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ORIGINAL RESEARCH

Video Tutorials in the Traditional Classroom: The Effects on Different Types of Cognitive Load

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Abstract
Are video tutorials better teachers? This pilot study examined the effects of video tutorials on different types of cognitive load. Participating students (N=45) attended two classrooms: a video tutorial-based classroom, and a traditional instruction-based classroom. The cognitive load scales indicated differences in cognitive load between the video classroom and the traditional classroom. Video tutorials decreased students' intrinsic load (t = -4.507, p<.001, d=−0.672) and increased germane load (t=4.749, p<.001, d=0.708) but did not affect extraneous load (t = -1.688, p=.098, d=−0.252). The results also indicated additivity for different types of cognitive load in the two classrooms. In general, our results demonstrate that video tutorials are a promising form of instructional material, especially to facilitate more effective and deeper learning.

Keywords Video tutorial · Video-based learning · Cognitive load

1 Introduction

With the development of technology and the accessibility of the Internet, video tutorials (VTs) have become an increasingly popular teaching tool in recent years (Martin & Martin, 2015; Mayer et al., 2020). Video tutorials have many advantages over traditional instructional materials: they can present complex concepts in a more intuitive way (Morain & Swarts, 2012), learners can control the pace of learning while using the video tutorials (de Koning et al., 2007; Martin, 2016), and through repeated viewing of the video tutorial, learners can manage and organize their study time more efficiently (Luke & Hogarth, 2011). Although many studies indicate that teaching with video tutorials has a positive effect on students' efficiency, engagement and learning outcomes (Lloyd & Robertson, 2011; Wells

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et al., 2012; Van der Meij & Van der Meij, 2014b; Martin, 2016; van der Meij & van der Meij, 2016; Wahyudi et al., 2017; Gonzalves et al., 2018; Hamas et al., 2019; Rizza et al., 2019; Rozi et al., 2020), there are also studies that show the opposite (Käfer et al., 2016; Ganier & de Vries, 2016; Zinn et al., 2021). This means that more research should focus on the conditions under which video tutorials improve learning outcomes and how to optimize them (Van der Meij & Van der Meij, 2014a).

In order to understand the effectiveness of video tutorials in-depth, it is necessary to examine learners' cognitive load. Cognitive Load Theory (CLT) provides an important theoretical foundation that guides the design of video tutorials (Noor et al., 2013). CLT identifies the different types of cognitive resources that individuals utilize in the course of completing a learning task. The three types of cognitive load utilized – intrinsic, extraneous, and germane – affect the task process and hence the task outcome (Sweller, 1988; Sweller et al., 1998). Intrinsic cognitive load is determined by the complexity of the material and the prior knowledge of the learner. Extraneous cognitive load is related to the way the learning material is presented and organized. Germane cognitive load is related to schema construction (Sweller, 1988; Sweller et al., 1998; Leppink et al., 2013; Klepsch et al., 2017).

Research suggests that video tutorials can have an impact on cognitive load (Paas et al., 2008). For example, it can lead to an increase in extraneous cognitive load and thus negatively affect learning (Mayer, 2005). But low cognitive load is also not beneficial for learning (Leppink & van den Heuvel, 2015). Ideally, a good video tutorial should allow learners to increase germane load that enhances learning and decreases extraneous load that is harmful to learning (Sweller, 1994; Sweller et al., 2011). However, in the past decade, there has been little research analyzing the sorts of cognitive load that manifests while learning through video tutorials. In addition, the types of cognitive load have rarely been explored in depth in comparative studies of video tutorials and traditional teaching methods. This make it difficult to link the findings of these comparative studies to the theoretical foundations (Mutlu-Bayraktar et al., 2019). Therefore, in the current research, there is a lack of research that compares the different types of cognitive load when video tutorials are being used in real classroom settings. The study aims to fill this gap by examining the differences in the types of cognitive load that arise during video tutorial-based classes (VC) and traditional instruction-based classes without video support (TC), in order to better understanding the different cognitive impacts of the two approaches.

2 Research Question

RQ (1) Are there differences in types of students' cognitive load between video classroom (VC) and traditional classroom (TC)?

RQ (2) Are there correlations between the types of students' cognitive load in the video classroom (VC) and traditional classroom (TC)?

3 The Literature Review

3.1 Cognitive Load Theory

Cognitive scientists have established that working memory or short-term memory is limited (Miller, 1956; Broadbent, 1958; Brown, 1958; Peterson & Peterson, 1959). Therefore, if the amount of information provided during instruction exceeds the learner's short-term memory capacity, the extra information is useless (Kalyuga & Sweller, 2014). In contrast, long-term memory (LTM) has a virtually unlimited storage capacity and provides a more permanent repository of knowledge and abilities (Bower, 2014). Memory research has shown that learners' prior knowledge experiences affect their recall of learning material (Bartlett, 1932), and these experiences are stored in long-term memory as schemas (Rumelhart, 1980). Once a schema is developed, it remains stable over long periods of time, allowing people to encode and classify information that has been or will be acquired. These cognitive processes are automatic and do not require conscious control or resource consumption (Rumelhart, 1980; Kirschner, 2002; Paas et al., 2003b).

In 1988, John Sweller explained the interaction between limited working memory (Miller, 1956) and long-term memory based on schema theory (Chi et al., 1982; Larkin et al., 1980). He provided a more comprehensive and systematic discussion of CLT from the perspective of cognitive resource allocation. CLT emphasizes that human cognitive resources are limited. The process of learning and problem solving consumes cognitive resources and thus generates a certain load. The purpose of applying CLT in the classroom is to reduce the cognitive load that hinders learning (Anmarkrud et al., 2019), and to promote the cognitive load that favors learning (Sweller et al., 1998). Therefore, cognitive load is not just a by-product of the learning process but should be considered a major determinant of the success of instructional interventions (Paas et al., 2003b; Kirschner, 2002). Instruction must consider how to avoid cognitive overload for the learner in a limited amount of time and be able to store knowledge in long-term memory.

3.2 Types of Cognitive Load

The discourse surrounding categorization of cognitive load has evolved over time. In the early stages when CLT was first proposed, cognitive load was categorized as either relating to schema construction (intrinsic cognitive load) or being unrelated to schema construction (extraneous cognitive load; Sweller et al., 1998). This is because early studies of cognitive load focused primarily on schema acquisition (Moreno & Park, 2010). Germane cognitive load was introduced in the 1990s when researchers found that partial cognitive load produced effects that were beneficial for learning (Sweller et al., 1998). It is capable of transferring knowledge to the cognitive load of long-term memory. In recent years, element interactivity has been expanded in research on cognitive load (Sweller, 2010), unifying the foundations of the three cognitive loads. The cognitive load discussed in this study uses a three-factor model: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Sweller et al., 2019).

3.2.1 Intrinsic Cognitive Load

Intrinsic cognitive load (ICL) is determined by the complexity of the learning material and the learner's prior knowledge (Sweller, 1988; Leppink et al., 2013; Klepsch et al., 2017). The complexity of learning materials is related to the element interactivity. Materials with low element interactivity have each element that can be learned independently of the others, so even though there are many elements, they do not require much working memory. Materials with high element interactivity cannot be learned independently, and multiple elements must be considered simultaneously in the learning process. Therefore, the higher the element interactivity, the higher intrinsic load (Sweller, 2010). Additionally, the learner's prior knowledge is also a factor that influences the intrinsic load. If the learner already has a richer prior knowledge of the domain covered by the learning content, the new knowledge can be more quickly categorized into existing schemas, thus reducing the load on working memory (Sweller et al., 2019). However, more working memory is required to process more of the learning content when the learner's prior knowledge is insufficient, resulting in an increased intrinsic load (Leppink et al., 2014).

3.2.2 Extraneous Cognitive Load

Extraneous cognitive load (ECL) or ineffective cognitive load, which is related to how learning materials are presented and organized (Sweller et al., 2019). When learning materials are poorly designed, it can cause learners to unnecessarily process elements that are not relevant to learning (Sweller et al., 1998). For example, learners may be asked to unnecessarily search within materials for information to solve a problem or for an unclear reference in an explanation (Paas et al., 2003b). This can cause the learner to experience the split attention effect, resulting in an increase in extraneous load (Ayres & Sweller, 2005). Therefore, excessive extraneous load can interfere with learning and should be kept to a low level when designing instruction (Paas & Sweller, 2014).

3.2.3 Germane Cognitive Load

Germane cognitive load (GCL) is considered as a load necessary for learning (Schnotz & Kürschner, 2007). More cognitive resources are allocated to intrinsic load when a learner's extraneous cognitive load is low. This results in the processing of elements from working memory and their transfer to long-term memory (schema construction). The cognitive resources used in this process are called germane cognitive load (Sweller et al., 1998; Leppink et al., 2013). Thus, germane load is a cognitive resource needed to deal with intrinsic cognitive load (Sweller et al., 2019). However, it is also due to the very close relationship between GCL and ICL that the concept of germane load has been controversial since it was proposed. Some researchers have argued that germane load is not independent of the other two cognitive loads, but rather uses the same theoretical foundations as intrinsic load, making it indistinguishable from intrinsic load (Kalyuga, 2011). Other researchers have argued that GCL is an active load and that high GCL is a cognitive resource that learners invest in, whereas ICL is a load that is passively experienced (Moreno & Park, 2010; Klepsch & Seufert, 2021). In our study, we aim to investigate whether video tutorials are effective in transforming information into schemas, and therefore we will use the three-factor cognitive load categorization.

3.3 Effects of Video Tutorials

Video tutorials (VT) are a type of material that combines audio and visual information to provide step-by-step instruction that builds knowledge and skills (Noor et al., 2014; Ponzanelli et al., 2016). In recent years, the production, use, and effectiveness of video tutorials have gradually become a focus of research. From script development, video recording, audio recording, adding subtitles, to final editing and encapsulation (Oujezdský, 2014), the process of video tutorial production can involve a number of key steps. It is worth noting that although some researchers produced video tutorials based on cognitive load theory (Noor et al., 2013), CLT does not provide help on specific design problems (van der Meij & van der Meij, 2013). Therefore, many researchers have proposed some general design principles and considerations for the production of video tutorials (Martin & Martin, 2015; Nasir & Bargstädt, 2017; Fiorella & Mayer, 2018; Guy & McNally, 2022; van der Meij & Hopfner, 2022; Ring & Brahm, 2022). For example, van der Meij and van der Meij (2013) suggested eight guidelines for the design of video tutorials. The guidelines include many specific details about the design of video tutorials, such as recommending the use of highlighting to direct attention and the use of a conversational style to enhance perceptions of task relevance.

Some studies have examined the effects of video tutorials. A three-year study investigated the use of video tutorials in university programming courses (Wells et al., 2012). The video tutorials were introduced into the courses the first year without any modifications. The results showed that the satisfaction of the course increased, but 40% of the students still did not participate in the unit content. In the second year, researchers adjusted the video tutorials to better fit the assignments. This approach increased the number of assignments submitted and improved learning outcomes. In the third year, they repeated the methods from the second year and the results showed that 87% of the students used the tutorials to complete the assignments. However, the study also observed that face-to-face lectures were rated lower after the introduction of the video tutorials. Students preferred to use video tutorials for their learning.

Compared with other types of instructional materials, video tutorials have many advantages (Balslev et al., 2005; Zhang et al., 2006; Lloyd & Robertson, 2011; Gonzalves et al., 2018). In an empirical research, van der Meij and van der Meji (2014a) examined the difference between four types of instructional configuration: paper-based, paper-based preview and video procedure (Mixed A), video preview and paper-based procedure (Mixed B) and video tutorials. The 111 fifth and sixth-grade participants were randomly split into two groups. The result of post-test shows that the participants who used the video tutorials achieved the highest score of 76.8%, while the participants who used the paper-based materials only scored 55.6%. For the training tasks, the video tutorials also achieved the best success rate of 89.7%, while the paper-based materials resulted in a success rate of 65.4%. The results are consistent with the findings of Palmiter and Elkerton (1993), who found that use of video tutorials during training resulted in better final learning outcomes.

Many studies show that video tutorials can influence learners' cognitive load (Chen & Wu, 2015; Biard et al., 2018; Hughes et al., 2018). However, there are also contrary results.

Garrett (2018) conducted a study comparing the text, video, and segmented video in Excel learning. The 48 participants were randomly assigned to the three materials. The average completion time was 200 s for the video tutorial, 271 s for the segmented video, and 318 s for the text. Although the video tutorial was the most efficient format, scales showed no difference in the type of cognitive load utilized. In another study (Homer et al., 2008), 26 university students attended two different classrooms, one using slides with video tutorials, the other using slides without video tutorials. The cognitive load scales showed that students experienced higher cognitive load during instruction with video. However, the students achieved good learning outcomes in both classes. These results indicated that both materials are beneficial for learning, but the video tutorials required more mental effort.

In summary, although the effects of video tutorials have been widely researched, the empirical evidence on video tutorials compared with traditional instruction is still not clear. Therefore, our study aims to provide further evidence to clarify the impact of video instruction versus traditional instruction on cognitive load.

3.4 Methods of Cognitive Load Measurement

Effective measurement of cognitive load provides a basis for further study on video tutorials and is also a challenge in cognitive load research (de Jong, 2009; Ayres, 2017). It is now widely accepted that measures of cognitive load are categorized as subjective and objective (Brunken et al., 2003; Plass et al., 2010).

Subjective assessment based on learners' experiences and feelings during the learning process has been the main method of measuring cognitive load. Questions are usually related to the psychology of the learner and the difficulty of the task (Paas et al., 2003b; Schnotz & Kürschner, 2007). Measuring cognitive load from a subjective perspective was originally proposed by Paas (1992), and other researchers have developed a variety of methods to assess cognitive load. However, because the measurement dimensions are too simple or can only measure the total cognitive load, many researchers have tried to develop scales that measure one of the categories of cognitive load or different types of them (Ayres, 2006; DeLeeuw & Mayer, 2008; Cierniak et al., 2009; Leppink et al., 2013; Klepsch et al., 2017). The main advantage of subjective measurement methods is the convenience, requiring almost no instruments. The data obtained is also easy to analyze, and it does not interfere with the learners' learning tasks. However, it has some limitations. The results of the scales come from the subjective feelings of the learners, but sometimes the feelings can be different from the real mental load. Also, due to the controversy surrounding GCL, the subjective scale still needs to be further investigated.

In terms of objective measurement, dual-task paradigms are often used to measure participants' resource allocation status (Brunken et al., 2003). As technology advances, biofeedback techniques are also being used as an objective measurement and have been validated in many studies. For example, electroencephalography (EEG; Antonenko et al., 2010), functional magnetic resonance imaging (fMRI; Whelan, 2007), heart rate variability(HRV; Cranford et al., 2014; Minkley et al., 2018; Solhjoo et al., 2019), galvanic skin response (GSR; Conway et al., 2013; Larmuseau et al., 2019), and eye-tracking techniques (Recarte & Nunes, 2003; Van Gerven et al., 2004; Karch et al., 2019).

4 Method

4.1 Curriculum and Participants

We conducted a four-group controlled experiment in two vocational schools and one high school (two groups) in Germany. By having lessons from different types of schools and subjects, we were able to examine the effectiveness of the video tutorials in variety of teaching and learning environment. This enhanced the generalizability of the results.

The four groups were taught by four different teachers. Each teacher used a video tutorial in one of the lessons (video classroom: VC) and traditional teaching methods in another lesson (traditional classroom: TC). Teachers decided by themselves which lessons to use video tutorials and students were not aware of this in advance. In addition, the content of the lessons was strictly in line with the students' original study program. Only the development parts of the lessons were replaced by video tutorials in VC, all other parts followed the original lesson plan. Although the content may vary slightly, we have ensured that the materials are coherent and relevant as much as possible. For example, in Group A the learning topic was "Light and Color". In the video classroom, students first learned the basics knowledge of color vision, including how colors are perceived, color addition and color subtraction. In the traditional classroom, students learned the wavelength of light and how its reflection affects color. They also needed to understand the RGB and CMYK color spaces. All video tutorials were selected by the teacher based on course content and were taken from online resources. All students were able to control the pace of the videos while watching them.

Only the students who participated in both classes were selected as a sample to ensure that the observed cognitive load were not due to individual differences. In order to detect an effect size of Cohen's $d=0.50$ with 90% power ($\alpha=0.05$, two-tailed), G*Power 3.1 suggests we would need 44 participants in a paired samples t-test (Faul et al., 2009; Serdar et al., 2021). A total of 45 students (46.67% male, M_{age}= 19.42, SD_{age}= 2.54) fully participated in both class lessons. Group A was organized at a vocational school in Hamburg, Germany with the theme "Light and Color". A total of 15 students participated in both classes (20.00% male, M_{age} = 22.27; SD_{age} = 2.55). Group B took place in a vocational school in Elmshorn, Schleswig-Holstein, Germany, and the topic of the lessons was "Economy". A total of 5 students participated in both classes (100.00% male, M_{age} = 18.40; SD_{age} = 0.55). Group C and Group D took place in a high school in Ahrensburg, Schleswig-Holstein, Germany, with students from grade 12. The topic of the lesson in Group C was "Biology". A total of 13 students participated in both classes (61.54% male, M_{age} = 18.00; SD_{age} = 0.41). Group D's class topic was "Economics and Politics". A total of 12 of these students participated in both classes (41.67% male, M_{age} = 17.83; SD_{age} = 0.83). All participants were informed about the study in advance and signed an informed consent. Underage students had informed consent forms signed by their parents. All data were collected anonymously.

4.2 Subjective Cognitive Load Scale

In this study, we used the Cognitive Load Scale (CLS) to measure students' cognitive load. The CLS was chosen firstly because it is convenient and does not interfere with the students' learning process. Secondly, the CLS allows us to distinguish between three different types of cognitive load, which is important for exploring the differences between video and traditional classrooms. In addition, CLS has been demonstrated to be able to distinguish between complexity levels of the problems for perceived difficulty and mental effort (Ouwehand et al., 2021), and is also applicable to non-traditional instructions (Costley et al., 2020; Andersen & Makransky,2020).

We selected Leppink et al.'s (2013) Cognitive Load Scale. The CLS consists of ten items grouped into three dimensions, including ICL (three items, from 1 to 3), ECL (three items, from 4 to 6), and GCL (four items, from 7 to 10). The scale uses an 11-point Likert scale, where 0 means "not at all the case" and 10 means "completely the case". The reliability of the original version of the dimensions is Cronbach's α: ICL=0.82, ECL=0.75, and GCL=0.82. In another meta-study that examined the reliability of various cognitive load scales, Leppink et al.'s scale also achieved good results (Cronbach's α: ICL=0.845, ECL=0.759, GCL=0.909) and has been more widely used (Mutlu-Bayraktar et al., 2019; Krieglstein et al., 2022). Since the original version of the scale was used in a statistics course, the parts of the scale related to statistics were modified (see Fig. 1) and translated into German by a native speaker.

4.3 Procedure

Before the lesson began, four video cameras were placed and set up in the four corners of the classroom, and audio recorders were placed on the students' desks. Headphones were distributed to each student in the video classroom so that they would not be distracted by other students' videos. We also used the OBS software (version 27.2.3) to record students' screens in real time while they were engaged in video classroom. This allowed us to observe in retrospect how students interacted with the video tutorials, as well as their choices and strategies during the learning process. Participants were assigned a code as they entered the classroom. Participants were first given instructions by the researchers and then asked to turn on the audio recorder placed on their desks. At the same time, researchers turned on the video camera's recording mode. The researchers then left the classroom and the teacher began the lecture. At the end of the lecture, participants were asked to complete a cognitive load scale and simple demographic questions (age, gender).

All of the following questions refer to the activity (lecture, class, discussion session, skills training or study session) that just finished. Please respond to each of the questions on the following scale (0 meaning not at all the case and 10 meaning completely the case).
[1] The topic/topics covered in the activity was/were very complex.
[2] The activity covered contents that I perceived as very complex.
[3] The activity covered concepts and definitions that I perceived as very complex.
[4] The instructions and/or explanations during the activity were very unclear.
[5] The instructions and/or explanations were, in terms of learning, very ineffective.
[6] The instructions and/or explanations were full of un- clear language.
[7] The activity really enhanced my understanding of the topic(s) covered.
[8] The activity really enhanced my knowledge and understanding of the theme(s).
[9] The activity really enhanced my understanding of the context(s) covered.
[10] The activity really enhanced my understanding of concepts and definitions.

Fig. 1 Cognitive Load Scale

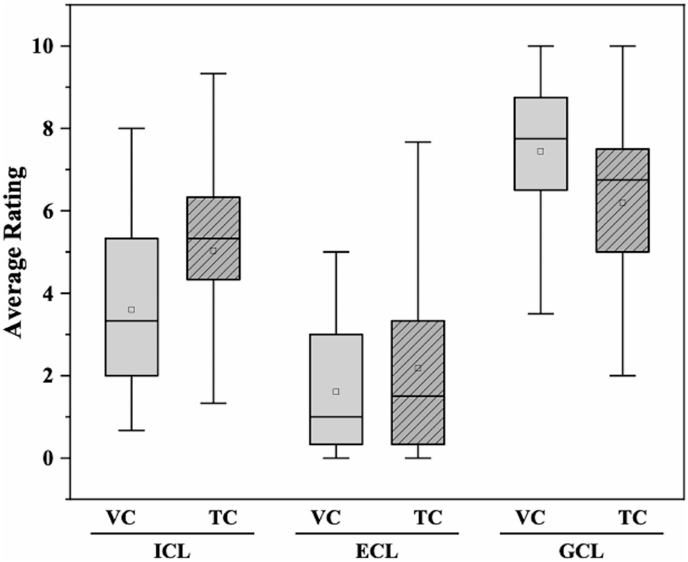

Fig. 2 Distributions of the three types of cognitive load for the video class versus the traditional class for the four groups combined. *Note N*=45. VC=Video classroom. TC=Traditional classroom

5 Results and Discussion

5.1 Differences in Cognitive Load for Four Groups

After checking the classroom of each group and selecting only the students who participated in both classes, 90 CLSs from 45 students were finally used for analysis. Initially, a normal distribution test using a quantile-quantile plot was performed on the difference between the two groups. The results showed that the data collected met the requirements for normal distribution. The ten items in the CLS were categorized according to cognitive load and dimensionality reduced for reliability analysis. The Cronbach's α: ICL=0.892, ECL=0.688, GCL=0.898, which are within the acceptable range.

Figure 2 shows the distribution of the three cognitive loads for the four groups. The video classroom (M=3.600, SD=2.100) reports significantly lower scores on the ICL than the traditional classroom (M=5.033, SD=2.313), t = -4.507, $p<.001$, d=−0.672. Although the mean ECL is lower in the video classroom (M=1.607, SD=1.474) than in the traditional classroom (M=2.174, SD=2.245), there is no significant difference, t = -1.688, $p=.098$, d=−0.252. In terms of GCL, the video classroom (M=7.444, SD=1.681) reports significantly higher means than the traditional classroom (M=6.200, SD=1.786), t=4.749, $p<.001$, d=0.708).

These results answer research question 1, by establishing that there are differences in cognitive load between the video classroom and the traditional classroom. The results are consistent with previous studies (Chen & Wu, 2015; Biard et al., 2018; Hughes et al., 2018; Griffith & Faulconer, 2022), which indicated the video tutorials affect learners' cognitive load. Of the three types of cognitive load, students who completed video tutorials experienced significantly lower ICL and significantly higher GCL, while ECL showed almost no difference between the two classrooms.

Students in the video classroom reported lower ICL. According to CLT, instructional interventions cannot change ICL (Sweller, 1994). Changes in ICL are therefore influenced by the complexity of the interactive elements of the learning material and the learner's prior knowledge. In order to avoid individual differences, only participants who attended two classes were used in our results. Therefore, we can assume that there will not be much difference in students' prior knowledge of the topic when they participate in two classrooms. Thus, the element interactivity of the learning material can be considered here as the main factor influencing ICL. Researchers often express concerns that video tutorials may increase cognitive load due to the richness of the visual and auditory content (Paas et al., 2008). However, our results showed that students experience less ICL when using video tutorials. This is potentially because, although the video tutorial has sound and images, the elements involved in the knowledge are already combined and students do not have to spend much effort to re-process them. It has also been shown that videos with lower linguistic complexity produce lower ICL (Castro-Meneses et al., 2019). On the other hand, paper-based materials used in traditional classrooms require students to find what they need to learn and combine elements on their own, which can lead to more ICL.

In the ECL section, although the video classroom reported lower scores, there was no statistically significant difference between the two classrooms. However, it is noteworthy that ECL can be altered by instructional interventions (Van Merrienboer & Sweller, 2005). Therefore, additional attention needs to be paid to ECL when ICL is increased. Because the total cognitive load cannot exceed the capacity of working memory, when element interactivity is high, there is a need to focus on reducing ECL through instructional design (Paas et al., 2003b). One reason for the lack of difference in ECL between the two classrooms could be that the video tutorials gave the same clear instructions as the traditional classroom.

In terms of GCL, it is evident that learners experienced greater GCL in the video classroom. GCL is related to schema construction. High GCL is a sign that learners are actively transforming cognitive resources into schemas (Klepsch et al., 2017). This indicates that students in video classrooms invest more cognitive resources to process information. It also might show that video tutorials provide a more engaging learning experience than traditional classrooms. In addition, video tutorials offer flexibility. In the students' screen recordings, we found that students often watched a particular section repeatedly through the strategies by pausing and rewinding, which can contribute to deeper cognitive engagement. In contrast, the traditional classroom had a lower GCL. This means that although the traditional method was effective in transferring information, it was not as effective as video tutorials in promoting deep cognitive processes and meaningful learning.

It is important to note that although the video tutorial generally showed lower ICL and higher GCL, there may have been different results in different groups.

5.2 Differences in Cognitive Load for each Group

Because each classroom may produce different results due to differences in lesson design and teaching styles, we compare the differences in each of the four groups. Figure 3 shows the distributions of the three cognitive loads for Group A (N=15), Group B (N=5), Group

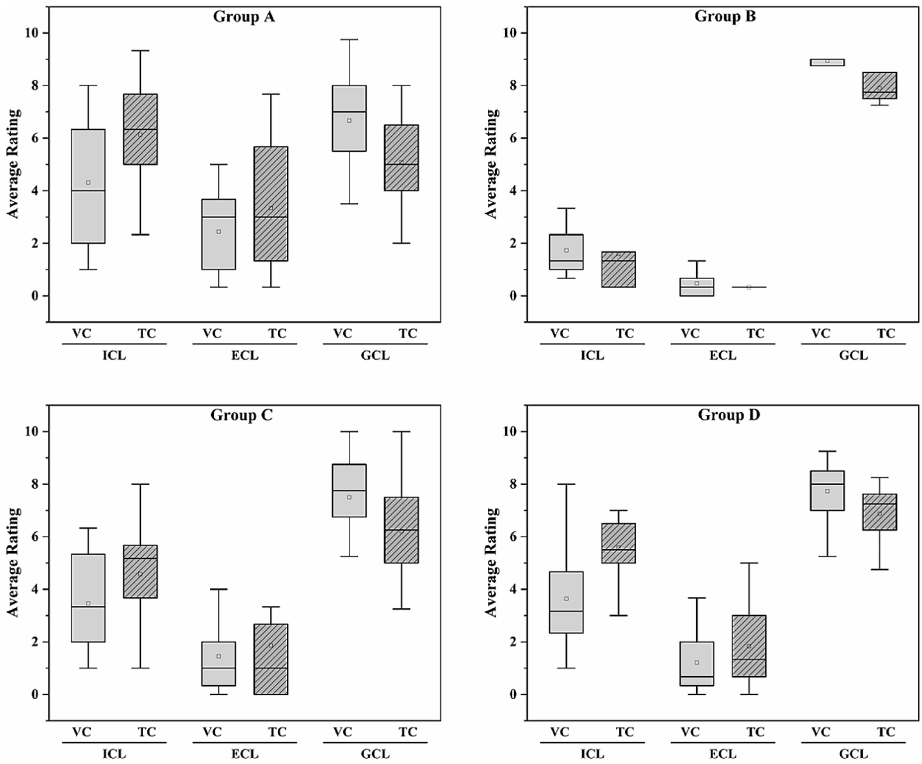

Fig. 3 Distributions of the three types of cognitive load in Group A, Group B, Group C and Group D for the video and traditional classrooms. *Note* Group A, *N*=15. Group B, *N*=5. Group C, *N*=13. Group D, *N*=12. VC=Video classroom. TC=Traditional classroom

Table 1 Paired t-test results of three types of cognitive load in Group A

	VC		TC		t (14)	*p*	Cohen's d
	M	SD	M	SD			
ICL	4.311	2.248	6.133	2.363	-2.815	0.014	−0.727
ECL	2.444	1.499	3.333	2.407	-1.186	0.255	−0.306
GCL	6.667	1.741	5.083	1.713	2.877	0.012	0.743

Note *N*=15. VC=Video classroom. TC=Traditional classroom

C (*N*=13) and Group D (*N*=12) for the video and traditional classroom. Tables 1, 2, 3 and 4 show the results of the paired t-test for the four groups.

From the results, it can be seen that Group A and Group C show the same results as the overall trend of significantly lower ICL and significantly higher GCL for the video classroom compared to the traditional classroom. Interestingly, Group B and Group D individually showed some differences to the overall cognitive load results. In Group B, the three cognitive loads barely differed between the two classrooms. One of the reasons for the lack of statistically significant differences in all items of Group B could be the small sample size (*N*=5). It is worth noting that students in Group D report lower ECL when learning with

Table 2 Paired t-test results of three types of cognitive load in Group B

	VC		TC		t (4)	p	Cohen's d
	M	SD	M	SD			
ICL	1.733	1.090	1.600	1.640	0.431	0.668	0.193
ECL	0.467	0.558	0.333	0.236	0.459	0.670	0.205
GCL	8.950	0.716	7.900	0.576	1.971	0.120	0.882

Note $N=5$. VC = Video classroom. TC = Traditional classroom

Table 3 Paired t-test results of three types of cognitive load in Group C

	VC		TC		t (12)	p	Cohen's d
	M	SD	M	SD			
ICL	3.462	1.989	4.577	2.028	-2.028	0.016	−0.777
ECL	1.449	1.478	1.859	2.468	−0.544	0.597	−0.151
GCL	7.500	1.920	6.211	1.928	2.646	0.021	0.734

Note $N=13$. VC = Video classroom. TC = Traditional classroom

Table 4 Paired t-test results of three types of cognitive load in Group D

	VC		TC		t (11)	p	Cohen's d
	M	SD	M	SD			
ICL	3.639	2.042	5.583	1.120	-2.737	0.019	−0.790
ECL	1.208	1.258	1.833	1.580	-2.245	0.046	−0.648
GCL	7.729	1.135	6.875	1.155	1.927	0.080	0.556

Note $N=12$. VC = Video classroom. TC = Traditional classroom

Table 5 Descriptive statistics and correlations for CL in Video Classroom

Variable	n	M	SD	1	2	3
1. ICL	45	3.60	2.10	—		
2. ECL	45	1.61	1.47	0.337^{*}	—	
3. GCL	45	7.44	1.68	-0.442^{**}	-0.332^{*}	—

*p<.05. **p<.01

Table 6 Descriptive statistics and correlations for CL in Traditional Classroom

Variable	n	M	SD	1	2	3
1. ICL	45	5.03	2.31	—		
2. ECL	45	2.17	2.24	0.498^{**}	—	
3. GCL	45	6.20	1.78	-0.451^{**}	-0.628^{*}	—

*p<.05. **p<.01

video tutorials. This means that the video tutorials in Group D could fit even more the students need. Further research it is necessary to analyze this specific difference.

5.3 Relationship between Three Types of Cognitive Load

Based on the results of the four groups, we can see that there are differences between video classroom and traditional classroom in terms of ICL and GCL. According to the additivity hypothesis of cognitive load, different types of cognitive load change dynamically when the total load does not exceed working memory capacity. The total cognitive load can be maintained by decreasing another type of cognitive load when one type of cognitive load increases. (Moreno & Park, 2010; Paas et al., 2003b). To explore the correlations between different types of cognitive load, we conducted a correlational analysis of the CLS results from each of the two classrooms (Research Question 2).

In Tables 5 and 6, we can see that the correlation between different types of cognitive load in both classrooms are similar. These results answer research question 2. ICL and ECL are in positive correlation, ICL and GCL are in negative correlation, and ECL and GCL also show negative correlation. According to the additivity hypothesis, when ICL levels are low, learners will have sufficient cognitive resources to deal with ECL. And when cognitive resources are progressively consumed by ECL, then fewer will be available for GCL (Park et al., 2015; Costley et al., 2020; Krieglstein et al., 2022). Our results show that ECL changes with ICL. In the video classroom, when the ICL is lower it leads to a higher GCL. And when ICL increased in the traditional classroom, leading to an increase in ECL, then GCL decreased. Changes in cognitive load between the two classrooms appear to be consistent with the additivity hypothesis. However, because of the limitations of subjective measures, and because we did not measure students' total load, we cannot determine whether students reached the limit of total load during the lesson. Therefore, our results can only suggest a potential feature of additivity across different types of cognitive load.

Meanwhile, to explore differences in correlations between different types of cognitive load in the two classrooms, we used Fisher's r-to-z transformation (Silver & Dunlap, 1987) to conduct a difference-in-difference analysis. As can be seen in Fig. 4, comparing ICL and ECL, the correlation for the video classroom is $z=0.397$, while the traditional classroom is $z=0.547$. The difference between the two classes is $z=-0.688$, which is not statistically significant, $p=.492$, $q=-0.150$. Comparing ICL and GCL, the correlation for the video classroom is $z=-0.475$ compared to $z=-0.486$ for the traditional classroom. The observed difference between the two classes is $z=0.052$, which is not statistically significant, $p=.959$, $q=0.011$. Comparing ECL and GCL, the correlation for the video classroom is $z=-0.345$, the correlation for the traditional classroom is $z=-0.738$. The difference between these correlations is $z=1.801$, $p=.072$, $q=0.393$. This suggests a trend towards statistical significance.

Based on the results of Fisher's r to z transformation, we can further answer research question 2. The ECL and GCL correlations in the two classrooms is approaching the border of significance ($z=1.801$, $p=.072$, $q=0.393$). ECL and GCL showed negative correlations in both the video classroom ($r=-.332$, $z=-0.345$) and the traditional classroom ($r=-.628$, $z=-0.738$), suggesting that GCL decreases as extraneous load increases. However, the decrease in germane load was greater in the traditional classroom compared to the video classroom. This means that in the traditional classroom, when there is an unfavorable ECL, there is a greater reduction in the cognitive resources available for schema construction

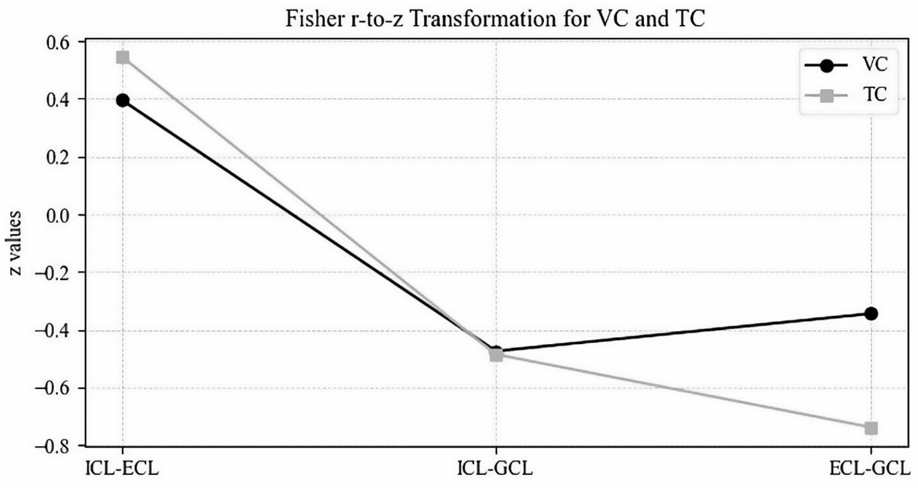

Fig. 4 Fisher r-to-z transformation for video classroom and traditional classroom

(GCL). The stronger negative correlations in the traditional classroom may be an indication that the overall cognitive load reaches its limits more often. As ECL increases, it takes away cognitive resources that could have been used for GCL.

6 Conclusions

Based on the results, we draw the following conclusions. There are differences in types of cognitive load experienced between video and traditional classrooms. In our study, students reported less ICL and increased GCL during the learning process using video tutorials compared to the traditional classroom. From the correlation analysis of the different types of cognitive load, it can be seen that learners adjust the use of other loads according to the use of different types of loads. This supports assertions that cognitive load is additive. As well, the correlations between ECL and GCL showed a trend of difference between the two classrooms. Learners were able to use the GCL to a greater extent when learning through video tutorials. Therefore, video tutorials appeared to be a favorable instructional material in this study. Not only did it involve less intrinsic load, but it also left more resources available for processing the germane load. These results demonstrate the potential of video tutorials to facilitate more effective and deeper learning.

7 Limitations and Future Work

At the same time, this study has several limitations. First, assessment of students' cognitive load used self-rating scales. This approach responds to students' subjective experiences, but not detailed information about specific cognitive processes. Therefore, in future studies, we will introduce objective measures such as heart rate variability to analyze cognitive load in more detail.

Second, the focus of this study was to measure the overall cognitive load of students in the classroom and not the specific details of the video tutorials. Although we recorded students' screens, we did not analyze them in detail. In future research, we could analyze the screen recordings in more depth. We could also add pre- and post-tests (Kulgemeyer et al., 2022) to examine whether students' viewing strategies created cognitive load and influenced learning outcomes. Eye tracking could also be used to more specifically analyze students' viewing strategies (Cook et al., 2017). For example, if students repeatedly use pause and rewind at some point in the video, is this related to their prior knowledge? Are students having a positive impact on learning outcomes by implementing viewing strategies?

Third, different instructional processes and learning steps may also affect changes in cognitive load. For example, ECL can be changed by instructional interventions (Van Merrienboer & Sweller, 2005), and teaching styles and instructional steps can also affect cognitive load. Therefore, students' classroom behaviors and teachers' organizational behaviors should be quantitatively coded in future research. Changes in cognitive load need to be analyzed from multiple perspectives including time on task, learning steps, social forms and motivation. We also suggest that similar studies in the future should include a follow-up survey of participants. For example, learning outcomes should be tested after one week to see how the knowledge is stored in long-term memory.

Fourth, although we controlled the variables in our study as much as possible, such as paired samples students, the same teacher in each group, strictly following the study program to ensure consistency and relevance of the teaching content, and the lesson design that only varies in the development part by using video tutorials or not, we still face some limitations. There may still be some slight differences in content, perhaps the video tutorials covered more complex or simpler content in one group than in the traditional classroom. And each teacher's approach may vary from classroom to classroom, even within the same instructional framework. Such differences may be due to adjustments based on student responses in the classroom, or due to different strategies in different instructional settings.

Finally, although the results observed changes in different cognitive loads and the potential for additivity, a more comprehensive study is required to draw firmer conclusions about the additivity hypothesis. And as learners progress in the classroom, it is possible that the intrinsic load decreases over time while other loads change accordingly. This fluidity implies that cognitive load is not static during the learning process, and therefore it is necessary to add dynamic studies of cognitive load in the future (Leppink et al., 2013; Paas et al., 2016). Furthermore, the present study was conducted under the assumption of the existence of germane cognitive load, whereas there are still many questions about the concept of germane cognitive load (de Jong, 2009). Germane cognitive load is difficult to distinguish from intrinsic cognitive load, and more research is required to explore and clarify the framework of cognitive load theory.

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