Exploring teachers' perceived intrinsic cognitive load while learning to use visual thinking tools

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ABSTRACT

This study aims to explore the potential extraneous cognitive load (ECL) that learners may encounter when using visual thinking tools (VTTs) as pedagogical aids, which is comparable to the intrinsic cognitive load (ICL) associated with these tools' learning process. An online questionnaire adapted from the Cognitive Load Scale was sent to in-service teachers who participated in a 21-day online training course on three VTTs (thinking maps, mind maps, and concept maps), and 220 valid responses were collected. We conducted a two-way ANOVA with repeated measures to analyze the differences in the teachers' perceived ICL at different learning levels for each VTT. The participants' homework and feedback are also collected and analyzed to triangulate the results from the questionnaire. A two-way ANOVA with repeated measures was conducted to analyze the differences in the teachers' perceived ICL at different learning levels for each VTT. The participants' homework and feedback are also collected and analyzed to triangulate the results from the questionnaire. The results reveal that: 1) Concept maps, thinking maps, and mind maps have the highest perceived ICL, ranging from high to low. 2) Among the four learning levels (understanding, manipulating, applying, and evaluating), the participants perceive the slightest ICL at the applying level for all three VTTs. 3) Thinking maps, mind maps, and concept maps cause the heaviest ICL at the understanding, evaluating, and manipulating levels, respectively. Implications for designing professional development programs on VTTs were discussed.

Keywords: *Concept maps, Intrinsic cognitive load, Mind maps, Thinking maps, Visual thinking tools.*

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Highlights of this paper

- This study explored teachers' learning experiences of three popular VTTs and is the first empirical study comparing the learning experiences of three VTTs from the Cognitive Load Theory perspective.
- The study found that: 1) The sequence of perceived ICL from high to low is concept maps, thinking maps, and mind maps. 2) Among the four learning levels (understanding, manipulating, applying, and evaluating), the participants perceive the slightest ICL at the applying level for all three VTTs. 3).
- Thinking maps, mind maps, and concept maps cause the heaviest ICL at the understanding, evaluating, and manipulating levels, respectively.

1. INTRODUCTION

Education systems worldwide have paid more attention to developing students' higher-order thinking skills than ever (Greiff, Niepel, & Wüstenberg, 2015). As a series of innovative teaching approaches aiming to promote the students' thinking abilities, teaching thinking has become popular in K-12 education (Long et al., 2022; Long, Zhao, Yang, Zhao, & Chen, 2021). Thinking tools, including *visual thinking tools* (VTTs) and *thinking strategy tools*, are widely used as effective scaffoldings in teaching thinking (Long et al., 2022). To visualise students' thinking processes in class, various VTTs, such as *thinking maps* (Hyerle & Alper, 2011), *concept maps* (Novak, Gowin, & Bob, 1984), and *mind maps* (Buzan & Buzan, 2006), have been widely adopted (Schroeder, Nesbit, Anguiano, & Adesope, 2018; Zhao, Yang, & Xiong, 2019). The selection and application of VTTs typically determine their effectiveness in teaching and learning. If inappropriately used, VTTs bring unexpected *extraneous cognitive load* (ECL) to users, occupying many mental resources and preventing learners from processing learning materials (Skulmowski & Xu, 2022; Sweller, Van Merriënboer, & Paas, 2019).

As *Technology Acceptance Model* (Davis, 1989) suggests, teachers choose teaching aids based on their perceived ease of use and usefulness. However, most teachers' knowledge about VTTs remains superficial and fragmented partly due to VTTs' absence from most pre-service teacher preparation programmes and their limited exposure to in-service training (Zhao et al., 2019). Although *concept maps*, *thinking maps*, and *mind maps* are widely used in K-12 education, only a few teachers realise their nuanced differences and make the most suitable choices. Therefore, a comprehensive understanding of the popular VTTs is fundamental for teachers to choose the one(s) most suitable to their teaching scenarios (Zhao et al., 2019).

Cognitive load theory Sweller, Ayres, and Kalyuga (2011) provides a feasible theoretical framework for designing instruction. As Sweller et al. (2011) suggested, instructional design should aim to reduce the *extraneous cognitive load* (ECL) to devote working memory resources to germane processing. Therefore, teachers tend to choose easy-to-use VTTs as teaching or learning aids because they are believed to produce lower ECL. However, few studies have investigated how teachers perceive the ECL of various VTTs while using them.. As learners' perceived ECL while using VTTs is their perceived *intrinsic cognitive load* (ICL) while learning to use them, this study explores teachers' perceived ICL of the three most popular VTTs (*thinking maps*, *mind maps*, and *concept maps*) during their learning them.

2. LITERATURE REVIEW

2.1. Thinking Tools and VTTs

Many education-related academic disciplines use thinking tools, often in an ambiguous manner. Pakdaman-Savoji, Nesbit, and Gajdamaschko (2019) occasionally use thinking tools interchangeably with cognitive ones. The researchers have found that *thinking tools*, if properly used, could help learners reserve mental resources for higher-level thinking processing activities by providing support through relatively low-level cognitive activities to realise the sharing of cognitive load (Ge, Turk, & Hung, 2019; Tan, 2019). (Long et al., 2022) categorize thinking tools into VTTs and thinking strategy tools..

VTTs are a set of visual representations that can help users visualize their thinking processes and content, whereas thinking strategy tools can guide the thinking process and provide practical guidance on what and how to think (Long et al., 2022; Zhao et al., 2019). VTTs help students visualise their ideas, structure their thinking patterns, find gaps in their thinking and knowledge, verify their ideas, and explore topics in-depth (Rafik-Galea, 2005). Students understand more quickly in visual forms than in written descriptions or oral conditions (Jacob, Lachner, & Scheiter, 2020). Teachers find that VTTs enhance their teaching efficiency, as structured diagrams, perceived as more comprehensible than words, provide a more straightforward approach to understanding complex topics (Long et al., 2022). Also, VTTs can help teachers improve students' thinking skills. In the teaching process, VTTs can further assist teachers in problem-solving-oriented classes, guide students to understand better and solve cognitive conflicts independently, and finally achieve the purpose of thinking training (Jonassen, 1992).

Thinking maps, *mind maps*, and *concept maps* are the most commonly used VTTs (Long et al., 2022; Rafik-Galea, 2005). Thinking maps consist of eight diagrams, each of which corresponds to a specific thinking skill (Hyerle, 1996). For instance, (Hyerle, 1996) uses the double bubble map to compare and contrast, the multi-flow map to explain cause and effect, and the bridge map to illustrate analogies. Thinking maps are often used to improve reading (Bataineh & Alqatanani, 2017) and writing skills (Cooks & Sunseri, 2014) because they focus on specific thinking skills. *Mind maps* serve as a universal key to unlocking the brain's potential as the external expression of radiant thinking and a powerful graphic technique (Buzan & Buzan, 2006). Novak et al. (1984) *invented concept maps during science classes to document students' learning processes.* Concept maps, which use circles or boxes to represent concepts and connect lines to map relationships, intend to represent meaningful relationships between concepts in propositions (Novak et al., 1984). Using circles or boxes to represent concepts and connecting lines to map relationships, *concept maps* intend to represent meaningful relationships between concepts in propositions (Novak et al., 1984). *Concept maps* were effective in teaching, training, testing (Ruiz-Primo & Shavelson, 1996), and thinking (Eachempati, Ramnarayan, & Mayya, 2020). People often use concept maps to foster critical thinking (Tseng, 2020) and system thinking (Brandstädter, Harms, & Grossschedl, 2012; Khajeloo & Siegel, 2022).

Several studies have concerned the differences between the three VTTs (Davies, 2011) summarised the differences between *concept maps* and *mind maps* from the perspectives of purpose, structure, level of abstraction, nodes, linking devices, linking words, language register, and "granularity." Zhao et al. (2019) pointed out that *thinking maps* are specific representations of particular thinking skills, *mind maps* are fuzzy representations that integrate various thinking skills, and *concept maps* are precise representations that incorporate multiple thinking skills. Moreover, some researchers have identified that various VTTs lead to different learning results. Redhana, Widiastari, Samsudin, and Irwanto (2021) found that Indonesian high school students achieved better academic results using *mind maps* than *concept maps*. Wei, Hutagalung, and Peng (2020) found that first-year indigenous students showed different learning achievements when using *thinking maps*, *concept maps*, and *mind maps*. Davies (2011) emphasised that the choice of a given mapping tool largely depends on the purpose and suggested that educators could discover the unrealised and potentially complementary functions in practice. Thus, using VTTs appropriately in class requires teachers to understand various VTTs comprehensively. An incomplete or confused understanding of commonly used VTTs will prevent them from choosing the most suitable one for the specific teaching scenario. However, based on the literature review, most studies focused on one or two VTTs (mind maps or concept maps). Few studies explored the teachers' understanding of different VTTs.

2.2. Cognitive load of VTTs

A specific task imposes mental activity on an individual's cognitive system, known as cognitive load (Sweller et al., 2011). Since working memory has limits, if the resources required to deal with the task exceed the available resources, the cognitive system will fail to process the necessary information (Sweller et al., 2011). Sweller et al. (2011) further distinguished cognitive load into three types: ICL imposed by the intrinsic nature of the material; ECL imposed by how the material is presented; and germane cognitive load (GCL) devoted to the processing, construction, and automation of schemas. Van Merriënboer and Sweller (2005) research has demonstrated that tasks with high ICL require the management of ECL. When a person uses a complex problem-solving strategy, the ECL it produces may interfere with learning while problem-solving (Sweller, 1988). Therefore, Sweller et al. (2011) asserted that the goal of instructional design is to "reduce ECL, thereby dedicating a greater percentage of the pool of working memory resources to GCL." Many studies sought instructional methods to reduce ECL to increase the GCL (Paas, Renkl, & Sweller, 2003; Sweller, Van Merrienboer, & Paas, 1998; Van Merriënboer & Sweller, 2005).

The perspectives on ICL, ECL, and GCL have developed over time (as shown in Figure 1). According to the model introduced by Sweller et al. (1998), cognitive load is composed of ICL, ECL, and GCL. However, in the updated model by Sweller et al. (2019), the germane load is no longer viewed as a mere component of the total load. Instead, they recognized it as germane processing, and an increase in this load is not necessarily associated with cognitive overload. More recently, the cost-benefit model has suggested that a learning task might encompass various types of extraneous load, each with its own level of germane load, as outlined by Skulmowski and Xu (2022).

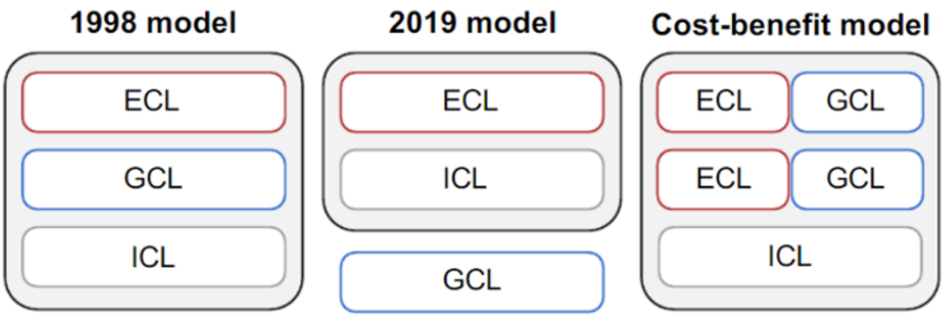

Figure 1. The evolution of the models of cognitive load.

Note: Skulmowski and Xu (2022).

In this study, we employed the 2019 model (Skulmowski & Xu, 2022). When teachers or students use VTTs as teaching or learning aids, the challenges they face can lead to ECL (Sweller et al., 2011). According to the model, the VTTs with lower ECL could be more suitable for teachers and students because lower ECL implies that VTTs are easy to learn and use, which could free up more resources for germane processing (Sweller et al., 2011). Theoretically, *thinking maps*, *mind maps*, and *concept maps* will bring their users different ECLs. However, only a few studies have compared the perceived ECL of teachers using these three VTTs.

2.3. Difficulties at Different Learning Levels

In the *cognitive* domain, Bloom, Engelhart, Furst, Hill, and Krathwohl (1956) classified cognitive skills into six levels (*knowledge*, *comprehension*, *application*, *analysis*, *synthesis*, and *evaluation*), in which the below level serves as the basis of its higher levels. Anderson and Krathwohl (2001), based on Bloom's classic work, separated the knowledge dimension from their cognitive processes and reclassified cognitive processes into remember, understand, apply, analyze, evaluate, and create. The revised model also suggests *cumulative hierarchy*, which indicates that "mastery of a more complex category requires prior mastery of all the less complex categories below it Anderson and Krathwohl (2001)." Similarly, in the *psychomotor* domain, Dave (1970) identified five levels of motor skills (*imitation*, *manipulation*, *precision*, *articulation*, and *naturalisation*), which capture the levels of competence in the stages of learning from initial exposure to final mastery.

However, many scholars criticised the hierarchical structure of learning objectives. Ormell (1974) reported contradictions in the frequent inversion of various goals and tasks. Amer (2006) found that specific demands for *knowledge* are more complex than demands for *analysis* or *evaluation*. According to Marzano, Pickering, and Pollock (2001), the learning objective level differs not only with the learning content itself or the complexity of the cognitive operation, but also with learners' familiarity with the relevant content.

For teachers, *understanding* the rationale behind VTTs, proposing and *applying* scenarios of VTTs in teaching, and *assessing* students' VTT works are essential cognitive skills to be acquired during learning VTTs. Also, *manipulating* VTTs is a fundamental psychomotor skill. Therefore, the present study focuses on these four learning levels and seeks to understand at which levels teachers perceive the highest ICL.

2.4. Research Questions

Using the *Cognitive load theory* lens, this study explored in-service teachers' perceived ICL while learning VTTs. The following research questions were raised in this study:

(1) RQ1: How does the teachers' perceived ICL differ between these three VTTs?

(2) RQ2: At which learning level do teachers perceive the highest ICL for these three VTTs?

3. METHOD

3.1. Research Design

A precondition for comparing the perceived ICL of various VTTs is that all participants should have learned all involved VTTs sufficiently. Therefore, this study conducted investigations after the participants finished a 21-day online training course on VTTs. The online questionnaire was delivered to the participants, and a two-way ANOVA with repeated measures was conducted to analyze the differences in the teachers' perceived ICL at different learning levels for each VTT. The participants' homework and feedback are also collected and analyzed to triangulate the results from the questionnaire.

3.2. Participants: Research Population

The VTT training course lasted from July 10-31, 2022. Altogether, 399 teachers enrolled in the study. Shortly after the participating teachers finished the course, questionnaires were sent out through Wenjuanxing(https://www.wjx.cn/), a widely used online questionnaire platform in China. A total of 220 valid responses were collected, with an effective recovery rate of 55.10%. All the participants completed the questionnaire voluntarily and anonymously.

The valid responses were from teachers from 30 schools in 10 cities in eight provinces in China, representing a variety of geographic distributions. Female teachers comprised 84.55%, which met the typical gender composition of in-service teachers in China. Participants had a large age range (<35: N=153, 69.55%; 35-45: N=45, 20.45%; >45: N=22, 10.00%). Up to 64.09 % (n =141) of the participants taught in elementary schools, 24.55 % (n = 54) in middle schools, and 11.36 % (n =25) in high schools. Appendix Table A1 presents more detailed demographic information.

3.3. Materials and Instrument

3.3.1. Materials

The researchers at a top university in China designed the training course on VTTs and delivered it through Xiaoetong (https://xiaoe-tech.com/), a widespread online knowledge-sharing platform in China. The course comprises ten units, each corresponding to one specific VTT (eight thinking maps, mind maps, and concept maps). Each unit follows a four-phase design (*learning guidance*, *online self-study*, *comment and revise*, *summarise and reflect*) (Figure 2).

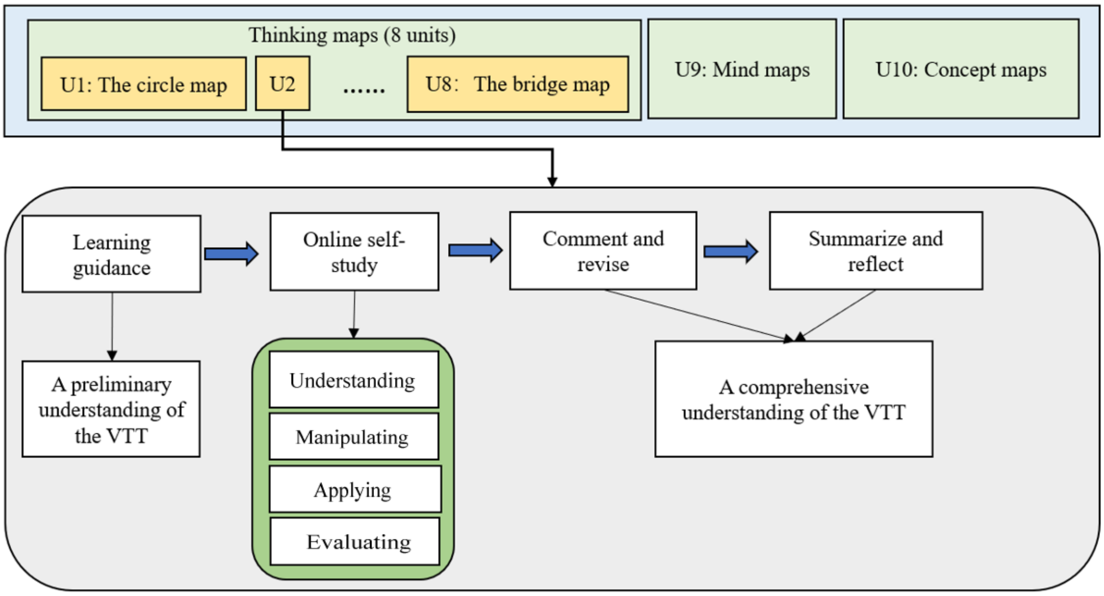

Figure 2. The structure of the training course.

In the *learning guidance* phase, the chief tutor (the course designer with eight years of using and training on VTTs) helped the participating teachers gain a preliminary understanding of VTTs through online live video lectures. During the online self-study stage, the participating teachers watched video clips about a specific VTT. Then, they created maps using familiar topics (such as daily lives and the subjects they taught). In the *comment and revise* phase, the tutors (expert teachers with three or more years of experience using VTTs in their instruction) commented on the works submitted by teachers, and the teachers revised accordingly. In the *summarise and reflect* stage, researchers in teaching thinking gave lectures to help teachers deepen their understanding of the VTTs.

The online self-study phase of each VTT consists of four parts corresponding to four levels of learning objectives, i.e., three of Bloom's revised cognitive objectives (understanding, applying, and evaluating) (Anderson & Krathwohl, 2001) and one of Dave's psychomotor objectives (Dave, 1970). The understanding part introduces VTTs' fundamental principles and concepts. The understanding part introduces VTTs' fundamental principles and concepts. The *manipulating* component presents the mapping rules for each VTT. The application section discusses the teaching scenarios for VTTs. The evaluating part helps teachers assess the quality of the work created with VTTs.

3.3.2. Instrument

The questionnaire with 19 items was used to collect the participants' background information and measure their perceived ICL of the three VTTs. No personal data that might permit the identification of the participants was collected. The demographic information section included the participants' gender, age, teaching experience, and subjects, which may have influenced their learning experience..

We made the Intrinsic Cognitive Load Scale for VTTs (ICL-VTTs) by changing some items in the Cognitive Load Scale (Leppink, Paas, Van Der Vleuten, Van Gog, & Van Merriënboer, 2013) that measure ICL. The Cognitive Load Scale is a three-part psychometric that is commonly used to measure ICL, ECL, and GCL. We measured four items for perceived ICL, which corresponded to four learning levels for each VTT.. For example, we used the item "*The underlying theories and principles of thinking maps are hard to understand*" to measure teachers' perceived ICL while *understanding* thinking maps. The response pattern followed a five-point Likert scale that ranged from "1" (totally disagree) to "5" (totally agree). Appendix Table A2 presents the questionnaire.

3.4. Validity And Reliability Tests

We used SPSS 23.0 to analyse the quantitative data. First, confirmatory factor analysis (CFA) was employed, and Cronbach's alphas (α) were computed to examine the validity and reliability of ICL measures.

Standardised factor loadings were calculated (Figure 3), and the loadings ranged from .63 to .77 for *thinking maps*, .81 to .84 for *mind maps*, and .81 to .90 for *concept maps*, meeting the criterion that all items should be over .50 (Hair, Black, Babin, & Anderson, 2010). The overall Cronbach's alpha was .928, while the value for each factor was over .800, showing satisfactory reliability. The composite reliability (CR) was used to examine the scale items' internal stability with criteria higher than .70 to be considered acceptable (Hair et al., 2010), and all CR values met this requirement (Table 1). As for convergent validity, the average variance extracted (AVE) was calculated, and all AVE values ranged from .515 to .721, higher than the standard of .50, showing good convergent validity (Hair et al., 2010).

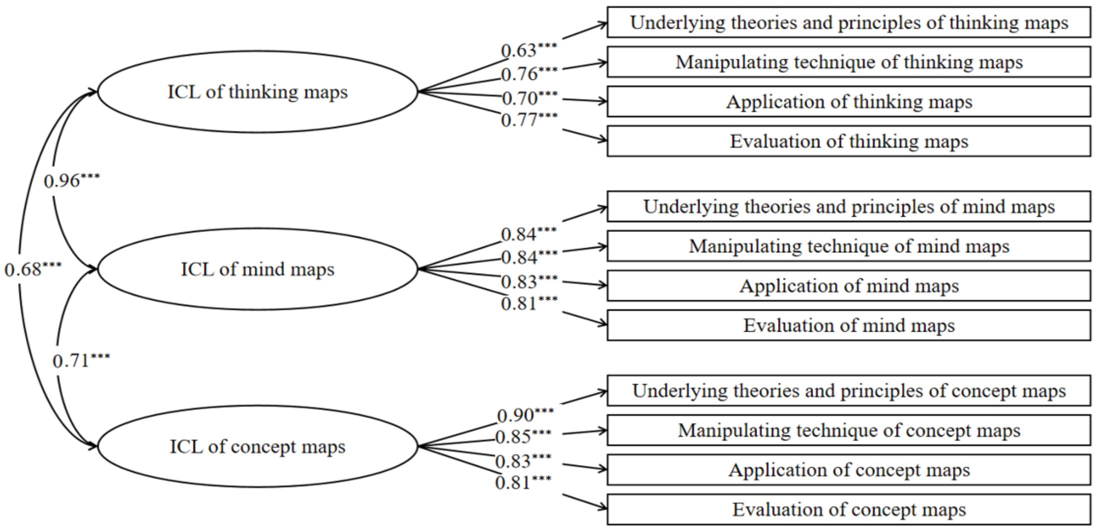

Figure 3. The measurement model of ICL of three kinds of VTTs.

Note: $^{***}p < 0.001$.

Table 1. Results of the CFA on the ICL-VTTs.

Factors	Mean	SD	Cronbach's alpha	CR	AVE
ICL of thinking maps	2.11	0.62	0.801	0.808	0.515
ICL of mind maps	2.00	0.63	0.897	0.897	0.685
ICL of concept maps	2.33	0.81	0.911	0.912	0.721

In addition, the model fit of CFA was tested (Table 2). All the fit indexes met or were close to the criteria suggested by McDonald and Ho (2002), Bentler (1995), Hu and Bentler (1999); Mulaik et al. (1989), and Bollen (1989). Therefore, the adapted scale has acceptable reliability and validity.

Table 2. Fit indices of the measurement model.

Model	χ^2	df	RMSEA	CFI	SRMR	PGFI	IFI
Measure model	198.165	51	0.115	0.922	0.055	0.569	0.922
Recommended value			<0.08	>0.95	<0.08	>0.50	>0.90

Note: RMSEA - Root mean square error of approximation, CFI - Comparative fit index, SRMR - Standardized root mean square residual, PGFI - Parsimony goodness of fit index, IFI - Incremental fit index.

4. RESULTS

4.1. Descriptive Statistics and Inter-Correlations for All Measures

Table 3 displays the means, standard deviations, and correlations between the teachers' perceived ICL of the three VTTs. The results show that the sequence of teachers' perceived ICL is concept maps (M = 2.33, SD =.81), thinking maps (M = 2.11, SD =.62), and mind maps (M = 2.00, SD =.63). The participants' perceived ICLs for the three VTTs are highly correlated, ranging from.51 to.69..

Table 3. Descriptive statistics and Spearman correlations for all measures.

Construct	Score range	M (SD)	1	2
1. ICL of thinking maps	1.00-5.00	2.11(.62)		
2. ICL of mind maps	1.00-5.00	2.00(.63)	0.69**	
3. ICL of concept maps	1.00-5.00	2.33(.81)	0.51**	0.59**

Note: *p < 0.05. **p < 0.01.

Repeated-measures ANOVA was conducted to compare teachers' perceived ICL among the three VTTs (Table 4). The results show that the participating teachers' ICL of different VTTs varied significantly, $F(2, 438) = 36.44$, $p < .001$, partial $\eta^2 = .14$. According to Bonferroni's post hoc tests, participants perceived the heaviest ICL on concept maps and the slightest on mind maps..

Table 4. Repeated-measures ANOVA and Bonferroni's post hoc tests.

Variable	F	Sig.	Partial η^2	Bonferroni's Post hoc comparisons
ICL	36.44	0.000	0.14	Mind maps < Thinking maps < Concept maps

4..2. Perceived ICL of Vtts at Different Learning Levels

Repeated-measures Analysis of Variance (ANOVA) compared teachers' perceived ICL at different learning levels for each VTT (Table 5). The interaction effect was significant, $F(6,1314) = 4.56$, $p < .001$, partial $\eta^2 = .02$.

Table 5. Descriptive statistics of ICLs at four learning levels.

learning level	Thinking map		Mind map		Concept map	
	Mean	SD	Mean	SD	Mean	SD
Understanding	2.17	0.82	1.99	0.71	2.35	0.94
Manipulating	2.10	0.75	2.02	0.73	2.49	1.00
Applying	2.04	0.89	1.93	0.73	2.19	0.86
Evaluating	2.15	0.68	2.05	0.73	2.30	0.84

Figure 4 shows the estimated marginal means of the different VTTs at different learning levels.

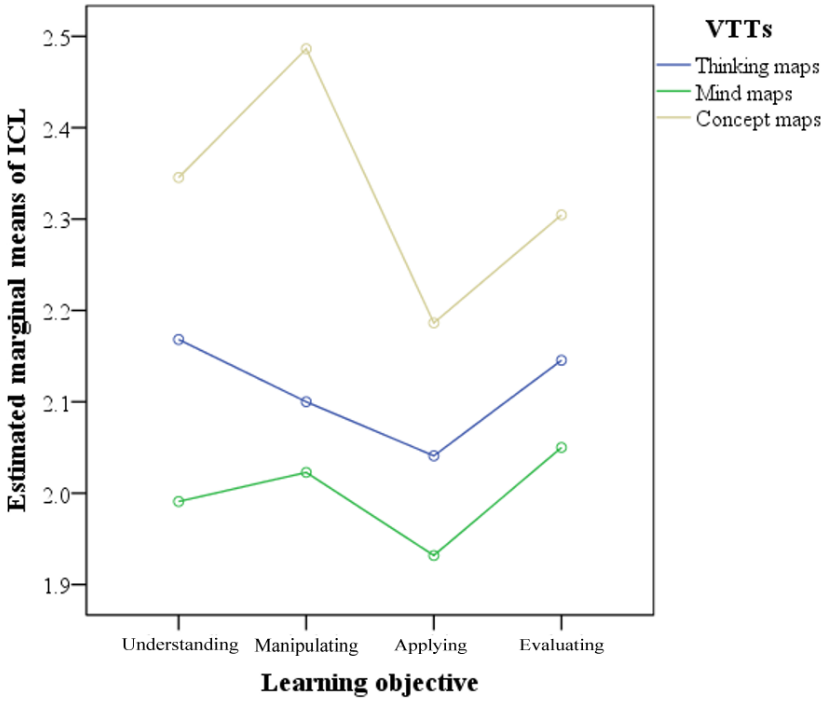

Figure 4. ICL on different learning objectives for the three VTTs.

One-way ANOVAs with repeated measures as further tests for simple effects were run for three VTTs (Table 6). No significant differences were found among the four learning levels for *thinking maps*: $F(3,657) = 2.23$, $p = .083$, partial $\eta^2 = .01$. However, significant differences among four learning levels were found for *mind maps*, $F(3,657) = 3.44$, $p = .017$, partial $\eta^2 = .02$, and *concept maps*, $F(3,657) = 14.42$, $p < .001$, partial $\eta^2 = .06$. Bonferroni's post hoc tests revealed further results, with $p < .05$ as the threshold of significance. For *mind maps*, *evaluating* produced a significantly heavier ICL than *applying*. For concept maps, we found that manipulating had the highest ICL, while applying had the lowest.

Table 6. Simple effects and Bonferroni's post hoc tests.

VTT	F	Sig.	Partial η^2	Bonferroni's post hoc comparisons
Thinking maps	2.23	0.083	0.01	
Mind maps	3.44	0.017	0.02	Applying < Evaluating
Concept maps	14.42	0.000	0.06	Applying < (Understanding, evaluating) < Manipulating

The submitted concept maps and the online feedback from the tutors validate the participants' perceived difficulties in manipulating concept maps.. Over 50% of the concept maps submitted by the participants did not meet the requirement. One participant explained that she misunderstood the "focus question" and forgot about the linking words between concepts (Figure 5). Someone found concept mapping challenging: *"It is difficult to find a piece of paper large enough for drawing a concept map…. "*(Figure 6). Another participant commented, *"I found concept mapping difficult because it requires a high level of logic ….*" (Figure 7). Despite the quality of some participants' concept maps, they expressed dissatisfaction due to the excessive time it required.

"The process of drawing was a bit unfamiliar to me. Initially, I mistakenly wrote the focal issue as 'unit theme, 'influenced by the habit of taking notes on the classroom board. I also tended to forget to include connecting words later on. It was only after completing the drawing that I realized this issue upon reviewing it as a whole. Concept mapping feels quite challenging."

#Lesson 11: Concept maps

Figure 5. A teacher claimed the complexity of concept mapping.

"Task 2 was chosen.Issue encountered:
1.Encountered the problem of the paper being too small during the drawing process and could't find a larger one, so I had to write smaller.
2. Sometime, when it's a bit more complex, it's challenging to achieve a very aesthetic result.
3. For bidirectional relationships, I chose to use double-headed arrows in a way that I understand (Uncertian whether this complies with the standard)."

#Lesson 11: Concept maps

Figure 6. A teacher mentioned the difficulties of concept mapping.

"I'm working on task 3 assignment. I've always found concept maps quite challenging with their numerous logical links. So, I'm starting with the simpler ones to overcome the fear."

#Lesson 11: Concept maps

Figure 7. A teacher expressed her fear of concept mapping.

5. DISCUSSION

5.1. Teachers' Perceived ICL of the Three Vtts

The study revealed that participants perceived varying levels of ICL when learning three VTTs, with concept maps, thinking maps, and mind maps ranking from high to low. According to cognitive load theory, learning materials' element interactivity levels entirely determine ICL (Sweller et al., 2011). We focus on only one thinking skill at a time when creating a thinking map. Divergent thinking and sorting-out skills are the main cognitive processes for *mind-mapping* activities. However, when it comes to concept mapping, users must take into account focus questions, concepts, linking phrases, propositions, and cross-links. As learners' prior knowledge helps reduce their perceived ICL (Sweller et al., 2019), this phenomenon might also be related to the professional development practices of VTTs in China. *Mind maps* have been popular in China for over 20 years. Teachers might have learned mind maps from current professional development programmes or other contexts at leisure. While *thinking maps* have also become popular recently, training on concept maps is still rare.

This study further confirmed the difficulty of *concept mapping* for beginners. This finding is consistent with many existing studies. For example, Conradty and Bogner (2010) identified the mistakes often found by beginners on their concept maps, including the lack of linking, faulty connections, or errors in the directions of arrows. In this study, the participants also encountered these difficulties. The tutors' feedback and the participants' reflections confirmed that they usually missed the linking words during their mapping.

The difficulty of connecting concepts with linking words leads to deep reflections on the relationships among ideas and shapes the knowledge network. Sanchiz, Amadieu, Lemarié, and Tricot (2023) found that students obtained a deep exploration of the hypertext with concept maps. Therefore, the challenges participants faced with concept mapping could potentially mirror the process of building knowledge structures during learning, a process often overlooked in K–12 classrooms. Concept mapping helps visualize the weakness of connecting the knowledge or concepts, which prompts the participants to concentrate on the interrelationships behind the knowledge.

5.2. Perceived ICL of the Vtts at Different Learning Levels

This study found that the participants perceived the slightest ICL at the *applying* level for all three VTTs among the four learning levels. This finding confirms the ease of using all three VTTs claimed by their inventors. During their instruction, the teachers can easily identify suitable application scenarios.

This study also identified the difficulties of learning each VTT at different learning levels. The nature and characteristics of these three VTTs provide insight into this finding. *Thinking maps consist of eight different diagrams, each corresponding to a specific thinking skill, and several pairs (such as the brace map and the tree map) confuse new learners.* Once accurately understood, no significant challenges exist at the *applying, manipulating,* and *evaluating* levels. *Mind mapping* is easy to *understand, manipulate,* and *apply* since it mainly comprises two cognitive processes (brainstorming and sorting out). However, due to a lack of clear and practical evaluation indicators, teachers may struggle to *evaluate* the quality of mind maps that students create. In contrast to thinking maps and mind maps, *concept mapping* has fruitful underlying educational and psychological theories that regulate and constrain the *manipulating* process. These constraints have indeed increased the teachers' reported ICL at the manipulating level. All the findings are exciting and provoking since they uncover the exact "choke points" that the teachers often encounter while learning VTTs.

5.3. Implications for Practice

This study provides insights into the development of professional development programs focused on VTTs for teachers. First and foremost, teachers should systematically learn VTTs before applying them to teaching and learning. Teachers' thorough understanding of VTTs will reduce their perceived complexity while using VTTs and free more working memory for germane processing, which leads to meaningful learning. Secondly, teachers should teach or learn a set of VTTs together, rather than solely or separately. A comprehensive understanding of VTTs can help teachers choose the most appropriate one according to specific teaching scenarios. For another, as Marzano et al. (2001) pointed out, identifying similarities and differences is the most high-yield instructional strategy; learning *thinking maps, mind maps,* and *concept maps* together enables teachers to reflect on the similarities and differences among these three popular VTTs and gain a comprehensive understanding. Thirdly, teacher professional development courses on three VTTs should focus on *understanding* the subtle differences between eight diagrams of thinking maps, *manipulating* concept maps, and *evaluating* mind maps.

5.4. Limitations and Future Work

There are several limitations to the current study. First, this study explored the participants' experience with *thinking maps* in general. However, the participants' feedback indicated differences between the eight diagrams of thinking maps. Exploring the ICL separately for eight different diagrams. Second, this study measured the ICL mainly on a self-reported questionnaire, which could be complemented with other tools in the future, such as performance-based tasks or eye tracking (Andrzejewska & Skawińska, 2020).

6. CONCLUSIONS

VTTs play a critical role in teaching thinking in K–12 schools. Choosing the most appropriate VTT and using them reasonably in class depends on teachers' understanding of the VTTs. Well-designed professional development programs can help teachers gain a comprehensive understanding of VTTs. This study investigated teachers' learning experiences with three popular VTTs, and it is the first empirical study comparing the learning experiences of three VTTs from the Cognitive Load Theory perspective.

This study verified that *concept maps* have the highest inherent complexity, followed by *thinking diagrams* and *mind ma*ps. Results also show that, among different learning levels, *applying* is the most accessible level for all three VTTs. However, the biggest challenge arises when it comes to understanding, evaluating, and manipulating thinking maps, mind maps, and concept maps during the learning process. These findings are based on the teachers' self-reported ICLs following their systematic training of the three VTTs, thereby avoiding any potential deceptive clarity issues. The findings contribute to the teaching thinking area by verifying the simple use of three VTTs and uncovering the challenges while learning each VTT.

In addition, this study also suggests that ICL is a useful theoretical tool to reflect the participants' learning experiences and guide the design of training courses. Future research should involve a larger number of VTTs and include students from various grades as participants. More research should also be done on the connections between the ECL that VTTs cause and the relevant resources that are needed for substantial learning when VTTs are used as teaching aids.

REFERENCES

Amer, A. (2006). Reflections on Bloom's revised taxonomy. *Electronic Journal of Research in Educational Psychology, 4*(1), 213-230.

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. New York: Longman.

Andrzejewska, M., & Skawińska, A. (2020). *Examining students' intrinsic cognitive load during program comprehension–an eye-tracking approach*. Paper presented at the International Conference on Artificial Intelligence in Education. Springer, Cham.

Bataineh, R., & Alqatanani, A. (2017). The effect of a thinking maps-based instructional program on Jordanian EFL tenth-grade students' critical reading skills. *Asian EFL Journal, 101*(2), 31-61.

Bentler, P. M. (1995). *EQS structural equations program manual* (Vol. 6). Encino, CA: Multivariate Software.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals. Handbook 1: Cognitive domain. In (pp. 1103-1133). New York: Longman.

Bollen, K. A. (1989). *Structural equations with latent variables*. New York: John Wiley and Sons, Inc.

Brandstädter, K., Harms, U., & Grossschedl, J. (2012). Assessing system thinking through different concept-mapping practices. *International Journal of Science Education, 34*(14), 2147-2170. https://doi.org/10.1080/09500693.2012.716549

Buzan, T., & Buzan, B. (2006). *The mind map book*. Harlow: Pearson Education.

Conradty, C., & Bogner, F. X. (2010). Implementation of concept mapping to novices: Reasons for errors, a matter of technique or content? *Educational Studies, 36*(1), 47-58. https://doi.org/10.1080/03055690903148605

Cooks, J., & Sunseri, A. (2014). Leveling the playing field: The efficacy of thinking maps on English language learner students' writing. *CATESOL Journal, 25*(1), 24-40.

Dave, R. H. (1970). *Psychomotor levels. In R. J. Armstrong (Ed.), Developing and writing behavioral objectives*. Tucson: Educational Innovators Press.

Davies, M. (2011). Concept mapping, mind mapping and argument mapping: What are the differences and do they matter? *Higher Education, 62*, 279-301. https://doi.org/10.1007/s10734-010-9387-6

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340. https://doi.org/10.2307/249008

Eachempati, P., Ramnarayan, K. K. K., & Mayya, A. (2020). Concept maps for teaching, training, testing and thinking. *MedEdPublish*, *9*, 171. https://doi.org/10.15694/mep.2020.000171.1

Ge, X., Turk, M., & Hung, W. (2019). Revisiting cognitive tools from a social and motivational perspective. *Australasian Journal of Educational Technology*, *35*(2), 1-13. https://doi.org/10.14742/ajet.4887

Greiff, S., Niepel, C., & Wüstenberg, S. (2015). 21st century skills: International advancements and recent developments. *Thinking Skills and Creativity*, *100*(18), 1-3. https://doi.org/10.1016/j.tsc.2015.04.007

Hair, J. J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis* (7th ed.). New York: Prentice Hall.

Hu, L. t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1-55. https://doi.org/10.1080/10705519909540118

Hyerle, D. (1996). *Visual tools for constructing knowledge* (Vol. ASCD): Alexandria, VA.

Hyerle, D., & Alper, L. (2011). *Student successes with thinking maps®: School-based research, results, and models for achievement using visual tools* (2nd ed.). Thousand Oaks, CA: Corwin Press.

Jacob, L., Lachner, A., & Scheiter, K. (2020). Learning by explaining orally or in written form? Text complexity matters. *Learning and Instruction*, *68*, 101344. https://doi.org/10.1016/j.learninstruc.2020.101344

Jonassen, D. H. (1992). What are cognitive tools? In Kommers, Piet A. M., Jonassen, David H., & Mayes, J. Terry., Ferreira, Alcindo (Eds.), Cognitive tools for learning. In (pp. 1–6). Berlin, Heidelberg: Springer.

Khajeloo, M., & Siegel, M. A. (2022). Concept map as a tool to assess and enhance students' system thinking skills. *Instructional Science*, *50*(4), 571-597. https://doi.org/10.1007/s11251-022-09586-5

Leppink, J., Paas, F., Van Der Vleuten, C. P., Van Gog, T., & Van Merriënboer, J. J. (2013). Development of an instrument for measuring different types of cognitive load. *Behavior Research Methods, 45*, 1058-1072. https://doi.org/10.3758/s13428-013-0334-1

Long, T., Zhao, G., Li, X., Zhao, R., Xie, K., & Duan, Y. (2022). Exploring Chinese in-service primary teachers'technological pedagogical content knowledge (TPACK) for the use of thinking tools. *Asia Pacific Journal of Education*, *42*(2), 350-370. https://doi.org/10.1080/02188791.2020.1812514

Long, T., Zhao, G., Yang, X., Zhao, R., & Chen, Q. (2021). Bridging the belief-action gap in a teachers' professional learning community on teaching of thinking. *Professional Development in Education*, *47*(5), 729-744. https://doi.org/10.1080/19415257.2019.1647872

Marzano, R. J., Pickering, D., & Pollock, J. E. (2001). *Classroom instruction that works: Research-based strategies for increasing student achievement*. Alexandria, VA: Association for Supervision and Curriculum Development.

McDonald, R. P., & Ho, M.-H. R. (2002). Principles and practice in reporting structural equation analyses. *Psychological Methods*, *7*(1), 64-82. https://doi.org/10.1037//1082-989x.7.1.64

Mulaik, S. A., James, L. R., Van Alstine, J., Bennett, N., Lind, S., & Stilwell, C. D. (1989). Evaluation of goodness-of-fit indices for structural equation models. *Psychological Bulletin*, *105*(3), 430–445. https://doi.org/10.2466/pr0.67.6.669-670

Novak, J. D., Gowin, D. B., & Bob, G. D. (1984). *Learning how to learn*. London: Cambridge University Press.

Ormell, C. P. (1974). Bloom's taxonomy and the objectives of education. *Educational Research*, *17*(1), 3-18.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1-4. https://doi.org/10.1207/s15326985ep3801_1

Pakdaman-Savoji, A., Nesbit, J. C., & Gajdamaschko, N. (2019). The conceptualisation of cognitive tools in learning and teachnology: A review. *Australasian Journal of Educational Technology*, *35*(2), 1-24. https://doi.org/10.14742/ajet.4704

Rafik-Galea, S. (2005). Visual thinking tools in enhancing ESL students' writing ability. *English Language & Literature Teaching, 11*(2), 67-89.

Redhana, I. W., Widiastari, K., Samsudin, A., & Irwanto, I. (2021). Which is more effective, a mind map or a concept map learning strategy? *Jurnal Cakrawala Pendidikan, 40*(2), 520-531. https://doi.org/10.21831/cp.v40i2.33031

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 33*(6), 569-600. https://doi.org/10.1002/(sici)1098-2736(199608)33:6%3C569::aid-tea1%3E3.0.co;2-m

Sanchiz, M., Amadieu, F., Lemarié, J., & Tricot, A. (2023). Do graphic and textual interactive content organizers have the same impact on hypertext processing and learning outcome? *Journal of Computing in Higher Education, 35*(3), 433-465. https://doi.org/10.1007/s12528-022-09328-z

Schroeder, N. L., Nesbit, J. C., Anguiano, C. J., & Adesope, O. O. (2018). Studying and constructing concept maps: A meta-analysis. *Educational Psychology Review, 30*, 431-455. https://doi.org/10.1007/s10648-017-9403-9

Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. *Educational Psychology Review, 34*(1), 171-196. https://doi.org/10.1007/s10648-021-09624-7

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257–285. https://doi.org/10.1016/0364-0213(88)90023-7

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory* (1st ed.). New York: Springer.

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

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. https://doi.org/10.1007/s10648-019-09465-5

Tan, S.-C. (2019). Learning with computers: Generating insights into the development of cognitive tools using cultural historical activity theory. *Australasian Journal of Educational Technology, 35*(2), 1-14. https://doi.org/10.14742/ajet.4848

Tseng, S.-S. (2020). Using concept mapping activities to enhance students' critical thinking skills at a high school in Taiwan. *The Asia-Pacific Education Researcher, 29*(3), 249–256. https://doi.org/10.1007/s40299-019-00474-0

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review, 17*(2), 147–177. https://doi.org/10.1007/s10648-005-3951-0

Wei, Y. S., Hutagalung, F. D., & Peng, C. F. (2020). *The effectiveness of thinking maps, mind maps, and concept maps toward cognitive abilities among year 1 indigenous learners in the social sciences empowered* (1st ed.). London: CRC Press.

Zhao, G., Yang, X., & Xiong, Y. (2019). On the Principles and Focal Points of Applying Thinking Visualization Tools in Teaching and Learning. *E-Education Research, 40*(9), 59–66.

Appendix A

Appendix A includes the Table A1 which illustrates the demographic information of the participants and Table A2 presenting the questionnaire of ICL-VTTs.

Table A1. Demographic information of the participants.

Characteristics	Categories	Frequency	Percentage (%)
Gender	Male	34	15.45%
	Female	186	84.55%
Age	Under 35 years old	153	69.55%
	35–45 years old	45	20.45%
	More than 45 years old	22	10.00%
Teaching experience	Under two years	78	35.45%
	2–3 years	31	14.09%
	3–4 years	14	6.36%
	5–10 years	32	14.55%
	More than ten years	65	29.55%
Grade	Primary school	141	64.09%
	Junior high school	54	24.55%
	Senior high school	25	11.36%
Subject	Chinese	76	34.55%
	Mathematics	41	18.64%
	English	26	11.82%
	Science	6	2.73%
	Physics	8	3.64%
	Chemistry	6	2.73%
	Biology	5	2.27%
	History	4	1.82%
	Geography	5	2.27%
	Politics	14	6.36%
	IT	5	2.27%
	Music	4	1.82%
	Arts	4	1.82%
	PE	13	5.91%
	Others	3	1.36%
City	Beijing	79	35.91%
	Guangzhou	4	1.82%
	Shenzhen	76	34.55%
	Luoyang	4	1.82%
	Pingdingshan	1	0.45%
	Changzhou	1	0.45%
	Yinchuan	9	4.09%
	Weifang	3	1.36%
	Xi'an	39	17.73%
	Shanghai	4	1.82%
Degree	Associate or below	19	8.64%
	Bachelor	103	46.82%
	Master	92	41.82%
	Doctor	6	2.73%

Table A2. Reliability coefficients and descriptive statistics of ICL-VTTs.

Item	Description	Mean	S. D.
Cognitive load (Cronbach's α = .928)			
The intrinsic cognitive load of thinking maps (Cronbach's α = 0.801)		2.11	0.62
ICL_thinking_map_1(Understanding)	The underlying theories and principles of thinking maps are hard to understand.	2.17	0.82
ICL_thinking_map_2(Manipulating)	The manipulating technique of thinking maps is hard to grasp.	2.10	0.75
ICL_thinking_map_3(Applying)	The application context of thinking maps is hard to find.	2.04	0.89
ICL_thinking_map_4(Evaluating)	The quality of a thinking map is hard to evaluate.	2.15	0.68
The intrinsic cognitive load of mind maps (Cronbach's α = 0.897)		2.00	0.63
ICL_mind_map_1(Understanding)	The underlying theories and principles of mind maps are hard to understand.	1.99	0.71
ICL_mind_map_2(Manipulating)	The manipulating technique of mind maps is hard to grasp.	2.02	0.73
ICL_mind_map_3(Applying)	The application context of mind maps is hard to find.	1.93	0.73
ICL_mind_map_4(Evaluating)	The quality of a mind map is hard to evaluate.	2.05	0.73
The intrinsic cognitive load of concept maps (Cronbach's α = 0.911)		2.33	0.81
ICL_concept_map_1(Understanding)	The underlying theories and principles of concept maps are hard to understand.	2.35	0.94
ICL_concept_map_2(Manipulating)	The manipulating technique of concept maps is hard to grasp.	2.49	1.00
ICL_concept_map_3(Applying)	The application context of concept maps is hard to find.	2.19	0.86
ICL_concept_map_4(Evaluating)	The quality of a concept map is hard to evaluate.	2.30	0.84