (2009). Individual and group-based learning from complex cognitive tasks: Effects on retention and transfer efficiency. *Computers in Human Behavior*, *25*(2), 306–314.

Latif, A., Waznah, S., Matzin, R., Jawawi, R., Mahadi, M. A., Jaidin, J. H., ... & Shahrill, M. (2017). Implementing the flipped classroom model in the teaching of history. *Journal of Education and Learning*, *11*(4), 374-381.

Mancinetti, M., Guttormsen, S., & Berendonk, C. (2019). Cognitive load in internal medicine: What every clinical teacher should know about cognitive load theory. *European Journal of Internal Medicine*, *60*(September 2018), 4–8.

Mooring, S. R., Mitchell, C. E., & Burrows, N. L. (2016). Evaluation of a Flipped, Large-Enrollment Organic Chemistry Course on Student Attitude and Achievement. *Journal of Chemical Education*, *93*(12), 1972–1983.

Nawi, N., Jawawi, R., Matzin, R., Jaidin, J. H., Shahrill, M., & Mundia, L. (2015). To Flip or Not to Flip: The Challenges and Benefits of Using Flipped Classroom in Geography Lessons in Brunei Darussalam. *Review of European Studies*, *7*(12), 133–145.

Ou, C., Goel, A. K., Joyner, D. A., & Haynes, D. F. (2016, April). Designing videos with pedagogical strategies: Online students' perceptions of their effectiveness. In *Proceedings of the Third (2016) ACM Conference on Learning@ Scale* (pp. 141-144).

Pachman, M., Sweller, J., & Kalyuga, S. (2013). Levels of knowledge and deliberate practice. *Journal of Experimental Psychology: Applied*, *19*(2), 108–119.

Schmid, R. F., Bernard, R. M., Borokhovski, E., Tamim, R. M., Abrami, P. C., Surkes, M. A., … Woods, J. (2014). The effects of technology use in postsecondary education: A meta-analysis of classroom applications. *Computers and Education*, *72*, 271–291.

Seery, M. K., & Donnelly, R. (2012). The implementation of pre-lecture resources to reduce in-class cognitive load: A case study for higher education chemistry. *British Journal of Educational Technology*, *43*(4), 667–677.

Seng Toh, T., Amilin Tengah, K., Shahrill, M., Tan, A., & Leong, E. (2017). The flipped classroom strategy: The effects of implementation at the elementary school level mathematics lessons (Vol. 3, pp. 186–197).

Skulmowski, A., & Xu, K. M. (2021). Understanding Cognitive Load in Digital and Online Learning: a New Perspective on Extraneous Cognitive Load. *Educational Psychology Review*.

Stockwell, B. R., Stockwell, M. S., Cennamo, M., & Jiang, E. (2015). Blended Learning Improves Science Education. *Cell*, *162*(5), 933–936.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285.

Sweller, J., Ayres, P., & Kalyuga, S. (2011a). Emerging Themes in Cognitive Load Theory: The Transient Information and the Collective Working Memory Effects. In *Cognitive Load Theory* (pp. 219–233). sage.

Sweller, J., Ayres, P., & Kalyuga, S. (2011b). Measuring Cognitive Load. In *Cognitive Load Theory* (pp. 71–85). Springer US.

Sweller, J., Ayres, P., & Kalyuga, S. (2011c). The Split-Attention Effect. In *Cognitive Load Theory* (pp. 111–128). Springer US.

Sweller, J., & Cooper, G. A. (1985). The Use of Worked Examples as a Substitute for Problem Solving in Learning Algebra. *Cognition and Instruction*, *2*(1), 59–89.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. *Educational Psychology Review*, *31*(2), 261–292.

Talip, S. B., Ismail, Z. I. M., & Hadie, S. N. H. (2021). Investigating the Benefits of Integrated Anatomy Instruction: A Cognitive Load Theory perspective. *Education in Medicine Journal*, *13*(3), 1–14.

Torío, H. (2019). Teaching as coaching: Experiences with a video-based flipped classroom combined with project-based approach in technology and physics higher education. *Journal of Technology and Science Education*, *9*(3), 404–419.

Turan, Z., & Goktas, Y. (2016). The flipped classroom: Instructional efficiency and impact on achievement and cognitive load levels. *Journal of E-Learning and Knowledge Society*, *12*(4), 51–62.

Van Alten, D. C., Phielix, C., Janssen, J., & Kester, L. (2019). Effects of flipping the classroom on learning outcomes and satisfaction: A meta-analysis. *Educational Research Review*, *28*, 100281.

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.