Enhancing Conceptual Understanding through Concept Map Recomposition: Strategies for Improving the Activity and Extending its Use to the Procedural Domain

(概念マップの再構成による概念的理解の促進：活動の改善と手続き的領域への活用のための戦略)

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Declaration of Authorship

I, Nawras Nazar Khudhur, hereby declare that I am the sole author of this dissertation. This is a true copy of the dissertation, including any required final revisions, as accepted by the examiners. Therefore, I declare:

- All direct or indirect sources used are acknowledged as references.
- This dissertation was not previously presented to another examination board and submitted for the requirement of any other degree.
- Other external sources are cited and acknowledged with bibliography appearing at the end of this dissertation.

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Abstract

Conceptual understanding is the core component of learning. It refers to a state of learning where new knowledge is related to learners' previous knowledge, which allows for the application and use of knowledge in new contexts other than the base context. Concept map is a popular method for promoting conceptual understanding, as it creates a visual representation of the relationships between various concepts. Concept map recomposition is a specialized concept map activity tailored for educational purposes, where the teachers' understanding of a topic is an essential component of it. In concept map recomposition, the learners are given the necessary components to recompose the ideal concept map. These components are generated by decomposing the ideal concept map created by an expert (mostly teachers in the educational setting). Although many studies confirm the superiority of recomposition method compared to traditional concept map in multiple aspects, the activity of recomposing concept maps can be difficult and cognitively demanding, especially when dealing with complex topics. Investigating best practices during concept map recomposition is heavily needed in order to improve learners' experience and significantly influences the efficiency of concept map recomposition in conceptual understanding. In this study, the effectiveness of concept map recomposition in promoting conceptual understanding was examined, with a focus on improving the recomposition activity and extending its use to the procedural domain, particularly in object-oriented programming. Procedural domain knowledge is where the learner focuses on the knowledge-how. It focuses on problem-solving tasks that have practical implications involving specific steps to solve. To improve the efficiency of the recomposition activity, this study investigates reducing its' cognitive load. Reducing the cognitive load in recomposition is crucial to allow learners to focus more on the content of the learning task, rather than being overwhelmed by the instructional demands of it. However, cognitive load is necessary to create motivation and prevent learners from becoming bored with the learning task which could impact the learning outcome. Thus, controlling for motivation and learning quality has also been considered. Partial decomposition approach is proposed to reduce the cognitive load while maintaining the learning benefits of traditional concept map recomposition. In partial decomposition, learners are given a partially decomposed ideal concept map instead of a fully decomposed one. The experimental results showed a significant reduction in the embedded cognitive load of concept map recomposition across different dimensions while learning effect and motivation remained similar to the traditional recomposition activity. In addition, understanding the relationship between reading materials and learning quality during the recomposition activity is important for improving the activity. To investigate this relationship, a study was conducted, examining the influence of reading time on reading comprehension and the effect of providing access to the reading material on reading comprehension during concept map recomposition. Analysis revealed that higher reading times were associated with better reading comprehension and better retention. Furthermore, having access to the reading material improves short-term reading comprehension compared to not having access, but long-term retention was not improved. This suggests that having access to the text while recomposing the concept map can improve reading comprehension, but long-term learning can only be improved if students invest time in accessing both the map and the text. The use of proposed strategies improved the effectiveness and efficiency of the recomposition activity. Results suggest that when preparing for recomposition activity, educators consider using partially disconnected concept maps to save time and keep the learners motivated so that the saved energy and time can be directed toward a different form of activity to boost the learning process. One recommended activity could be to encourage learners to take time to read the base material during the concept map recomposition as the results showed that reading time during the recomposition activity is associated with higher learning quality. Moreover, the application of concept map recomposition to object-oriented programming (OOP) was explored. OOP is a programming paradigm that consists of several core concepts which are crucial to the novice learner, and it is said to be challenging at the same time. Novice learners often struggle to see the connections between the concepts of OOP and how their practical implications are applied in real-world scenarios. To address this, a novel cognitive diagram was created for both theoretical and practical knowledge of OOP. Theoretical knowledge refers to the principles and concepts of a subject, while practical knowledge is the application of those concepts in actual source-code. By combining both theoretical and practical knowledge in the cognitive diagram and using concept map recomposition to improve understanding of OOP concepts, this study aims to support novice learners in their learning of these complex topics within the procedural domain of programming. The implementation of this approach in a real classroom setting suggested that the new cognitive diagram is well-received and highly engaging for learners. The results suggest that the proposed strategy can be considered as one important activity to increase the conceptual understanding of OOP concepts and their practical application.

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Finally, I hope that readers of this dissertation will find it enjoyable and informative, and I hope that it will contribute to the field of educational technology and learning analytics in a meaningful way.

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クルディスタンに捧げます。

Dedicated to my beloved people of Kurdistan.

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List of Publications

Journal Article

- Khudhur, N., Pinandito, A., Hayashi, Y., & Hirashima, T. (2024). Investigating the Efficacy of Partial Decomposition in Kit-Build Concept Maps for Reducing Cognitive Load and Enhancing Reading Comprehension. *IEICE Transactions on Information and Systems*, E107-D(5), 714–727. doi:10.1587/transinf.2023EDP7145
- Furtado, P. G. F., Hirashima, T., Khudhur, N., Pinandito, A., & Hayashi, Y. (2021). Influence of access to reading material during concept map recomposition in reading comprehension and retention. *IEICE Transactions on Information and Systems*, E104-D(11), 1941–1950. doi:10.1587/transinf.2021EDP7069
- Khudhur, N., Nurmaya, Hayashi, & Y. Hirashima, T. (2023). Conceptual Representation of the Source-Code to Support the Learning of Object-Oriented Programming Concepts. *International Journal of Information and Education Technology*, Vol.13(12), 1858-1867. doi:10.18178/ijiet.2023.13.12.1999

International Conference Article

- Khudhur, N., Furtado, P. G. F., Pinandito, A., Matsumoto, S., Hayashi, Y., & Hirashima, T. (2021). Conceptual Level Comprehension Support of the Object-Oriented Programming Source-Code Using Kit-Build Concept Map. In *Proceedings of the 29th international conference on computers in education. asia-pacific society for computers in education*, 1, 315–320.

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Chapter 1

Introduction

A concept is an abstraction of knowledge and is considered as a fundamental building block of thought. A concept can be described as a perceived regularity in events or objects, or records of events or objects designated by a label. The label for most concepts is a word, but it could also be described in symbols (Cañas et al., 2013).

Conceptual understanding refers to a state of learning in which new knowledge is connected to a learner's previous knowledge (Mills, 2016). It allows the learners to think with the comprehended concept, and apply the new knowledge in contexts beyond the base context in which they learned it. This type of understanding is considered to be a core component of learning, as it enables learners to fully grasp and retain new information and to use it to solve problems and make informed decisions in a variety of contexts. Without a strong foundation of conceptual understanding, learners may struggle to retain and apply new knowledge, leading to poor learning outcomes. Therefore, it is important for educators to focus on promoting conceptual understanding in their teaching practices for the long-term success of the learners.

Concept map is one of the successful and proven techniques to promote conceptual understanding in a variety of subjects including scientific ones (Gabel, 2003). Concept map creates a visual representation of the relationships between different concepts of a topic. A comprehensive conceptual understanding would involve knowing about these relationships that exist in the topic. From this perspective, concept maps support learners to visualize and organize the connections between different concepts and fit the visualized knowledge into the larger structure of the topic. Furthermore, the utility of concept maps extends beyond visualization, actively engaging learners in the process of constructing their mental models. As individuals create concept maps, they must articulate the relationships and hierarchies between different concepts, fostering a deeper level of cognitive processing. In essence, concept maps serve as dynamic tools that not only capture existing knowledge but also facilitate the ongoing evolution of a learner's conceptual framework.

One form of concept map activity is concept map recomposition (Hirashima, 2019; Hirashima et al., 2015). In this activity learners are given the necessary components needed to recompose an ideal concept map. The ideal concept map is a concept map that is created by an expert (usually a teacher in an educational setting). The objective of the expert map is to direct learners to a shared understanding of a topic and prepare a ground for better critical discussion.

Despite being superior to traditional concept mapping activity in multiple educational aspects (Nurmaya et al., 2023; Pinandito, Hayashi, & Hirashima, 2021; Prasetya et al., 2021), it can also be cognitively demanding as described by previous study (Fonteles Furtado et al., 2018). It is expected to be even more difficult when dealing with complex topics. Therefore, this study aims to investigate best practices for improving the efficiency of the recomposition activity. The best practice is investigated from two perspectives, one is to focus on reducing the demanding cognitive load of the recomposition task. The second is to explore the effects of providing/removing access to the reading material during the recomposition task. It is important for educators to understand the (de)merits to customize the recomposition activity that best suits the environment and the desired learning outcome.

In addition, this study aims to extend the concept map recomposition use to the procedural domain, which focuses on problem-solving tasks with practical implications. Particularly, we focus on promoting the conceptual comprehension of the concepts of Object-Oriented Programming (OOP). In the literature, it is been shown that educators of computer programming courses specifically concepts of OOP, are facing difficulties providing sufficient support and activity style to the learners, as the learners find it difficult to understand this abstracted knowledge of programming. Although learners study the concepts in theory, but they struggle in connecting it to the practical aspect of it. Most of the research in this area either focuses on the theoretical aspect of OOP concepts or the visualization of the source-code. However, no study up to the authors' knowledge has tried to integrate both of these knowledge bases to provide a structure where the learner can connect the theoretical concepts to their applications in practice. By examining the effectiveness of concept map recomposition in promoting conceptual understanding in this context, this study aims to provide insights and recommendations for educators looking to improve the learning experience and outcomes of these classes. Conceptual Representation of the Source-code (CRS) is proposed as the unique visualization approach to support the learners in integrating two different knowledge bases where one has theoretical abstracts and the other has procedural nature in it.

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Chapter 2

Related Works

2.1 Concept map and Types of Concept map Construction

A concept map is a graphical diagram that depicts knowledge through interconnected concepts and relationships. Individuals can articulate their understanding by creating A concept map is a graphical tool used to organize and represent knowledge or information visually. It consists of a collection of concepts or ideas that are linked together by relationships or connections to form a structured and hierarchical representation of a subject or topic. Concept maps can be used to show the relationships between ideas, identify patterns, and clarify complex information. The visual structure of a concept map makes important information and relationships between ideas clear and apparent, allowing individuals to convey their ideas more efficiently. Concept maps are commonly used in education, research, and problem-solving to help individuals better understand and visualize information (Balım, 2013; Gijlers & Jong, 2013; Hu & Chen, 2013; Hubwieser & Mühling, 2011; S.-P. Wang & Chen, 2018). Figure 2.1 shows an example of a concept map.

Prior studies revealed that integrating learning activities with concept maps could significantly enhance students' problem-solving skill performance (Hwang et al., 2014; Kamble & Tembe, 2013; Karadag et al., 2021). In addition to promoting meaningful learning to students, using concept maps in learning could potentially improve students' interests and learning achievements better than the traditional learning expository (Chiou, 2008). Concept mapping has the potential to enhance teacher-student interactions and foster the generation and expansion of knowledge (Hay et al., 2008). Even though

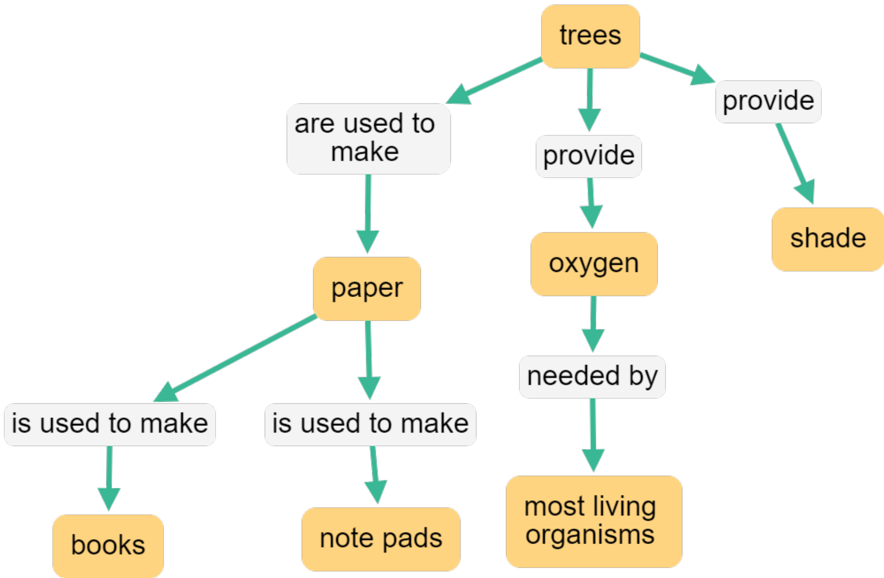

Fig. 2.1 A sample Concept Map depicting a visual representation of the relationships between various concepts related to trees

prior studies indicated various challenges and limitations in utilizing concept maps in academic practices for both teacher and student (Opotamutale Ashipala et al., 2023; Pinandito, Prasetya, et al., 2021), concept maps can be accepted as an alternative method for learning (Machado & Carvalho, 2020).

Essentially, there are two types of concept mapping approaches in terms of how a concept map is constructed or developed. The first approach provides a flexible method where authors begin with a blank canvas, allowing them to freely incorporate and personalize their own interests, knowledge, and external resources into the concept map. This approach is commonly referred to as Open-end Concept Map (OCM) (Oliver, 2008). The second approach is referred to as a Closed-end Concept Map (CCM). In CCM environment, the author is provided with a finite set of pre-selected concepts and links offering a different cognitive activity. Closed-end Concept Map (CCM) learning strategy can help teachers assess students' understanding and improve the quality of their teaching (Wu et al., 2012).

This work utilizes concept maps as graphic organizers. By adopting concept maps, individuals can effectively organize and represent their understanding of a subject matter. This work specifically focuses on the recomposition of the educator's concept map, where learners are tasked with rearranging and reestablishing the interconnections between concepts and relationships as understood by the educator to create a shared understanding within the learning environment. Such understanding is said to facilitate effective communication, collaboration, and problem-solving.

2.2 Kit-Build Concept Map Recomposition

Hirashima et al. (2015) introduced *Kit-Build Concept Map Recomposition (KB-CMR)* that adopts the CCM approach. In a KB-CMR, domain experts or teachers create a concept map (i.e. expert map) of a learning topic and learners recompose the expert map by using the same set of concepts and links used in the expert map. The pre-selected set is generated by disconnecting the links from the concepts. Expert concept map in the context of this study refers to the ideal map according to the understanding of a professional in the subject of matter. The expert map serves as the baseline for learners to have a shared understanding about a particular subject. The professional is the teacher in an educational setting. The basic steps of a KB-CMR activity are as follows: 1) The expert creates a concept map for a material. 2) The expert concept map is then decomposed into its basic parts by removing the connections, thus creating a *kit* of concepts and links. 3) The kit is then given to the learners to recompose it back to the expert map.

In KB-CMR, *kit* refers to the components that make up a proposition. In a proposition, there are two concepts connected by a single link. One of these concepts is known as the source concept. This concept represents the 'subject' or 'agent' within the proposition. It usually denotes the entity carrying out the action or being described by the proposition. The second concept is referred to as the target concept. It serves as the 'predicate' or 'complement' within the proposition, often providing information about the action or description associated with the subject. For example, in the proposition "Fish lives in the water", The source concept is "Fish", and the target concept is "in the water". During the kit generation, the formation of the source and target concepts are derived automatically from the expert map based on the expert's decision.

Since the concept of recomposition is central to our study, in the following sections we delve into key aspects of recomposition from theoretical and practical perspectives.

2.2.1 Recomposition's Challenge and Learning Value: Theoretical Perspective

From a theoretical standpoint, recomposition emerges as a demanding cognitive process. When learners embark on recomposing a concept map from its specified components, the initial step involves recognizing these components correctly. Any misinterpretation at this stage may impede the entire recomposition process. Subsequently, learners must comprehend the meaning of each component and make connections that form meaningful propositions. Given the vast possibilities for connections, identifying the appropriate propositions to represent the target content's essence is paramount. Moreover, recognizing the structure being recomposed is crucial to adequately complete the recomposition. For instance, previous research (Rismanto et al., 2023) reported that learners who recompose specific parts of a concept map sequentially obtained better learning results than learners who recompose a concept map randomly. This theoretical analysis underscores that recomposition is far from a simple replication task; it involves a profound understanding of the map's meaning and structure.

Recomposition serves as a powerful tool for learning, primarily because it necessitates the active engagement of the learners' cognitive processes. In the recomposition process, learners are required to draw upon their individual understanding. Correctly recognizing components, formulating propositions, and identifying substructures all demand the application of their own comprehension. As a consequence, recomposition inherently encourages learners to reflect upon their understanding. Learners cannot complete the recomposition if their understanding is not enough or wrong. Thus, recomposition serves as a mechanism through which learners become aware of gaps or inaccuracies in their knowledge, which, in turn, motivates them to improve their understanding.

In the studies of KB-CMR, we define learners' understanding as their ability to comprehend others' perspectives, which can be referred to as *empathetic understanding*. It focuses less on arriving at the correct answer and more on grasping how someone else perceives a situation. Hence, it is crucial to emphasize that the absence of a learner's ideas in the expert map does not necessarily imply their ideas are incorrect, rather it supports learners in their communication. For effective communication, the expert decides on the ideal knowledge to be shared by the learners through the expert map. The elements within the expert map serve as scaffolds to enhance this communication. In the learner-educator context, the learner gets a chance to reflect upon their understanding via educators' understanding i.e. recomposing expert map. In the learner-learner context as in the case for reciprocal KB-CMR Sadita, Hirashima, Hayashi, Wunnasri, et al. (2020), learners actively attempt to build the map of their partner, promoting effective communication among themselves. Being aware of both another person's understanding and one's own, can foster an environment for more effective discussion. This awareness helps learners appreciate the variations or gaps in comprehension among learners or with the educator. Viewing learning as a social activity underscores that this facilitation of communication inherently fosters learning itself.

2.2.2 Evidence of Recomposition's Learning Value and Challenge: Practical Perspective

Recomposition, as a concept, is not merely theoretical; it finds validation in practical educational settings. Our university-level experiences substantiate that recomposition is no easy feat, even for students at this level. The effectiveness of recomposition concept maps has been demonstrated in several studies targeting university students, to cite a few (Hirashima, 2019; Nurmaya et al., 2023; Pinandito, Hayashi, & Hirashima, 2021; Rismanto et al., 2023; Sadita, Furtado, et al., 2020; Sadita, Hirashima, Hayashi, Furtado, et al., 2020; Sadita, Hirashima, Hayashi, Wunnasri, et al., 2020; Wunnasri et al., 2018). These studies have consistently reported significant achievements, providing empirical support for the theoretical underpinnings of the recompositional concept map.

In a recent investigation by Nurmaya et al. (2023), the significance of Kit-Build concept maps in fostering higher-order thinking was explored. Undergraduate students were assigned to two conditions: Open-end Concept Map (OCM) and Kit-Build recomposition. The study found that Kit-Build was more effective in enhancing higher-order thinking skills than OCM. The authors contend that Kit-Build concept mapping enables students to allocate more cognitive resources to organizing and integrating knowledge, rather than becoming halted in defining concepts. By relieving students from lower-order tasks like concept definitions, they can more deeply engage in higher-order cognitive activities, such as analyzing relationships and synthesizing concepts, ultimately enhancing their higher-order thinking abilities.

Another study proposed reciprocal Kit-Build concept mapping. The study was implemented in a real classroom setting, allowing the reconstruction of a partner's concept map. The proposed method revealed improved pair discussions about map differences before collaborating to construct a new map. This approach was deemed valuable for eliciting ideas, understanding partners, and integrating diverse perspectives (Sadita, Furtado, et al., 2020; Sadita, Hirashima, Hayashi, Wunnasri, et al., 2020). Furthermore, Pinandito, Wulandari, et al. (2021) showcased that Kit-Build surpasses traditional OCM in collaborative environments, particularly in fostering meaningful discussions among students and enhancing overall learning outcomes. The Kit-Build approach encourages students to engage in discussions about the content of the concept maps, shifting the focus from procedural matters. The study also found that Kit-Build stimulates students to explore and contemplate ideas beyond those suggested by the prescribed components, thereby fostering curiosity and creating a "spread of effect" that motivates them to consider additional ideas.

2.3 Cognitive Load in Kit-Build Concept Map Recomposition

Cognitive load in learning concerns to the amount of information or instructional methods processed in one's working memory during learning activities (Sweller et al., 1998). Because students have a limited capacity of working memory to process new information, instructors should efficiently manipulate students' working memory with activities or learning tasks that directly contribute to learning (Artino, 2008; Mayer, 2014; Sweller et al., 2019).

Three categories of load are defined by cognitive load theory (CLT) that includes intrinsic load, extraneous load, and germane load. Sweller (2010, 2011) explains each category of the CLT as follows. Intrinsic load, is a load related to the nature of the subject material and generally, it cannot be adjusted. Extraneous load, on the other hand, is generated by inappropriate instructional format. It is related to the cognitive effort that is not contributing to comprehending the subject material. Lastly, germane load refers to the utilization of memory resources to cope with the intrinsic load. Learning tasks should be designed in such a way that the available working memory capacity is efficiently used to achieve the highest return on mental effort investment. This means that extraneous load should be minimized so that working memory capacity is freed, which may permit an increase in the working resources devoted to intrinsic cognitive load (also called germane processing).

The nature of KB-CMR activity requires the learner to hold multiple pieces of information in the working memory while searching for the matching node. As described by Fonteles Furtado et al. (2018), recomposing a proposition in KB-CMR could be in any order of Concept-Link-Concept (CLC) or Concept-Concept-Link (CCL) or Link-Concept-Concept (LCC). In CLC learner searches for a source concept first, then looks for an appropriate link while keeping the information about the source concept in memory. Finally, the learner has to look for the target concept while keeping the information of the source concept and the link in memory. Similarly, CCL requires finding the source concept first and keeping it in memory. Then finding the target concept before looking for the appropriate link between them. Again while keeping the information about both concepts in memory. In the LCC approach, the link is defined first, then the learner looks for the source concept while keeping the information about the link in memory. After finding the appropriate source concept, the search for the target concept starts while keeping the previously found information in memory. These search processes are repeated for each proposition until all of the provided nodes are reconnected recomposing the assumed correct propositions same as the expert map.

Therefore, the task puts a lot of strain on learners working memory due to the gap of understanding between learner and teacher. Learners need to repetitively understand the concepts in general, recognize two related concepts, and find the most suitable link to re-create the propositions until the whole concept map is fully recomposed. The pressure on the learner's working memory during the concept map recomposition task of KB-CMR could impede their learning performance as confirmed by previous study (Fonteles Furtado et al., 2018). Thus, a more efficient method for the KB-CMR task is strongly demanded. An efficient recomposition task minimizes waste in the limited working memory resources during the recomposition task by lowering the cognitive burden on learners without sacrificing its' benefits of learning.

Fonteles Furtado et al. (2018) tried to reduce the cognitive load of the KB-CMR by introducing auto-layout organization thus, removing the burden of positioning the pieces of the concept map. the results did show a reduction of the cognitive load in terms of activity time but at the cost of learning quality. By introducing partial decomposition in this study, we change the instructional design of the KB-CMR such that the learner is allowed to make fewer searches to recompose each proposition. In CLT, this approach is described as partial completion (Sweller et al., 1998). It is said that partial completion could reduce the extraneous cognitive load by shrinking the search space. Thus, we define a new approach to generate the recomposing kit in KB-CMR Target Search Decomposition (TSD). In TSD, the generated kit has its' source concept and link intact for each proposition. Reducing the search space can have positive impacts on learning and cognitive load because learners are allowed to keep the least possible amount of information in memory, resulting in less repetitive work and increased focus. It can also have negative impacts on learning because it may make learners become less engaged with the provided concept map kit. These uncertainties make it necessary to investigate the impact of TSD on cognitive load and learning.

2.4 Target-Search Decomposition

The concept map decomposition in KB-CMR is by nature performed by disconnecting all of the connections between links and concept nodes from the expert map. The FD approach refers to this decomposition method. Figure 2.2b shows this traditional decomposition method of generating a kit from an expert map.

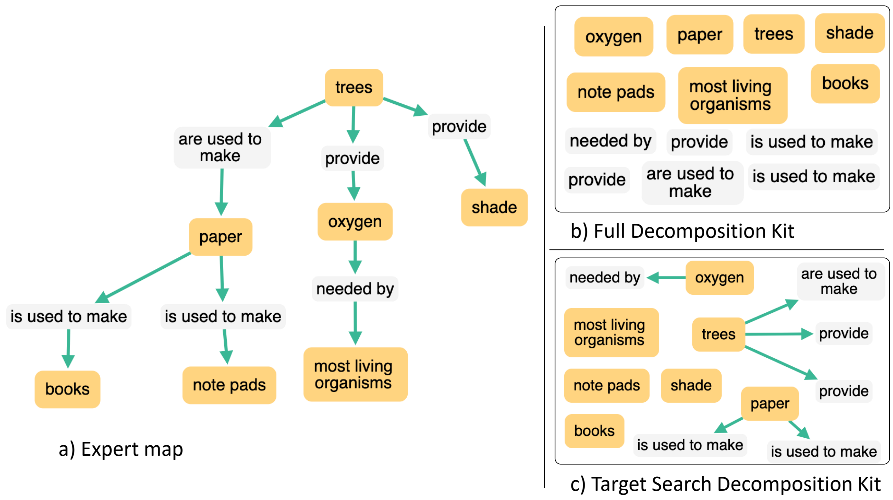

Fig. 2.2 An example of an expert map and the two decomposition approaches.

Recomposing a kit generated using the traditional method into the expert concept map requires the skills to grasp the understanding of another individual (usually the teacher in the educational settings), hence needing a high engagement from the learner (Furtado et al., 2021). In addition, the expert map is not shown during the recomposition activity of KB-CMR, encouraging the learners to think carefully about how to form the expected propositions using the given components only. The KB-CMR task requires learners to repeatedly understand concepts, identify related concepts and find the appropriate link to recreate propositions until the entire concept map is recomposed. The pressure on working memory during this task can negatively impact learning, as previously demonstrated by Fonteles Furtado et al. (2018). Therefore, there is a need for a more efficient method for theKB-CMR task that reduces the burden on working memory and maintains the benefits of learning.

In CLT, there are several suggestions to reduce the unnecessary cognitive load depending on the activity type. One such applicable suggestion is partial completion as it reduces the size of the problem space and lets the learners reach the solutions more efficiently (Sweller et al., 1998). Based on this suggestion, this paper proposes a new technique to kit generation in which all of the propositions in an expert map are only partially dissected.

In this approach, instead of disconnecting both the source and target concepts from the link when generating the kit, we let the source concept remain connected to its corresponding link while disconnecting the target concept for all of the propositions in the expert concept map. We call this decomposition approach, TSD. Figure 2.2 shows an example of kit generation for an expert map using both FD and TSD approaches. Figure 2.2a is an expert map used for demonstration. Figure 2.2b is a kit generated from this expert map using the traditional FD approach. The kit consists of a full set of concepts and links from the expert map with no connections among them. The learner should use this kit to recompose all the propositions back to the expert map without being able to refer to the expert map at any stage of the recomposition. Contrarily, figure 2.2c is a kit that is generated via TSD approach. The kit consists of a full set of concepts and links from the expert map where the connection between starting concept and the link is preserved. The learner is supposed to complete the connections for all of the links to recompose the same expert map; similarly without referring to the expert map during the recomposition.

In FD kit generation, even though learners may know the correct proposition, they would face the difficult task of manually searching through all of the given concept map parts to find the suitable pieces for each proposition which may not necessarily contribute to the learning process and could drain learners' energy. While with TSD, learners can reduce the repetitive search task to only the target concept, hence, reducing the search space dramatically. This reduction affects the recomposition task of TSD kit by putting less load on working memory since the learner needs to keep less information in the working memory while searching for the target concept. Additionally, this reduction is expected to speed up the recomposition process safely by keeping the learner engaged in the important task of proposition completion. Completing the proposition by looking for the target concept needs the learner to review the proposition multiple times to be sure the target concept matches the proposition, which is believed to enhance comprehension.

2.5 Flow in Kit-Build Concept Map Recomposition

Flow is a psychological mental state that occurs when people are fully immersed or engaged in an activity. Flow referred to as the optimal state of motivation, can be experienced in daily life, including but not limited to sports, education, and creative working activities (Csikszentmihalyi, 1997). Flow also highly corresponds to a positive experience and is connected with one's peak performance (Biasutti, 2017).

In learning, the flow state can be attained when learners get total focus and enjoy the learning activities at the same time. According to the flow model, flow occurs when learners' current skill level and the challenge level of a learning task are balanced at their highest (Csikszentmihalyi, 2018). Learners who perform tasks while in a state of flow may experience greater enjoyment, emotion, and happiness during the activity, leading to deeper learning and higher levels of satisfaction (Csikszentmihalyi, 2018). Because flow could actuate one's peak performance, tapping students into the flow state during learning activities becomes essential. The way how teachers design and constitute the learning environment to be more enjoyable and fun is necessary to cater to an optimal learning experience. Keeping learners in a flow leads to better use of educational tools and a more effective learning environment.

The embodied difficulty of the KB-CMR task may not contribute to the learning outcome directly but it could improve the flow and keep learners motivated to continue the activity by creating more challenges for the learners to take. Thus, removing such cognitive load may cause a reduction in the motivation for KB-CMR activity leading to difficulty in implementing the proposed method in an educational environment. Likewise, a change in flow might disturb the self-reported measures of cognitive load making it less powerful. The reason is that a high motivational state reduces the feeling of task difficulty and working-memory overloading (Schnotz et al., 2009). Therefore, It is important to look into the differences that could happen to the flow during TSD kit recomposition. It could be that the recomposition task becomes boring by reducing the challenge of FD compared to learners' skills. It could also be improving the motivation toward kit recomposition. Either way, the differences in flow state can lead to differences in the self-reported cognitive measures making them less reflected on the actual occurred cognitive load.

2.6 Reading Time and Reading Comprehension

Reading comprehension is a process of connecting new information to prior knowledge McNamara and Magliano (2009). When education shifts from early reading skills to understanding the content and attaining new information in texts, some students start falling behind Moss (2005). This happens more often in students from low-income families Chall and Jacobs (1983). Concept mapping is one technique that can support reading comprehension Chang et al. (2002); Guastello et al. (2000); Riahi and Pourdana (2017); Sánchez et al. (2010); Usman et al. (2017). Concept maps are graphical tools that represent knowledge. Concept maps are composed of propositions, which are made up of two concepts and one link. The link represents the relationship between the two concepts. One explanation of how concept maps help comprehension is the idea that they provide a template, which helps organizing and structuring information Cañas and Novak (2010). Another explanation is that graphical structures, like a concept map, are closer to the macro structure of a text, which makes it easier to understand Van Dijk et al. (1983). Furthermore, building the map allows students to continuously process the concepts Armbruster and Anderson (1984). Concept maps can also help with retention Armbruster and Anderson (1984); Cañas and Novak (2010). This is important because learners benefit from remembering more information for later use.

KB-CMR approach of concept mapping is often built while having access to a text Alkhateeb et al. (2015); Andoko et al. (2019); Pinandito et al. (2020). However, one alternative is to not allow students to have access to the text while building the map. Instead, students would read the text before building the map and then lose access to it. Without access to the text, students would have to rely on their memory and understanding of the content. By letting the learner to remember, this could have an enhancing effect to the retention of the content. Building the map in this case, could be similar to a test in the testing effect Rowland (2014). On the other hand, by allowing learners to have access to the text while building the map, they would be able to come revisit the text while building the map. By doing so, students might be able to cover up the parts they do not understand. Furthermore, handling two mediums at the same time could increase access to memory, enhancing retention. At the same time, having two mediums available could increase cognitive load, which can impair learning Mayer and Moreno (2003).

Given the above, verifying if having access to the text during concept map recomposition is beneficial or not to learning is necessary. As far as the authors know, this comparison has not been done before.

2.7 Procedural Domain and Concept mapping

The capacity to understand and ability to carry out specific tasks or procedures is part of the procedural domain knowledge. In the context of computer programming, this includes the understanding and ability to write code, debug programs, and design algorithms (Ma et al., 2023). It involves understanding of programming concepts in a practical setting, such as building software or solving a computational problem. It can be challenging for students to grasp abstract concepts since it can be highly technical. As such, it is seen to be difficult to effectively represent these concepts in a visual format such as a concept map. Despite these challenges, concept maps can still be a useful tool for promoting understanding in the procedural domain by visualizing the relationships between concepts and showing the context of these concepts with respect to a practical source-code.

Computer programming is a fundamental subject in computer science-related fields and a mandatory course in many study programs. In recent decades, computer programming education has significantly shifted from the procedural programming paradigm to a more robust and productive paradigm called Object-Oriented Programming (OOP) (Kölling & Rosenberg, 1996). OOP has numerous advantages, including increased coding efficiency and reusability and making problem-solving more natural and comprehensible (Isaiah et al., 2019).

OOP consists of several strongly interrelated concepts, including *object, class, method, inheritance, polymorphism, and encapsulation* (Armstrong, 2006). Teaching and learning these fundamental concepts and understanding their application in an actual source code is believed to be a difficult task for both educators and students. Several studies have identified the difficulties students face, particularly when comprehending the relationships and interactions among OOP concepts (Kaczmarczyk et al., 2010; Ragonis & Ben-Ari, 2005; Sorva, 2018; Teif & Hazzan, 2006). Students find it difficult to comprehend the relationship and interaction that happens among OOP concepts (Sajaniemi et al., 2008). Furthermore, (Liberman et al., 2011) states the difficulties in learning specific concepts and behaviors in the source-code, such as inheritance and polymorphism. It also identifies problems with the analogy approaches that are used in many classes to teach OOP concepts. They recommend a teaching model such that the instructor can identify the difficulties at an early stage. In terms of these difficulties, a lack of active practice and suitable teaching tools is considered to be one of the reasons why it is hard for students to learn about OOP concepts (Kölling et al., 2003; Sarpong et al., 2013).

In the problem-solving task which is a key skill in programming, one needs theoretical background knowledge i.e. theoretical knowledge, and the application of theoretical knowledge which is the practical knowledge (M. Wang et al., 2018; Whitfield et al., 2007). Traditionally, students learn OOP by studying the theory of the concepts and then learning about the application of these concepts during a practical session. Previous research about computer programming for novices has mostly focused on independently supporting students in either knowledge base. However, programming in general and specifically the concepts of OOP are strongly related to each other. Additionally, the inter-relationship between theoretical knowledge and its application is one crucial aspect of programming. Even having good programming skills without theoretical background knowledge leads to poor program design; thus, both knowledge bases are needed during the learning process (Eckerdal, 2009). Therefore, we suggest that to support OOP comprehension, students need an activity that considers both knowledge bases during the learning process.

Concept map can be used to evaluate students' conceptual learning and progress while KB-CMR is shown to exceed the learning-related performance of traditional concept maps in several aspects of education. Despite the aforementioned studies about concept maps and particularly KB-CMR, there are no investigations about using it in procedural comprehension tasks such as to represent source-code and its concepts up to the authors' knowledge. By introducing CRS in this study, we achieved extending the concept map recomposition to promote conceptual representation of the source-code in OOP.

2.8 Conceptual Representation of the Source-code

Conceptual Representation of the Source-code (CRS) combines the two knowledge bases: theoretical knowledge base and practical knowledge base. Theoretical knowledge refers to the principles and concepts of a subject, while practical knowledge is the application of those concepts in actual source-code. There is a mutual and complex relationship between these two knowledge bases, and a concrete understanding of programming concepts needs to address both (Eckerdal, 2009). CRS creates an environment to support externalizing these two knowledge bases and the complex cognitive interaction between them. The objective of the CRS concept map is to visualize both knowledge bases in one diagram and act as an intermediary between the two. Bridging these two knowledge bases allows the learner to connect the concepts of OOP to their actual implementation in the source-code. Consequently, it can promote conceptual interrelationships and how concepts affect each other.

In CRS, the educator creates an ideal concept map for both theoretical and practical knowledge. In the theoretical knowledge concept map, the theory behind the concepts like their definition, properties, how one concept relates to another concept, etc. are described. In the practical knowledge concept map, a source-code example is prepared beforehand that applies the targeted concept(s) in practice. The structure of the source-code is then described using the concept map, such as identifying the class, methods, fields, data-types, etc. Afterward, the relationships between the structure of the source-code and the theoretical background of the OOP concepts are created using bridging links. This is a major step in CRS, as these connections serve the crucial role of demonstrating to learners how each concept is practically implemented within the source-code. Thus, we believe that the effectiveness of the CRS method strongly depends on the suitability of the connections made between the two knowledge bases in the concept map. The guideline to create the best bridging links is not covered in this research, rather, this research investigates the effectiveness of generating a good quality CRS in integrating theoretical and practical knowledge of OOP. The size of the concept map to describe each OOP concept is decided by the educator to fit the teaching class material and students' performance.

For the purpose of illustration, we point to a simplified example of CRS concept map in Figure 2.3. By simplified, we mean that only the concepts and definitions related to polymorphism are included. The figure is originally made in Indonesian for students at an Indonesian University, but has been translated into English for this thesis.

The CRS map clarifies the theoretical background of the concepts of overloading and class, i.e., theoretical knowledge, in green. It tells that the current teaching material talks about OOP concepts: class and polymorphism then gives a definition or needed notation to each concept as shown in the

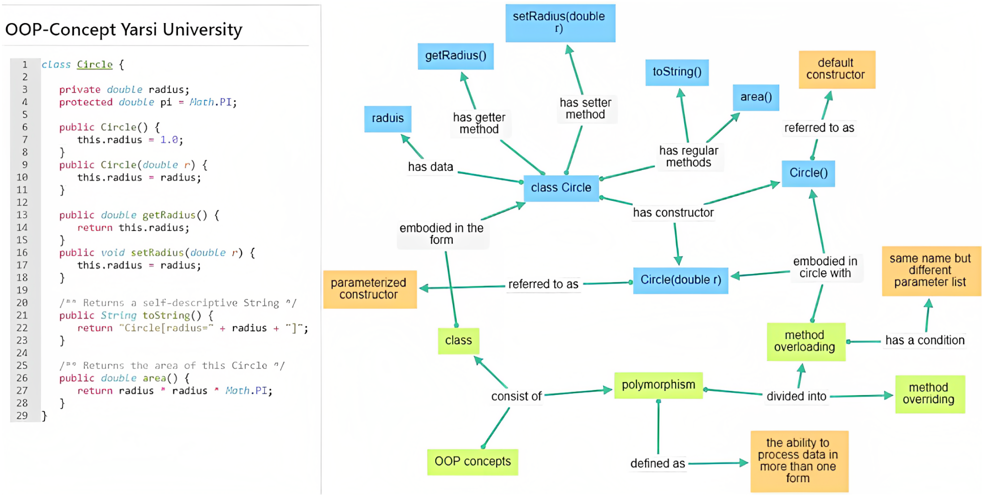

Fig. 2.3 CRS in concept map with a focus on the concept of overloading along with its' source-code example

brown-colored concepts. The source-code is a simple example that implements constructor overloading in a class called "Circle". The structure of the source-code is drawn in the concept map that includes all elements of the class, i.e., practical knowledge, in blue with the needed notations colored in brown. The practical knowledge concept map clarifies the methods and their types, such as regular methods, setter and getter methods, constructors, and data fields within the "Circle" class. Afterward, connecting-links are added to connect both knowledge bases. These links connect the "overloading" concept to the constructors and the "class" concept to the "Circle" class in the source-code. The first link conveys the application of overloading in the source-code in the form of two constructors in class "Circle". The second link tells us that the concept of class is embodied in the form of source-code at the "Circle" class. The concept map as a whole reveals the connection between concept of overloading and the concept of class.

The process of creating a CRS concept map continues with the educator adding relevant notations and definitions to the map as needed, based on their understanding, the needs of the target class, and their teaching approach. For instance, to visualize other abstracted concepts such as objects, an "object" of type Cylinder can be added to the CRS concept map to reveal the access restrictions of an object toward different class variables and methods. It can also be used to depict the method calls and the concepts of argument transfer and pointers. The resulting concept map and the corresponding source-code are then presented to students as a recomposition activity. The inclusion of the source-code demonstrates the application of the concepts in the targeted programming language, thus providing a clear link between the concepts and their syntax in the code. This activity is not used independently; it is used along with the corresponding material. The activity can be extended to include collaborative concept map recomposition, where students collaborate and exchange their knowledge about the OOP concepts, but the use of such collaboration is outside the scope of our study.

Chapter 3

Research Questions

The objectives of this study encompass three distinct aims, each contributing to the advancement of concept map recomposition. These aims are designed to enhance the learner experience, optimize resourceful recomposition strategies, and explore novel applications within the procedural domain of object-oriented programming (OOP). In the first aim, we delve into strategies aimed at improving the effectiveness and efficiency of concept map recomposition by addressing the cognitive load associated with the activity. By strategically reducing this cognitive burden, we aim to enhance learners' engagement. Our second aim centers on resourceful recomposition. By understanding the effects of reading material accessibility during concept map recomposition, we explore the best practices to follow to optimize learners' comprehension. The third aim broadens our perspective on the procedural domain of OOP. By proposing a new visualization approach, we bridge theory and practice knowledge bases, providing valuable insights for OOP education.

The study is divided into two sections. The first section focuses on enhancement strategies to the concept map recomposition activity, while the second section discusses the use of concept map recomposition to promote understanding of OOP concepts. The research questions are organized according to the focus of each section.

3.1 Strategies to Enhance Concept Map Recomposition

3.1.1 Investigating Cognitive Load in KB-CMR

Changes in the cognitive load can influence the learning outcome since the cognitive load is part of the learning process. Similarly, changes in cognitive load can have an impact on the motivational state of learners, subsequently affecting the feasibility of the proposed approach. The rationale for this effect lies in the strong interconnection between motivation and cognitive load. When a challenge does not match the learners' skills, it may result in learners' loss of motivation and mental exhaustion (Schnotz et al., 2009). Maintaining high levels of motivation among learners when using educational tools is a crucial aspect affecting the effectiveness of such tools (Widjaja & Chen, 2017). This is because learners' motivation is a key element in enhancing learning performance and overcoming challenges (Tang et al., 2022; Tohidi, 2012). Therefore, we are concerned about the case where decreasing the cognitive load leads to easier tasks to a degree that learners lose the motivation to engage with the learning activity. Flow state is one of the proposed methods to capture individuals' optimal motivational state (Engeser & Rheinberg, 2008; Schnotz et al., 2009). Additionally, when learners are in an optimal motivational state where the skills and challenges are well balanced, learners tend to give a wrong reflection on their experienced cognitive load. Schnotz et al. (2009) indicate that people may report low cognitive load experience on the subjective self-reported metrics even though the cognitive load experienced was high. This is a limitation of the subjective metrics of cognitive load that we want to control for it between the conditions.

The following are the research questions investigated in this study:

RQA-1: Whether the concept map recomposition activity of TSD approach affects the Cognitive load.

RQA-2: Whether the concept map recomposition activity of TSD approach affects the Flow state.

RQA-3: Whether the concept map recomposition activity of TSD approach affects the immediate reading comprehension.

RQA-4: Whether the concept map recomposition activity of TSD approach affects the retention of reading comprehension.

In the first question, we aim to evaluate and describe the effects of TSD on cognitive load. The second question gives an insight into the changes that could happen to the nature of the activity in terms of difficulty versus the skill of the learners (i.e. flow state) on one hand, and on the other hand, it is used to confirm the strength of the cognitive load metrics. The third and fourth research questions focus on the importance and value of changes that may occur in terms of learning quality. These two last questions can show if the changes in the decomposition method are worth attention in the educational community.

3.1.2 Investigating Reading Time in KB-CMR

This work presents an activity of KB-CMR integrated with text reading. It also investigates the learning properties of such an activity by verifying how reading time affects learning. It compares the group performing the activity with two control groups.

The research questions of this study are as follows:

RQB-1: Whether reading time affects reading comprehension.

RQB-2: Whether reading time affects retention of reading comprehension.

RQB-3: What is the effect of having access to the reading material during KB-CMR on immediate learning gain compared to the control conditions.

RQB-4: What is the effect of having access to the reading material during KB-CMR on retention of learning gain compared to the control conditions.

The experiment group conducts a concept map recomposition in KB-CMR while having access to the text. One of the control groups conducts the concept map recomposition in KB-CMR without having access to the text. This group will be used to answer research questions (3) and (4), since the only difference between the two groups is the presence of the external resource. The other control group will read the text material one more time without building the map. This group mainly works as a baseline for both groups to give better context to the results.

The results of the Map&Text group reveal that there is a diverse reading time among learners. Thus, in addition to our main research questions, we want to examine how students who spend more time reading fare in comparison to those in controlled conditions. To address this, we have added the following two exploratory research questions:

RQBE-1: Do learners with high reading times while building the map outperform the two control groups in reading comprehension gains.

RQBE-2: Do learners with high reading times while building the map outperform the two control groups in retention of reading comprehension gains.

3.2 Investigating the Implementation of CRS in KB-CMR

In this study, we investigate a learning strategy that integrates the main aspects of OOP, namely, theoretical knowledge and practical knowledge into one learning activity using concept map recomposition. We call this combination representation *CRS*. In CRS, the educator creates an ideal concept map about the targeted OOP concepts and integrates it into a second concept map that implements these concepts in a source-code. The concept map is then disassembled and given to the students to be recomposed back to the original concept map. The aim of CRS is to support learners during the learning process of OOP by externalizing the OOP concepts combined with their application and the inter/intra relationships rather than teaching how to write code syntactically. It is worth mentioning that no activity or tool was suggested for merging these two components for conceptual comprehension to the extent of the authors' knowledge.

Two experiments were conducted to evaluate the use of CRS in a recomposition activity. In the first experiment the following research questions have been addressed:

RQC-1: How is the design of CRS incorporated into a concept map recomposition activity in an actual teaching class that integrates theoretical and practical knowledge bases of OOP concepts.

RQC-2: How is the students' likeness towards the proposed KB-CMR activity.

RQC-3: How is the students' expectation toward using the proposed KB-CMR activity in their learning of OOP concepts.

The first question puts CRS into trial and explores its' practical use while the second and third questions look into the students' subjective opinions on the new activity.

In the second experiment, the impact of CRS is further investigated to answer the following research questions:

RQC-4: Can an educator build a practical CRS in concept map according to the characteristics of the CRS in an actual teaching class.

RQC-5: What is the effect of integrating the two main aspects of OOP using CRS in a concept map activity on OOP comprehension in an actual classroom setting compared to the conventional method.

RQC-6: How do the students perceive the proposed method in terms of usefulness for learning OOP.

The 4th research question addresses the extent to which the characteristics of CRS can be followed to create a practical activity by the class teacher. The fifth research question evaluates the impact of using such activity on learning in a comparative approach. The last research question explores the perceived usefulness of the activity by students.

In addition to these research questions, the second experiment sets two more exploratory research questions to further guide the study outcome.

RQCE-1: Compared to the conventional method, can the learning gain of CRS affect the reviewed learning gain after one week.

RQCE-2: What is the correlation between performance in CRS and performance later in the course activities of assignments and mid-term test.

Both exploratory questions address the long-term effect of using CRS. The first question focuses on the learning gained after the review process and connections with learning gained through CRS, while the second exploratory question investigates the performance of students in CRS and its relation to later performance throughout the course.

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Chapter 4

Strategies to Improve Concept Map Recomposition

This chapter introduces two research studies aimed at analyzing the effectiveness of different modifications to enhance concept map recomposition. Specifically, it explores cognitive load in KB-CMR reported in Section 4.1, and reading time in KB-CMR reported in Section 4.2. These studies address the research questions outlined in Sections 3.1.1 and 3.1.2 respectively.

4.1 Study 1: Impact of TSD on Reducing the Cognitive Load in KB-CMR

4.1.1 Methodology

In this section, we provide a detailed overview of the experimental design and procedures to address the research questions in 3.1.1. The primary aim of our study was to investigate the impact of different levels of concept map decomposition (TSD and FD) on reading comprehension. To achieve this, we employed a between-subjects pretest-posttest design. The collected data encompass a range of variables, including reading comprehension scores, cognitive load measures, and flow experiences. These data were collected through a series of carefully designed tasks, as described below. Our analysis of this data will enable us to draw conclusions about the effectiveness of concept map decomposition levels in enhancing reading comprehension, shedding light on their pedagogical implications. Figure 4.1 shows the timeline of the experiment. The experiment consisted of two timely separate phases, the main phase, and an optional delayed phase.

The main phase included the following tasks:

1. Take a demographic questionnaire.
2. Read usage instructions of Kit-Build tool.
3. Build a training map using Kit-Build tool.
4. Read a narrative.
5. Take the reading comprehension pretest.
6. Complete the core activity depending on the condition.
   (a) TSD condition: Recompose a concept map from a kit where the source concept was already connected to its corresponding link in each proposition.
   (b) FD condition: Recompose a concept map from a kit where the source concept, link, and the target concept were disconnected for all of the propositions.
7. Take a cognitive load questionnaire.
8. Take a flow measurement questionnaire.
9. Take the reading comprehension post-test.

Participants who successfully finished all tasks in the main phase were invited to take part in the delayed phase. The delayed phase was implemented after 2 weeks from the main phase. It consisted of only one task, namely the delayed reading comprehension test. The test was exactly the same as the main phases' reading comprehension test.

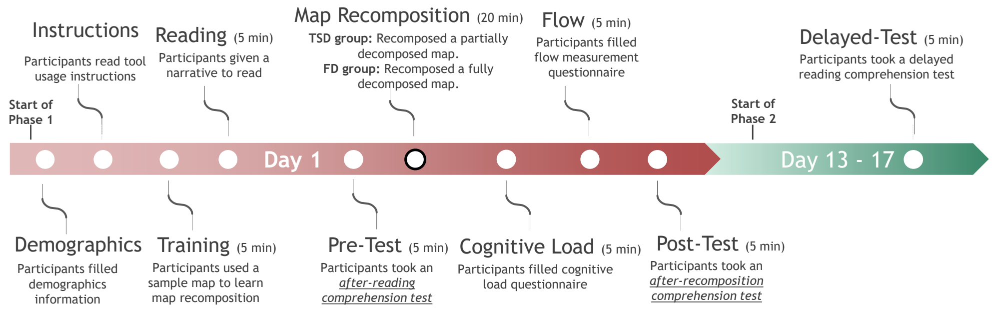

Fig. 4.1 Timeline of the experiment

Participants

A sample of 78 adults (39 for each condition) was recruited through an online crowd-sourcing platform Amazon Mechanical Turk (MTurk) also known as MTurk (Paolacci et al., 2010). Similar to the traditional recruitment methods, the data that is collected using Amazon Mechanical Turk (MTurk) recruitment are reliable and even better in some terms (Buhrmester et al., 2011; Hauser & Schwarz, 2016). The recruitment task was published and managed via CloudResearch, an online crowd-sourcing platform that can be linked to MTurk. CloudResearch has easier task management and extends MTurk functionality to allow applying additional criteria to the recruitment process (Chandler et al., 2019; Litman et al., 2017).

Participants were recruited from July 19, 2021, to August 14, 2021. The recruitment task accessibility was restricted to the "CloudResearch Approved List" only, to ensure the high quality of data and avoid automated programs. Additionally, in order to maintain consistency in language and context, participants were required to be residents of the United States or Canada, as the system and experiment were conducted in US English. Furthermore, participants were subject to specific eligibility criteria, including a minimum approval rate of 98% on the platform and a record of completing over 5000 tasks on MTurk. Participants were assigned to each condition randomly and permanently, no interchange was allowed. Participants who completed the initial task received compensation of $6.00, with a separate additional payment of $0.80 for those who later participated in the delayed phase. The rewards provided are intended to acknowledge and appreciate participants for their time and effort in the study.

Material

The narrative, comprehension questions, and expert map were adapted from a previous study material (Furtado et al., 2021). The narrative text[1] is based on a Wikipedia article about the "Komodo dragon" but modified and shortened to 442 words with no graphic content. The comprehension questions consisted of 10 multiple-choice items about the content of the material. Each question has 4 options including one correct answer. The question sequence and their corresponding options for each learner were shuffled between the pre, post, and delayed comprehension tests to reduce the chance of memorization. The expert map consisted of 17 propositions. From this expert map,

[1] https://git.io/JyeDr

two versions of the kit were generated for both conditions. TSD condition received a kit that is generated using the proposed approach; while the FD condition received a kit using the traditional approach. Figure 4.2 shows both of the kits used in the experiment.

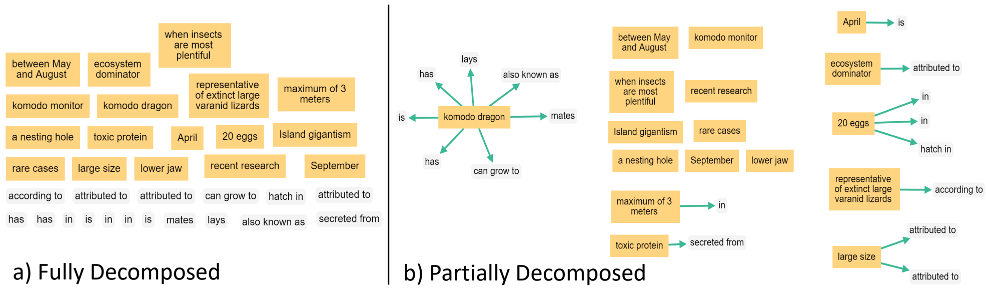

Fig. 4.2 Concept map kits for conditions TSD and FD used in the experiment.

A self-reported mental effort (F. G. Paas & Van Merriënboer, 1994) and perceived difficulty (Kalyuga et al., 1999) questionnaire were used to measure the cognitive load imposed by the concept map recomposition for both conditions. Both mental effort and perceived difficulty are important in measuring the cognitive load (DeLeeuw & Mayer, 2008; Kalyuga et al., 1999). The mental effort questionnaire is an indirect subjective method that has been widely validated and said to be sensitive to relatively small differences in cognitive load (Gimino, 2002; F. Paas et al., 2003). Participants were asked to reflect on their mental effort on a 7-point Likert-type scale ranging from "Very low mental effort" to "Very high mental effort". While the perceived difficulty questionnaire is a direct subjective measurement of the cognitive load (Brunken et al., 2003). The question asks the participants to reflect on their perceived difficulty of the task on a 7-point Likert-type scale ranging from "Very Easy" to "Very Difficult". Both of the questionnaires has been confirmed and adequately used in previous related research by Fonteles Furtado et al. (2018) to measure the same variables of perceived difficulty and perceived effort. In addition to the subjective methods, the user behavior during the concept map recomposition was captured to measure "time-on-task" and the "number of actions per proposition" during the recomposition activity. These variables are considered valid indirect objective measurements of the cognitive load (Brunken et al., 2003).

Flow Short Scale adopted from Engeser and Rheinberg (2008) was used to measure the flow state during map recomposition for both conditions. The test has been used and validated by multiple research works Fonteles Furtado et al. (2018); Rheinberg et al. (2007); Schüler (2007) The test consisted of 10 items with a 7-point Likert-type scale.

Procedure

An online tool was built and used for this experiment named Kit-Build concept map. Participants used MTurk to connect to the tool and go through the consent form. In the consent form, they were informed about the experiment's purpose, data collection, and data usage as well as the ability to leave the experiment at any time. The participants were also informed about conducting a follow-up test (delayed-test) for those who complete the current tasks successfully. Demographic questions followed the consent agreement. The demographic questions were about gender, age, and education level.

Afterward, they read the tool usage instructions and the flow of the required tasks. They also have been informed maximum time the experiment could take. At this point, they learned that once they proceed to the next step, all of the remaining steps will be automatically timed to a maximum of 5 minutes except for a map recomposition activity that will be 20 minutes. Thus, advised to keep focusing on the experiment and not to switch to external tasks. The time limit serves the purpose of keeping the participants engaged with the experiment and avoiding distraction by other tasks. Following the tool instruction section, they started a training map to get familiar with the tool features. The training concept map was unrelated to the rest of the experiment.

Next, the komodo-dragon reading material was given to the participants to read followed by the after-reading comprehension test (pre-test). After the pre-test, the participants were given a kit to recompose based on their condition. FD condition received a fully decomposed kit while TSD condition received a kit based on TSD approach where the first half of the proposition (source concept node and the correct link) was connected while the target concept was not. The time frame for this task was 20 minutes and the learner was restricted from moving to the next step until the concept map is completely and correctly recomposed or the designated time period is over. In that sense, learners could submit an incorrectly recomposed map after working on it for the specified 20 minutes. During the map recomposition, the learners could use a feedback feature to confirm the recomposition status. When clicked, the feedback feature highlights the correctly recomposed propositions and incorrectly recomposed propositions based on the expert map. This formative feedback directed the learners into looking for other alternatives to the wrong connections while keeping the correct ones unchanged.

The questionnaire about concept map recomposition experience followed the recomposition step. The questionnaire was divided into two subsections, cognitive load, and flow-state measurement. Finally, the participants answered the after-recomposition reading comprehension questions (post-test) which consisted of the same questions as in the pre-test.

The second phase of the experiment (delayed phase) started in two weeks. Participants were contacted by email twice, the day before starting and at the time of starting the delayed phase. Access to answering delayed phase was open for 4 days to give a chance for more participation rate. Comprehension questions in this phase were the same comprehension test questions as in the main phase with the same time limit of 5 minutes.

4.1.2 Analysis and Results

Data were collected from 78 participants using the provided online system, but 4 of them had to be excluded due to technical issues with data collection (N=74). At the outset of the experiment, we had emphasized that the system is fully compatible only with the latest versions of Google Chrome, Firefox, or Microsoft Edge, provided that JavaScript is not disabled. It is conceivable that these 4 participants encountered compatibility issues, which led to unsuccessful data collection.

Table 4.1 shows the characteristics of the participants in terms of the collected demographic data (age group, gender, and education). Both conditions were compared in terms of each demographic data to ensure the demographic bias between the conditions. According to the chi-square test of independence, none of the demographic variables were related to the assigned conditions (gender: $X^2(2, N = 74) = 1.03, p = .60$; age: $X^2(4, N = 74) = 1.93, p = .75$); education: $X^2(6, N = 74) = 6.04, p = .42$).

The Shapiro-Wilk test for normality could not show the normality of residuals in any of the collected data. Therefore, data analysis is made using non-parametric two-tailed methods at a significance level of $\alpha = 0.05$. Among these non-parametric tests, we have utilized the Mann-Whitney U test and the Wilcoxon signed-rank test. Mann-Whitney U test is a widely recognized non-parametric test, was selected for its robustness and appropriateness in situations where the data do not meet the assumptions of normality. This test is particularly well-suited for comparing two independent groups on a response variable. Similarly, the Wilcoxon signed-rank test, another widely recognized non-parametric test, was employed due to its performance in situations where normality assumptions are not met. It is well-suited for paired data analysis.

Table 4.1 Participants demographic information

Demographic Variables	Participants (N=74)
Gender	
Male	39
Female	34
Prefer not to answer	1
Age	
21 - 29	20
30 - 39	32
40 - 49	14
50 - 59	7
60 or older	1
Education	
High/Secondary school	14
College	8
Vocational training	5
Bachelor	40
Master	5
Professional	1
PhD	1

Cognitive Load

To address the first research question, whether the concept map recomposition activity of TSD approach affects the cognitive load, we have used the score of the questionnaire items for perceived effort and perceived difficulty. We also calculated the total time spent on the recomposition task for each learner in both conditions, and the number of actions needed to complete the recomposition task. We have analyzed the difference of these CLT measures between both conditions using non-parametric multivariate inference test (Burchett et al., 2017), which controls for type I error. The method is implemented in the R package "npmv". In this analysis, the condition was used as the predictor and the four cognitive load metrics were used as the response variable. The analysis result showed a significant difference in cognitive load with respect to the condition, $F(2.21, 158.9) = 24.2, P < .001$. Post-hoc analysis using Mann-Whitney U test revealed a significant difference for all of the response variables suggesting a lower cognitive load for the TSD group over the FD group in all four dimensions. The P values for this post-hoc analysis were adjusted using Benjamini and Hochberg (1995) method to control the false discovery rate and improve the power of the analysis. Table 4.2 presents the mean and standard deviation of cognitive load metrics for each condition, along with the corresponding sample sizes and statistical results.

Table 4.2 Mean and standard deviation M(SD) of cognitive load parameters and the statistical test result

Group	N	Actions per proposition M(SD)	Time on task M(SD)	Perceived difficulty M(SD)	Perceived effort M(SD)
FD	37	16.98 (11.21)	18.88 (2.69)	5.51 (1.26)	6.43 (0.90)
TSD	37	5.64 (4.29)	13.67 (5.96)	4.16 (1.55)	5.81 (1.20)
P Value		<.001	<.001	.001	.017

To measure the effect size we used Relative Treatment Effect (RTE) that is generated within the same statistical test of "npmv". RTE of treatment "k" is defined as *the probability that a randomly chosen subject from treatment "k" displays a higher response than a subject that is randomly chosen from any of the treatment groups, including treatment "k"* (Burchett et al., 2017). Table 4.3 shows the result of RTE for the cognitive load metrics between the conditions. The results show a very low probability of having a random sample from TSD condition experiencing a high cognitive load for all parameters. For example, the probability that a randomly chosen sample with a TSD condition experience a higher perceived difficulty from the whole sample is 0.26 where the general minimum/maximum possible effect is 0.23/0.77 for the TSD condition. The RTE suggests that the cognitive load metrics can discriminate one condition from the other almost perfectly using all response variables except for perceived effort which has a less distinctive probability compared to other parameters. The reason could be that both conditions engaged in information-processing resources in the recomposition activity to a high degree.

Table 4.3 Relative treatment effect (RTE) of different cognitive load metrics on concept map decomposition level using a non-parametric multivariate test

Group	Actions per proposition	Time on task	Perceived difficulty	Perceived effort
FD	0.90	0.75	0.74	0.65
TSD	0.10	0.25	0.26	0.35

Table 4.4 Correlation Between Subjective and Objective Measures of Cognitive Load in Experimental and Control Groups

	Time On Task	Action Map Ratio
TSD Condition		
Perceived Effort	r=0.36, p-value=0.028	r=0.25, p-value=0.13
Perceived Difficulty	r=0.73, p-value=3e-07	r=0.45, p-value=0.0047
FD Condition		
Perceived Effort	r=0.34, p-value=0.039	r=0.33, p-value=0.048
Perceived Difficulty	r=0.65, p-value=1.4e-05	r=0.33, p-value=0.046

Next, we performed a correlation analysis between objective and subjective cognitive load measures for both the experimental (TSD) and control (FD) groups. Our purpose is to complement the subjective assessments with objective data, strengthening our comprehension of cognitive load in concept map recomposition task. This analysis supports a more profound understanding of the learner experience in this demanding context. The results of this analysis are presented in Table 4.4.

In both groups, we observed significant positive correlations between "Time on Task" and both "Perceived Effort" and "Perceived Difficulty". This shared pattern underscores the vital role of time learners spent on solving the task in influencing their cognitive load perceptions. It implies that as learners invest more time in the task, they tend to view it as both more effortful and more challenging. This dynamic relationship between task duration and cognitive load perceptions reveals that extended engagement is linked with heightened perceptions of effort and difficulty.

Similarly, the interplay between perceived effort, perceived difficulty, and the action map ratio provides valuable insights into our study's cognitive load management. In both groups, we observed notable correlations that shed light on the connections between these variables. Notably, the "Action Map Ratio" reflects learners' efficiency in interacting with the recomposition task. In the experimental group TSD, there was a positive correlation between "Action Map Ratio" and "Perceived Effort," although it did not reach statistical significance. This suggests that in the TSD condition, where the task's interaction is designed to be highly efficient, learners who engage more actively and perform a higher number of actions may not necessarily perceive the task as more effortful. This finding indicates that when the recomposition task is carefully structured to minimize learner effort, a higher level of interaction may not correspond to increased perceived effort. Conversely, in the control group, there was a significant positive correlation between "Action Map Ratio" and "Perceived Effort". In this context, as learners in the control group engaged more actively and performed a higher number of actions on the concept map, they indeed reported the task as more effortful. This observation implies that, in FD condition, extensive engagement corresponds to increased perceptions of effort. Regarding "Perceived Difficulty", significant correlations with "Action Map Ratio" were observed in both groups, underscoring the role of learner engagement. These correlations emphasize that higher levels of learner engagement and interaction on the concept map are associated with greater perceptions of task difficulty. In the TSD group, although the learners are relieved from making excessive actions, the intrinsic difficulty of the recomposition task persists. In contrast, the control group learners face additional difficulty due to the increased number of actions required during recomposition.

Reflection on the Cognitive Load Analysis The analysis results could be explained mainly by the reduced problem space. Compared to FD approach, learners in TSD need to make fewer searches for each proposition which in turn reduces the overall needed time to recompose each proposition. Similarly, the minimum number of actions to recompose the concept map is reduced by half. let a node describe a concept or a link, per proposition, FD group needs to connect the first node to the second node, then connect the second node with the third node. While in TSD, the learner needs only to connect the second node which is the link to the target concept.

In addition to reducing the needed time and speeding up the recomposition process, the difficulty of the recomposition task and its effort are perceived to be lower compared to FD approach. In TSD, the learners are freed from the burden of repetitive tasks of heavy search/find that should be carried out normally when recomposing a concept map in FD approach.

Additionally, the correlational analysis between the objective and subjective measures supports these analyzed measurements positively. It also gives a broader understanding for the design of educational tools and interventions aimed at optimizing cognitive load management. It underscores the importance of monitoring and regulating task duration as well as excessive learner actions to ensure their alignment with the intended learning outcomes. Overall, the TSD approach aids in the effective reduction of unnecessary cognitive load, especially in scenarios involving cognitively demanding tasks.

Optimal Motivational State

To address the second research question, whether the concept map recomposition activity of the TSD kit affects the flow state, we analyzed the self-reported flow state score. We confirmed the consistency of the questionnaire items using Cronbach's Alpha $\alpha = .75$. The mean and standard deviation of the flow state score is shown in Table 4.5. We have compared both conditions using Mann-Whitney U test by having flow state measurement as the response variable and condition as the predictor. According to the test result, there was no significant influence of condition on flow scores ($U = 1300.5, n1 = n2 = 37, P = .35$).

Table 4.5 Mean and standard deviation of flow short scale

Group	N	Flow score M (SD)
FD	37	4.74 (0.81)
TSD	37	4.91 (0.76)

Reflection on Optimal Motivational State Analysis Usually, simplifying a task could lead to a state where learners lose interest in continuing to stay engaged. But, in TSD case we observe similar results to the original FD method; learners are still motivated in doing the recomposition activity. This is due to removing only the part of the activity that is repetitive and does not require a high skill whereas the core phase of the recomposition activity is still required in TSD.

This outcome offers two key perspectives on the activity. First, it reveals that making the recomposition task simpler through the TSD method does not make it less interesting for learners. That means, the learners of both conditions perceived similar challenges as well as the confidence to respond to the recomposition challenge. Second, it shows that the subjective self-reports of cognitive load metrics are strongly comparable and the differences between the two conditions' self-reports are not due to their flow-state.

Reading Comprehension

To answer the third and final research question, whether the concept map recomposition activity of the TSD kit affects the a) immediate reading comprehension. b) retention of reading comprehension, we analyze the comprehension scores of after-reading comprehension test (pre-test) score, after-recomposition comprehension test (post-test) score, and delayed-test score. Of the total of 74 participants, 54 participated in the optional delayed comprehension test. Table 4.6 shows the mean and standard deviation of the comprehension scores, while table 4.7 shows the mean and standard deviation for participants who also took the optional delayed comprehension test.

First, we examined the reading comprehension within each condition. The Wilcoxon signed-rank test with continuity correction revealed a significant increase in reading comprehension in conditions TSD ($Z = -3.75, P < .001, r = .597$) and FD ($Z = -2.45, P = .01, r = .419$) when pre-test score is compared with post-test score within each condition. The result confirms that both kinds of concept map recomposition activities are useful in immediate reading comprehension. The results for FD condition align with previous studies where the benefit of Kit-Build is investigated. Above that, the results for the TSD condition confirm that the benefits of traditional Kit-Build on reading comprehension are preserved with the new approach. Conducting the same statistical test to compare the delayed-test score with the pre-test score within each condition showed that both conditions retention lowered to slightly below the period of after-reading phase (Condition$_{TSD}$: $Z = 1.29, P = .195, r = .37$; Condition$_{FD}$: $Z = 1.95, P = .051, r = .22$). The statistical result does not show a significant difference of the two test scores in each condition. However, the results of FD condition are marginally significant affirming the possibility of a high rate of forgetting in the traditional kit generation method. Despite that, it is natural for the gained knowledge to dissipate over time which is happening in the delayed-test for both conditions. Although the average delayed test score is lower than the pre-test score, there could still be some learning gain relative to their before-reading stage since the pre-test score is measured after reading the text, meaning that their previous knowledge could be much lower than the pre-test score. Thus, the concept map recomposition activity may have helped both groups in retaining their basic comprehension.

Second, we focused on assessing the potential variations in reading comprehension between the conditions. To confirm the homogeneity of both conditions, we compared their pre-test scores using Fligner-Killeen test of homogeneity of variances (F-K). F-K test is said to have robustness toward departures from normality. The test confirmed the homogeneity of the conditions ($X^2 = 0.74, P = .39$). To analyze the immediate reading comprehension, we applied Mann-Whitney U test comparing the post-test score of both conditions. The median post-test score in both conditions were 9; the distributions in the two conditions were not significantly different ($U = 1325, n1 = n2 = 37, P = .48$). There is a possibility of having a ceiling effect since the pre-test, as well as the post-test scores, are already too high narrowing the room to show differences in improvement. Despite that, the mean for the TSD condition tends to go higher than the FD group which could give us a hunch to expect the TSD condition to improve better.

Before testing for the retention of reading comprehension we decided to re-operate the F-K test to confirm the homogeneity of both conditions since some of the participants from both conditions did not take part in this delayed comprehension test. F-K test confirmed the homogeneity of the conditions ($X^2 = 1.001, P = .32$). The median delayed-test score in the TSD condition and FD condition was 7.5 and 7.0 respectively. The Mann-Whitney U test comparing the delayed-test score of both conditions did not reveal any significant difference between the conditions ($U = 715, n1 = 32, n2 = 27, P = .14$).

Reflection on Reading Comprehension Analysis The reading comprehension analysis implied that both groups significantly gain knowledge after the recomposition activity while the magnitude of this knowledge disperses in the period of two weeks. Although there is a possibility of a ceiling effect during post-test, comparing both groups' knowledge, revealed that the quality of learning is similar between the two conditions. Thus, providing a partially recomposed kit did make the activity easier but did not lower the comprehension. What is more important is that, although we observe a similar learning effect, we should acknowledge that the TSD group spent significantly less time on the recomposition activity to accomplish this level of learning. It is expected that if the remaining time was utilized to perform another form of learning, the TSD approach learners would become superior in immediate as well as retention of reading comprehension.

These results can give a significant advantage to educators when designing the concept mapping activities. The proposed approach gives a chance to use a mixture of activities in less time thus encouraging the learners to get engaged better than having the time all allocated for one task.

4.1.3 Discussion

The results of this study show that the high cognitive effort of traditional Kit-Build concept map recomposition (FD) can be minimized without losing the advantages of learning and motivation. Target Search Decomposition (TSD) is proposed as one approach to minimize the unnecessary cognitive load and

Table 4.6 Mean and standard deviation M (SD) of after-reading comprehension test (pre-test) score, and after-recomposition comprehension test (post-test) score along with the statistical test result

Group	N	Pre-test M (SD)	Post-test M (SD)	P-Value
FD	37	7.78 (1.99)	8.65 (1.44)	.01
TSD	37	7.65 (2.28)	8.78 (1.62)	<.001
P-Value			.48	

Table 4.7 Mean and standard deviation M (SD) of after-reading comprehension test (Pre-test) score, after-recomposition comprehension test (Post-test) score, and delayed comprehension test (Delay-test) score along with the statistical test result

Group	N	Pre-test M (SD)	Post-test M (SD)	Delay-test M (SD)	P-Value
FD	27	7.56 (1.95)	8.56 (1.42)	6.52 (1.70)	.051
TSD	32	7.72 (2.17)	8.81 (1.57)	7.19 (2.26)	.195
P-Value				.14	

save a lot of time compared to the FD method. The core of the TSD approach is to disconnect the target concept of every proposition in the expert concept map when preparing for the recomposition task.

The cognitive load measurement included four dimensions, two of them subjective: perceived difficulty and perceived effort; another two metrics were objective measures: time spent on the recomposition task and number of actions needed during the recomposition task. The flow metric is used to support the subjective metrics and measure the motivation of the learners toward the proposed recomposition task. Finally, the reading comprehension test was used to evaluate the learners for their reading comprehension and their retention after two weeks.

Aligning with previous study results (Fonteles Furtado et al., 2018), the traditional method showed a high degree of cognitive load and good task motivation. Similarly removing some of the tasks in FD as in the previous study resulted in lower cognitive load. However, the task removed in this study was related to the act of recomposition directly not to the user interface as in the previous study, thus, it dramatically reduced the time, actions, effort, and difficulty to accomplish nearly the same outcome. This reduction of cognitive load measures is naturally expected because it is due to the reduction in the problem space. However, the proposed approach has successfully maintained the advantage of FD in terms of task motivation, immediate learning, and knowledge retention. Although, searching for information in the text is believed to be connected to a higher retention rate (Furtado et al., 2021), this study gives educators a method to manage this search-and-find task effectively such that the invested effort gives a high learning return in much a shorter time and less cognitive effort.

As mentioned above, the proposed TSD approach removes tasks that are needed during the recomposition itself. Naturally, we expect learners who invest more effort in the learning task to gain higher knowledge (Cole et al., 2008). The reason why the TSD approach does not suffer from losing the quality of learning can be explained as follows:While TSD eliminates the need to search for the source concept and an appropriate link for a proposition, it does not negate the necessity of investing effort in reviewing the content of the source concept and link. This is because the process of identifying the correct target concept to complete the knowledge necessitates a thorough review and comprehension of the first half of the proposition. That can explain why the difference between conditions in the probability of experiencing a low cognitive effort was less distinctive relative to other cognitive parameters according to the RTE result. We contend that it is this review process that sustains the effectiveness of learning in the TSD approach, aligning with the perspective presented by Furtado et al. (2021), which underscores the significance of reviewing as one of the central tasks during the recomposition activity.

The embodied difficulty of the Kit-Build recomposition task may not contribute to the learning outcome directly but it could improve the flow and keep learners motivated to continue the activity by creating more challenges for the learners to take. Thus, removing such cognitive load may cause a reduction in the motivation for Kit-Build activity leading to difficulty in implementing the proposed method in an educational environment. However, in this case study, the flow-state results confirmed that cutting the cognitive load via TSD approach does not remove the necessary cognitive load for learners to remain engaged. It is worth investigating how the components of TSD approach in the recompositional activity maintain the flow within the learners.

There can be concern surrounding the provision of source concepts and links to learners in advance in TSD. It is similar to the case of recomposition-based concept mapping and traditional concept mapping. However, this practice aligns with the concept of empathetic understanding, underlining the importance of replicating expert or partner maps as a valuable learning process. Therefore, aiding learners in this endeavor without compromising the educational benefits of the recomposition task in Kit-Build enhances its effectiveness in educational settings. This assistance not only conserves learners' time and energy but also opens up opportunities for engaging in additional learning activities where the focus shifts to building creative knowledge structures.

The results of this study are specific to Kit-Build type recomposition. Nonetheless, the nature of the recomposition task in general could contain similar tasks that increase the cognitive load on learners. Thus, the findings of this research have the potential to be generalized on different kinds of concept map recomposition with demands for further research.

Limitations and Potential Future Studies

Target Search Decomposition of the expert concept map in Kit-Build, is likely to generate bias since part of the proposition will remain attached. This attachment gives TSD learners an upper-hand in the recomposition task.

In addition, the provision of source concepts and links may affect the meta-cognition skills of the learners. To confirm the effect of this customization during the comprehension task, we are considering further research to monitor and measure the meta-cognitive aspects of TSD compared to the traditional FD approach as well as to the open-end concept map.

Another important future research about TSD approach is to confirm the hypothesis we put in the discussion as the explanation to why TSD method maintains the same learning quality as FD method but in quite a shorter time, much less cognitive effort, difficulty, and actions. Besides, in this study, we implemented a uniform partial decomposition across all of the propositions in the expert map. However, there can be an ideal threshold for defining the level of partial decomposition. In this sense, another potential future research is to consider different levels of partial decomposition on the cognitive load and the quality of reading comprehension.

4.1.4 Conclusion

The role of concept maps in reading comprehension is very crucial, and study toward improving such activity is necessary in many aspects of education. In this study, we have introduced a new approach to be used during concept map recomposition called Target Search Decomposition (TSD). The experimental results revealed the superiority of this approach over the traditional

Full Decomposition (FD) approach in four different dimensions of cognitive load. The 4 dimensions include reduction in: perceived difficulty, perceived effort, the time needed to complete the recomposition task, and the number of actions needed to successfully recompose a proposition. Besides the cognitive load parameters, motivational aspects of the concept map recomposition were maintained since the learners reported a similar (slightly higher) state of flow during the recomposition activity in contrast to the full decomposition method. Moreover, the new approach preserves the learning quality of the concept map recomposition giving educators a remarkable advantage in setting such activities without exhausting learners' cognitive load and motivation. The proposed TSD approach can be considered as the best customization to the traditional Kit-Build concept map recomposition investigated until now. Thus, we can recommend the use of the TSD approach in concept map recomposition activities since it reduces the strain on learners, reduces the needed time to complete the activity, hence, giving a better chance to educators to organize their materials so that the saved time and mental energy can be utilized toward other learning activities such as reviewing the material, pair discussions, or supplementary exercises.

4.2 Study 2: Influence of Reading Time During The Use of KB-CMR

4.2.1 Method

This study used a between-subjects design with three conditions: "Map & Text", "Map only", and "Double Text". There was no overlap between the groups. The experiment had a main phase and an optional delayed phase. Analyses are done using quantitative methods from test results. In the main phase, participants were required to:

- Read tool instructions ("Double Text" does not do this);
- Build the training map using Kit-build("Double Text" does not do this);
- Read a narrative;
- Take the comprehension after-text test;
- Perform their main activity depending on the condition ("Map & Text" build the map while being able to access the text, "Map only" builds the map with no access to the text, "Double Text" re-reads the text);

- Take the comprehension after-activity test.

Participants who completed the main phase were invited to participate in the delayed phase. The delayed phase consisted of the same comprehension post-test used in the main phase, but with a delay of two weeks. A timeline for this experiment can be seen in Fig. 4.3.

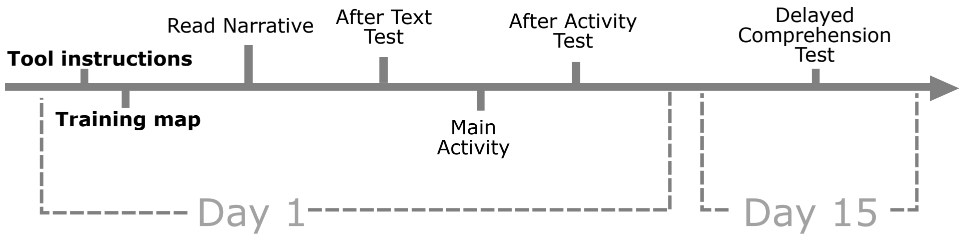

Fig. 4.3 Timeline for the Experiment. The steps in bold are only performed by the two conditions that build the concept map. The "main activity" is different for each condition. "Double Text" re-reads the text, "Map & Text" builds the map while having access to the text, and "Map only" only builds the map for the main activity.

Participants

Participants were recruited through Amazon Mechanical Turk (AMT). AMT is an amazon-run crowdsourcing system where requesters can hire remotely located crowdworkers to perform tasks. AMT has been used in past research in various fields and past research has attested for the quality of the data collected using the platform Paolacci et al. (2010). Participants were recruited in two different periods, between January and February of 2019 ("Map only" users) and between December of 2020 and January of 2021 ("Map & Text" and "Double Text"). There was no overlap between conditions and none of the learners had experience with Kit-build before. Participants were required to be residents of the U.S. and were also required to have completed more than 5000 tasks on AMT with an approval rate above 97%. This was done to ensure quality and avoid automated programs from participating in the experiment. Participants were also required to use a computer while participating since the experiment was not optimized for mobile devices. Participants who had to build the map were paid $2.50 upon completion of the activities. Participants who did not build the map were paid $1.85 upon completion. This difference in payment is due to the fact that the people who did not build the map were expected to expend less time during the main phase since reading the text one more time is faster than building the map. Participants who agreed to take the delayed post-test received an additional $0.80.

Materials

The narrative text[2] was based on a Wikipedia article describing various characteristics of the Komodo dragon, but modified and shortened to 442 words with no graphic content. The comprehension after-text and after-activity tests contained the same questions. The questions consisted of ten multiple-choice questions created to test the content of the text. An English native speaker who is a University teacher of English as a second language verified the test and found no problems with it. The map participants were requested to build was based on the text and on the reading comprehension exercises. The expert map used in this experiment had seventeen concepts and seventeen links. Since each link corresponds to a proposition, it contained seventeen propositions. The expert map was built based on the text.

Those materials have been used in other studies by 49 people. Those people were divided into two groups randomly. There are no differences between the groups at the moment they first performed the test. In Table 4.8, test scores for the first time they performed the test can be observed for all groups.

Table 4.8 Mean and Standard Deviation of Test scores for all learners who answered the test answers after reading the text

Group	N	Test Scores
Session 1	24	0.58 (0.22)
Session 2	25	0.65 (0.22)

Since all groups were drawn from the same population (Amazon Mechanical Turk users), we expect those scores to be similar if the test is reliable. This is confirmed by looking at the standard deviations and differences in average. Since the standard deviation is quite larger than the difference in means for this number of samples, it is assumed that there are no significant differences between the groups without the need of performing statistical tests.

To help testify further for the validity of the material, the correlation between the time the student took to read the text and the test scores was calculated for the participants of this study. The motivation for this is that it is assumed that if the test and the text are closely related, students who spend more time reading should have an advantage when doing the test. A statistically significant positive correlation between reading time and test scores was

[2] https://git.io/JyeDr

found, r = 0.35, p < 0.001. These results suggest that there is a relationship between the questions in the test and the content of the text.

Procedure

The experiment was delivered through a website. Participants belonged to three conditions. The conditions are "Map & Text", "Map only", and "Double Text". Two of these conditions built the concept map as part of the experiment.

First, the procedure for learners who built the map will be introduced. From this point, it is already clear the participants are aware that there will be an optional delayed phase. Those participants are informed about how their data will be used, the purpose of the experiment, the fact that they can stop the experiment at any time, and other information. The participants then proceeded to read instructions on how to use Kit-build. Afterward, they would build the training map to get used to Kit-build. The training map consisted of three concepts and three links. The content of this training map had no relation to the rest of the experiment. After building the training map, participants from both groups read the narrative and answered the after-text test. Following the 'after text test', participants had to build the map related to the text using Kit-build. "Map & Text" participants had access to the text while building the map. "Map only" participants had no access to the text. Participants then answered the after-activity test, ending the main phase of the experiment. All activities in the main phase had a 5-minute limit, except for building the map, which had a 20-minute limit. The reason behind the limit is that if the activities do not have a time limit, Amazon Mechanical users might take a long time to complete the experiment by taking long pauses. This could affect the results so the time has been limited and, from the experience of the authors in past experiments, the time allotted is enough to complete the task. Participants who did not build the map did the above procedure without reading instructions on how to use Kit-Build. Additionally, they did not build any concept maps. Their main activity was re-reading the text.

Two weeks later, participants were contacted by email to take part in the optional delayed phase. A shorter wait period (a week or two days) would possibly lead to more users coming back for the delayed phase but it would also be less interesting for measuring the retention of information. The delayed phase consisted of the same comprehension test taken in the after-text and after-activity tests. Participants did nothing else other than answer the comprehension test. For the analysis of the data, scoring the test is straightforward since it contains multiple answer questions with only one correct answer.

The maximum retention period for a particular user is 16 days and the minimum retention period is 12 days. This is because of how Amazon Mechanical Turk Works. This also means that participants could have done the delayed phase at a different time of the day from the regular phase. The influence of this difference in retention time is not part of the scope of this paper.

4.2.2 Results

101 people completed the experiment successfully. Of these learners, only 63 completed the delayed test. The distribution of reading time for the Map&Text condition can be seen in Figure 4.4. There are two peaks for the lowest values of reading time, suggesting that a large portion of learners spent little time reading the text while building the map. Figure 4.5 shows the distribution of the number of reading sessions. There are peaks similar to Figure 4.4, suggesting similar distributions for reading times and for the number of reading sessions. This means that learners with a higher value of reading sessions spend more time reading, which is expected. Most learners only read the text for one session and did it for a short amount of time. Figure 4.6 shows the relationship between learning gains and reading time during map creation. While learners who have low reading times have widely varying performance, increases in reading time seem correlated with better performance in learning, but it is hard to understand the whole picture with just that graph. Figure 4.7 can better illustrate the differences in learning caused by differences in reading time. In that figure, learners from the Map&Text condition are divided in half. One half has the learners with high read times (N=12). The other half has the learners with low reading time (N=22). From looking at the graph, learners who read more have better improvements both in short-term gains and after two weeks.

To address the first research question, whether reading times while building a closed concept map affect immediate reading comprehension, we performed a linear regression model with after-map scores as the dependent variable, reading time as the predictor, and after-text scores as a control variable. The model was fitted with a multiple R-squared value of 0.83. Reading time was identified as a significant predictor ($p < 0.001$) of immediate reading comprehension when controlling for after-text scores.

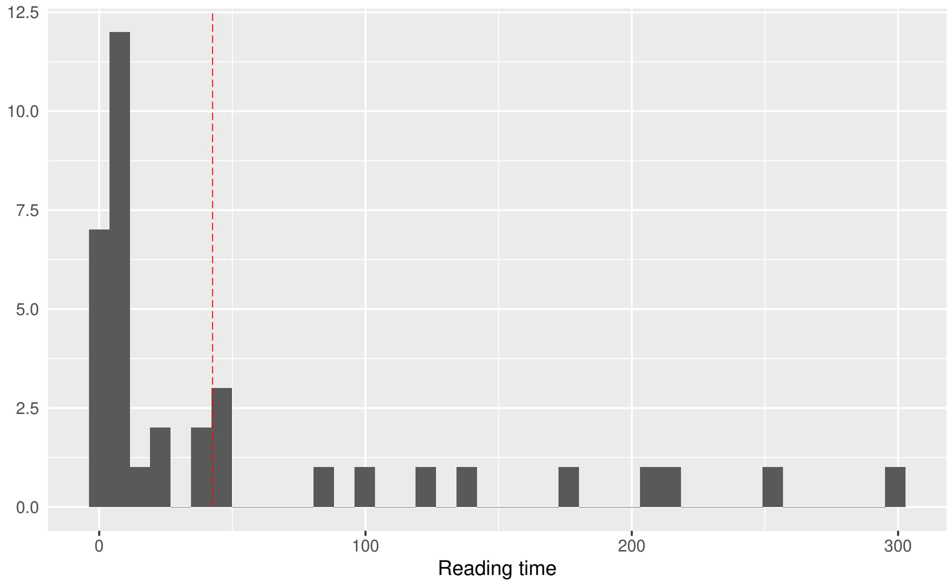

Fig. 4.4 Histogram of reading time while building the map for the Map&Text condition

To address the second research question, whether reading times while building a closed concept map affects reading comprehension retention, we performed a linear regression model with delay test as the dependent variable, reading time as the predictor, and after-text test scores as a control variable. The model was fitted with a multiple R-squared value of 0.44. Reading time was identified as a significant predictor ($p < 0.01$) of reading comprehension retention when controlling for after-text scores.

Mean and standard deviation for relevant metrics can be seen in Table 4.9, while similar metrics for people who completed the delayed post-test can be seen in Table 4.10. On Figure 4.8, how test scores varies through time can be visualized.

Table 4.9 Mean and standard deviation of measured statistics for all groups

Group	N	After-text Test	After-map test	Norm. change
Double Text	35	0.61 (0.19)	0.73 (0.20)	0.35 (0.39)
Map Only	30	0.64 (0.24)	0.67 (0.24)	0.04 (0.43)
Map & Text	36	0.55 (0.21)	0.71 (0.22)	0.44 (0.32)

To address the third research question, what is the effect of having access to the reading material during KB-CMR on immediate learning gain compared to the control conditions, we performed a Kruskal-Wallis test with nor-

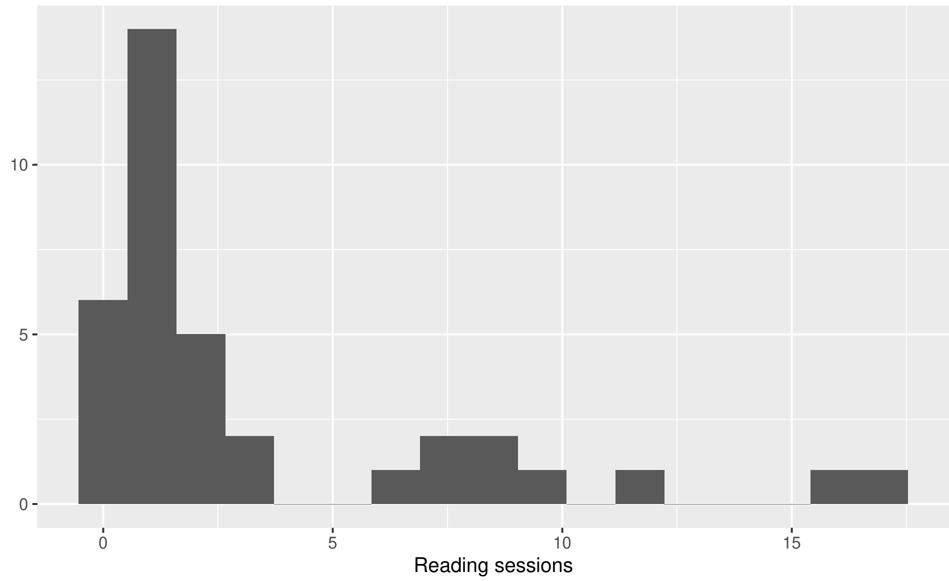

Fig. 4.5 Histogram of the number of reading sessions while building the map for the Map&Text condition

Table 4.10 Mean and standard deviation of measured statistics for all groups, only for the participants who completed the delayed test

Group	N	After-text Test	After-map test	Delay Test	Norm. change	Delayed Norm. Change
Double Text	19	0.63 (0.16)	0.74 (0.18)	0.51 (0.19)	0.29 (0.38)	-0.18 (0.33)
Map Only	20	0.64 (0.19)	0.66 (0.18)	0.56 (0.20)	0.08 (0.29)	-0.11 (0.30)
Map & Text	24	0.54 (0.20)	0.71 (0.23)	0.53 (0.25)	0.42 (0.34)	0.02 (0.47)

malized change as the dependent variable and condition as the predictor. The Kruskal-Wallis revealed a main effect of condition on normalized change (chi-squared = 9.95, $p < 0.01$). Post-hoc comparisons using Dunn's test revealed that the normalized change for the "Map & Text" (Med = 0.45) was significantly higher than the normalized change for the "Map only" (Med = 0), $p < 0.001$. No other pairwise comparisons were significant.

To address the fourth research question, whether students having access to text reading while building a closed concept map affects the retention of reading comprehension gains, we performed a Kruskal-Wallis test with delayed normalized change as the dependent variable and condition as the predictor. The condition did not have a significant effect on delayed normalized change.

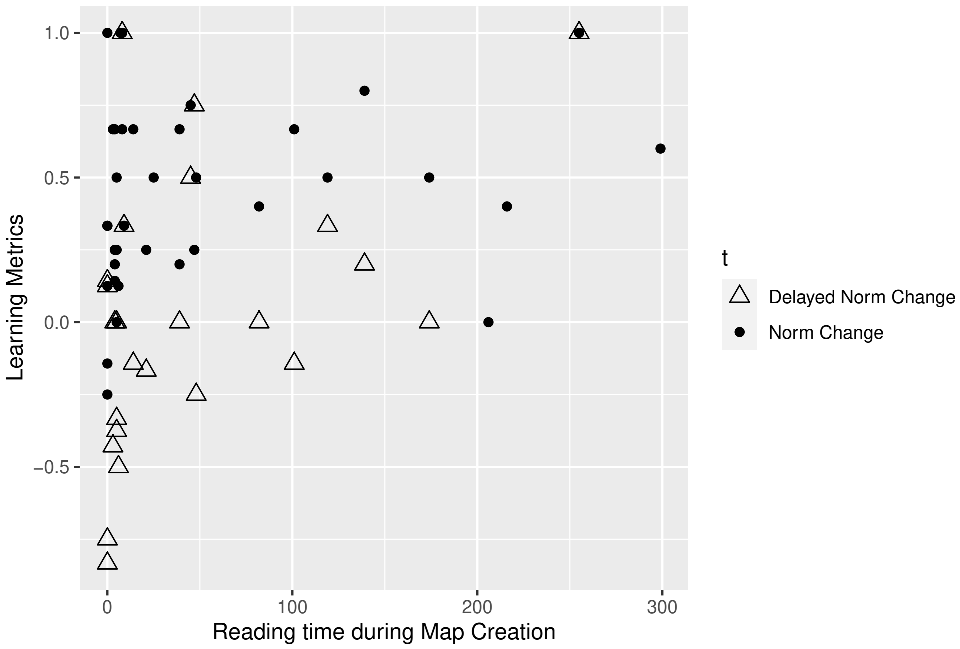

Fig. 4.6 Normalized Change and Delayed Normalized change against Reading Time while building the map for the Map&Text condition

Exploratory Analysis on the high read group

The research questions of this study have already been answered. However, results so far show that many learners of the Map&Text group have low reading times. Results also have shown that higher reading times have been associated with better learning results. As such, the following two exploratory research question comes to mind: Do learners with high reading times while building the map outperform the two control groups in (1) reading comprehension gains and the (2) retention of reading comprehension gains?

To address the first exploratory research question, whether high reading time students have better reading comprehension gains than the two control groups, we performed a Kruskal-Wallis test with normalized change as the dependent variable and condition as the predictor. The Kruskal-Wallis revealed a main effect of condition on normalized change, chi-squared = 14.30, $p < 0.001$. Post-hoc comparisons using Dunn's test revealed that normalized change for the high read learners (Med = 0.58) was significantly higher than normalized change for the MapOnly learners (Med = 0), $p < 0.001$ and significantly higher than normalized change for the "Double Text" learners (Med = 0.33), $p = 0.01$.

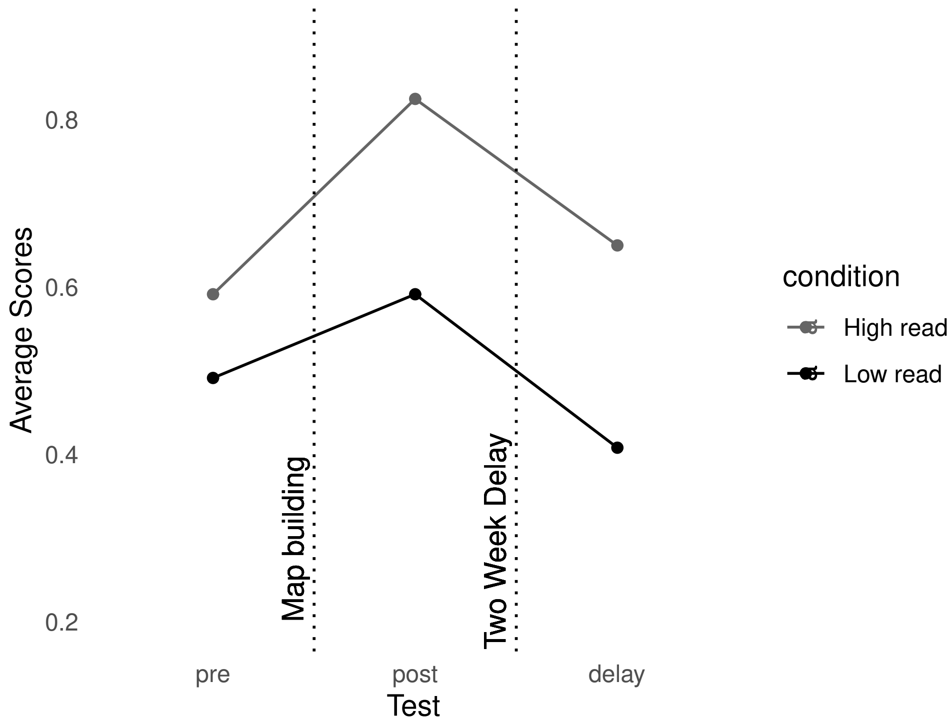

Fig. 4.7 After text, after activity and delay score averages for participants who built the map with access to the text, divided between learners with high text reading time and low reading time

To address the second exploratory research question, whether high reading time students have better retention of reading comprehension gains than the two control groups, we performed a Kruskal-Wallis test with delayed normalized change as the dependent variable and condition as the predictor. The Kruskal-Wallis revealed a main effect of condition on normalized change, chi-squared = 7.33, p = 0.03. Post-hoc comparisons using Dunn's test revealed that normalized change for the high read learners (Med = 0) was significantly higher than normalized change for the MapOnly learners (Med = -0.18), p = 0.02 and significantly higher than normalized change for the "Double Text" learners (Med = -0.25), p = 0.01.

Discussion

The main finding of this study is that higher reading times while building the map are associated with better reading comprehension both in the short and long term. However, a large portion of learners have low reading times, suggesting that making the text available while building the maps is not enough to improve long-term learning for the group as a whole. Short-term reading

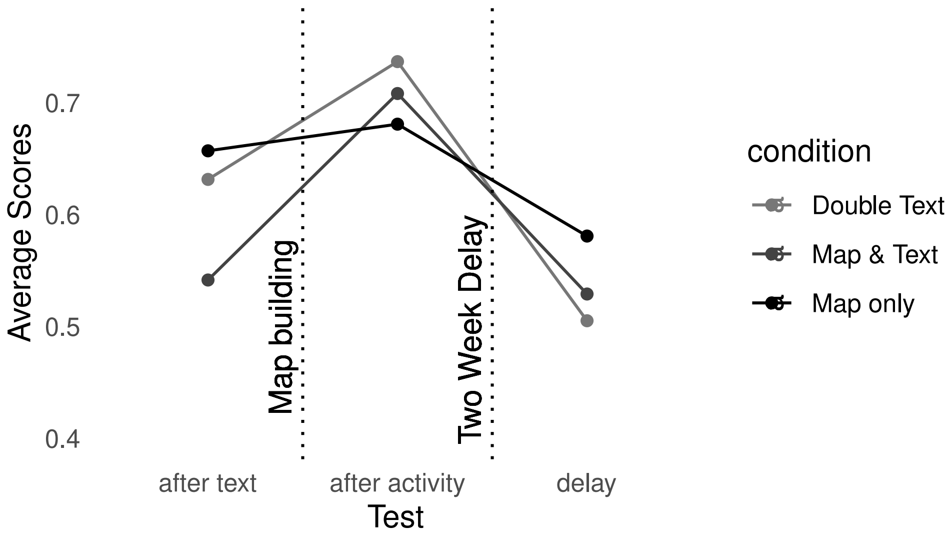

Fig. 4.8 After text, after activity and normalized change scores for all participants

comprehension, however, is improved significantly just by having access to the text. This suggests that learning gains obtained by learners who quickly read are not committed deeply into memory and might give a false idea of learning achievements by the students. It is believed that the improvement on long-term learning is caused by having to translate between two different media (the text and the map). Searching for information in the text and organizing it in the map results in a high number of access to the working memory of the student. This is believed to result in higher retention of that information.

4.2.3 Conclusion

Results suggest that having high reading times in parallel with building closed concept maps enhances reading comprehension and retention. Furthermore, many learners have low reading times during closed concept map creation. These findings potentially have broad applications for improving reading comprehension, since finding a way to improve reading times during closed map construction enhances both immediate comprehension and retention. One important limitation of these results is that only one material was used to obtain these results. The properties found on this experiment could be limited to this material. For future works, measuring whether or not these results are applicable to more materials is one important task. Also, whether or not incentivizing reading will result in better comprehension and retention is also necessary.

Chapter 5

Extending KB-CMR into Procedural Domain of Computer Programming

This chapter delves into the findings from two experiments aimed at validating the application of KB-CMR in the procedural domain of computer programming. The research questions outlined in Section 3.2 are thoroughly explored and addressed.

The first experiment reported in Section 5.1 serves as a preliminary exploration, proposing the new approach. It lays the foundation for the subsequent wider experiment, detailed in Section 5.2, which delves deeper into the integration of theoretical and practical knowledge in the context of OOP concepts.

Both experiments aim to develop an effective activity that integrates theoretical and practical aspects of programming knowledge to enhance students' comprehension of OOP concepts. A novel approach is proposed, involving the manipulation of a concept map to create an integrated cognitive diagram encompassing both theoretical and practical knowledge of OOP concepts as perceived by the educator. This diagram is then adapted into a recomposition activity for students to facilitate their learning process.

5.1 CRS Experiment 1

5.1.1 Method

To investigate the effectiveness of CRS, a quasi-experimental design was utilized. Students performed a pre-test, recomposed the map, and performed the post-test. At the end of the activity, students were asked to fill in a questionnaire about the activity.

Participants

The participants were 49 undergraduate third-year university students, majoring in computer science. The experiment was conducted during their regular class and KB-CMR is used as a part of class-teaching activity. Students were free to discontinue the experiment at any stage. Particularly, out of 49 students, 31 students completed the experiment, and only the data for those 31 students were included in the analysis.

Material

For this experiment, two materials were prepared. The first material was online lecture notes concepts specified by the class teacher. The second material was the expert map implementing CRS about the realized concepts in the given source-code prepared by the author and approved by the class teacher. The source-code was prepared in Java programming language by a professional teacher having experience in teaching OOP classes. The source-code consisted of two classes, "Circle" as super class and "Cylinder" as a subclass. Class "Circle" consists of two primitive variables, two constructors, and four methods. Class "Cylinder" on the other hand, consists of one primitive variable, two constructors, and five methods. The main class was also provided that creates objects from Class "Cylinder" and invokes some methods. Concepts included in the source-code are: inheritance, polymorphism, encapsulation, class, and composition. However, the map was simplified for this experiment to include fewer concepts and details, since the class time was very limited. The used expert map in the experiment is shown in Figure 5.1.

Procedure

The experiment began with the class instructor explaining the KB-CMR tool and its features to the students, and allowing them to build a training map

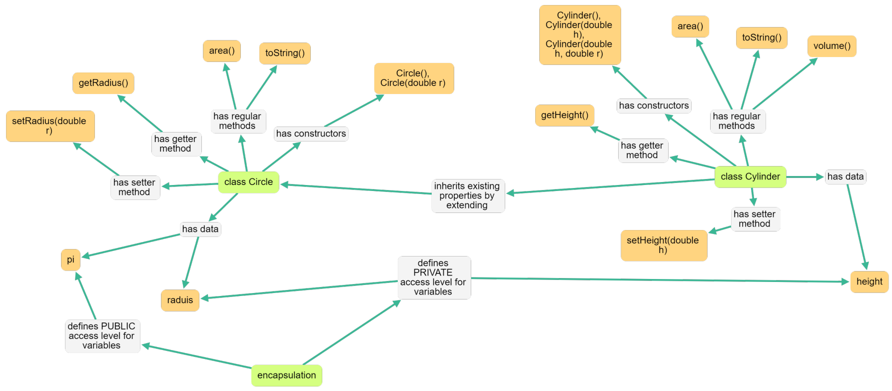

Fig. 5.1 The CRS concept map used in the preliminary experiment.

to become familiar with it. After that, students took a pre-test, answering multiple-choice questions about the concepts of applied in a given source-code, to assess their basic knowledge of the subject. This pre-test session lasted for 5 minutes. The instructor then provided material on the concepts of for the students to read, and briefly explained the material in 10 minutes. Students were then asked to recompose the kit using the KB-CMR tool in 25 minutes, while being allowed to refer to the source-code. The KB-CMR tool had a feedback feature to evaluate the students' recomposition progress, which reported any wrong propositions made by the students that did not exist in the expert map. After the concept map recomposition activity, students took a post-test and completed a questionnaire

5.1.2 Results

The successful completion of the experiment with the approval of the class teacher suggests the practicability of the proposed method as part of the class activity for teaching concepts. Further, we analyze the pre-score and post-score of the participants to get an idea about the advantage of this activity.

Learning Effect of CRS Recomposition on Concept Comprehension

We run the F-K to make sure there is no selection bias for students who decided to finish the experiment successfully. The result shows that the students were homogeneous with a p-value of 0.09639. To measure the learning outcome of using the CRS, we have compared the post-test scores against pre-test scores. The scores failed the Shapiro-Wilk normality test due to the small number of participants. Thus, we used the Wilcoxon matched-pairs signed-rank test to measure the difference. Figure 5.2 shows the comparison results. The pre-test and post-test scores had medians of 0.33 and 0.66, respectively. A Wilcoxon Signed-rank test showed a significant difference between the two scores (W=229, Z=-2.6754, p-value=0.006, r =0.346). The result suggests that using CRS recomposition may promote learning concepts. Thus, there is a potential for further research.

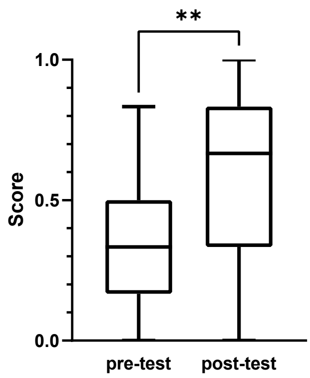

Fig. 5.2 Test Score Comparison Between pre-test and post-test after participating in CRS concept map recomposition.

Students' Feedback on Applying CRS in The Class

A questionnaire was given consisting of six 6-Likert scale questions to measure the students' likeness and expectation regarding the use of the CRS in learning. The original questions were in Japanese. The translation of the questions were as follows: Likeness questions:

(i) You feel KB-CMRs' recomposition learning method is memorable. (ii) You feel KB-CMRs' recomposition method to be a friendly learning method. (iii) You feel KB-CMRs' recomposition learning method fun to learn.

Expectation questions: (i) You think the feedback from the KB-CMR will help you understand what you are learning? (ii) You think the KB-CMR exercises are an effective way of learning to promote understanding of object-oriented programming? (iii) You think the KB-CMR exercises are an effective way to learn how to understand the source code?

Figure 5.3 shows the students' impressions for each question in the likeness and expectation categories. The questions in the questionnaire were found to have good reliability in representing each target category, with Cronbach's $\alpha > 0.90$. The students had a positive impression of using KB-CMR activity, with average scores of 4.2 and 4.4 for likeness and expectation, respectively. The likeness graph indicates that this activity was somewhat unusual for the students, as it differed from their typical learning methods, but still deemed useful. The students had high expectations for KB-CMR and believed it would help them understand the OOP concepts effectively.

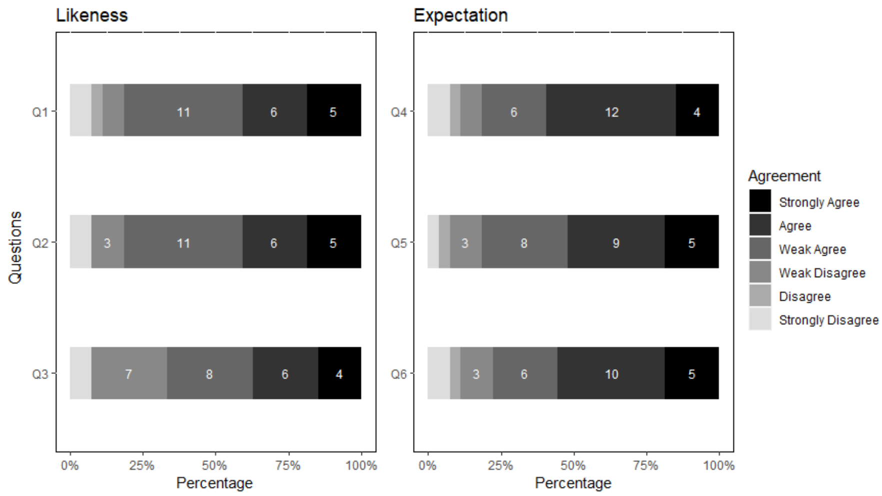

Fig. 5.3 Distribution of students' likeness and expectation response regarding the new activity of KB-CMR for learning about concepts of OOP.

Limitations and Future Work

The study have presented a novel way to visualize OOP concepts and combine them with the OOP-based source-code. The post-test score results showed a significant improvement in students' OOP concept comprehension after the recomposition activity of the proposed concept map. Additionally, the questionnaire analysis of students' feedback shows that learning with the proposed activity is memorable and friendly as well as fun to some extent. This study raises a new insight toward the perception of researchers and educators on OOP concept comprehension solutions coupled with source-code. The proposed approach has potential in various teaching aspects. It can be used in creating OOP-based activities to promote OOP comprehension. It also allows educators to create conceptual-based activities when teaching OOP.

The current study does not evaluate the learning effect of the students compared to a traditional teaching method, and the experimental design also limits the reliability of the findings in terms of the learning effect. Therefore, a more in-depth experiment of the proposed method is needed to provide sufficient and more accurate insights on the implementation of CRS in the KB-CMR tool for use in actual learning environments.

5.2 CRS Experiment 2

To address the limitations of the previous experiment, the second experiment is conducted. This experiment focuses more on the ability of class teacher to produce a satisfied CRS concept map and the learning effects of using CRS concept map in KB-CMR as part of an actual class environment.

5.2.1 Method

A comparative experiment is conducted using a between-subjects pre/post test design to address the research questions. The independent variable is the treatment practiced for OOP concept comprehension after reading the related material. In the treatment, the CRS condition was compared to the summary-making condition. Figure 5.4 shows the timeline of the experiment.

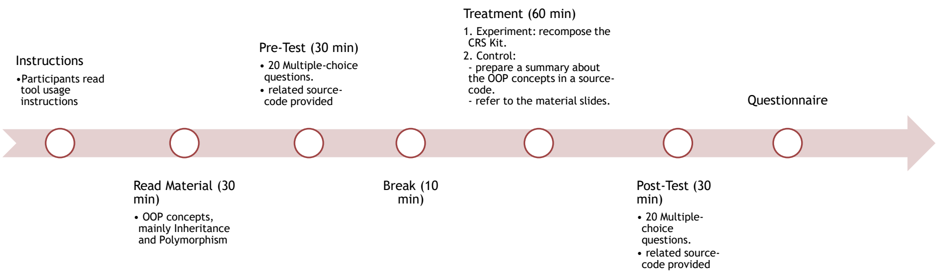

Fig. 5.4 Timeline of the experiment.

The experiment flow included the following tasks:

1. Reading material about OOP concepts focusing on polymorphism and inheritance – 30 minutes.

2. Taking the comprehension test (Pre-Test) – 30 minutes.

3. Completing the core activity depending on the condition:

   (a) CRS condition: Given a source-code, a concept map based on the proposed method.

   (b) SUM condition: Given a source-code, write a summary (about 250 words) connecting the concepts of OOP found in the material to the applied concepts in the given source-code.

4. Taking the comprehension test (post-test).
5. Answering a questionnaire about the use of the proposed method – CRS condition only.

Participants

The study was conducted in an OOP class for second-year Informatics Department students at the Universitas Yarsi in Indonesia. The class registrants for this class were 90 students, divided into 45 students per condition. The subject aimed to extend students' knowledge from basic programming into Object-Oriented Programming using Java programming language. Based on that, the source-code related to the experiment was also written in the Java.

Material

The main topics for this class material were Inheritance and Polymorphism in Java. The class teacher prepared digital slides explaining these topics. The class teacher regularly used the slides, regardless of the experiment. The comprehension questions consisted of 20 multiple-choice items that were novel in their content but were based on the topics of the material. Each question has four options, including one correct answer. The question sequence and their corresponding options for each learner were randomly shuffled between the pre- and post-comprehension tests to reduce the chance of memorization and cheating. To ensure the suitability and effectiveness of the comprehension questions in assessing the students' integration of theoretical and practical skills, we leveraged the expertise of the class teachers, who are familiar with their classes and have several years of experience teaching the same subject. By involving the class teachers in the question preparation process, we aimed to design questions that aligned with their teaching and assessment styles. Their deep understanding of the class context and student needs allowed them to create assessments that carefully considered the integration of theoretical knowledge and practical application. Combining the teachers' familiarity with the class and our objective of assessing both theoretical and practical skills, this collaborative approach ensures a comprehensive evaluation that captures the essence of effective object-oriented programming learning.

A professional teacher with experience in OOP classes prepared the source-code of a program in Java. The source-code consisted of two classes, "Circle" as a superclass and "Cylinder" as a subclass . The source-code was reviewed and verified by the class's main teacher and the teacher assistant to be compatible with the class material and students' capabilities. The class "Circle" consists of two primitive variables, two constructors, and four methods. The class "Cylinder," on the other hand, consists of one primitive variable, two constructors, and six methods. The main class was also provided to create objects from Class "Cylinder" and invoke some methods. The source-code is used for both conditions: control and experimental. The source-code's focus is inheritance and polymorphism, which correspond to the material of the class. The inheritance concept was depicted in the Cylinder-Circle relationship. The polymorphism concept was divided into two parts: overloading and overriding. The overloading part was explained by having multiple methods with the same name but different signatures within each class of Circle and Cylinder. While the overriding concept was explained within the inheritance relationship. Overriding is a phenomenon that occurs when a subclass has a method with the same name and signature as the superclass. As a result, the subclass's method will override the inherited method of the superclass. The expert map visually represents these concepts using multiple connected propositions.

The same professional teacher created the corresponding expert map, consisting of 76 propositions created with respect to the properties of CRS. The concept map is similarly reviewed and approved by the main class teacher and the assistant teacher to be used in correspondence with the class material. The expert map contained theoretical knowledge about the class material integrated with the practical knowledge represented in the source-code used in this experiment. Through review and discussions, the teachers decided on bridging links where the connection between theoretical and practical knowledge is constructed to create a high-quality CRS map. Figure 5.5 shows the translated version of the final expert map created by the teachers. This satisfies our first research question of this experiment about the possibility of the teacher creating a CRS concept map for an actual class, since the map has been created and approved by the teachers to be used as part of their class activity. From this expert map, the kit for recomposition was generated to be used by the experiment group. Following the findings of our first study, the kit is generated using the TSD method to reduce the cognitive load of the recomposition activity. The above materials were all in Indonesian since the medium of instruction at Universitas Yarsi is Indonesian.

In addition, a 7-point Likert-type scale (1: *extremely disagree* to 7: *extremely agree*) questionnaire was prepared to measure the perceived usefulness of the proposed method. The questionnaire consists of five questions, all in Indone-

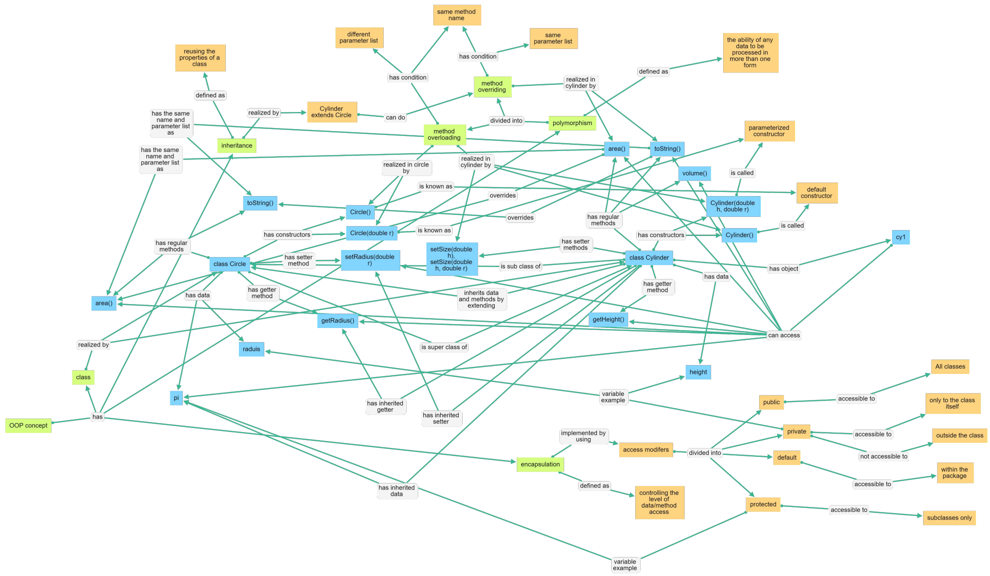

Fig. 5.5 Translated version of the expert map utilized in the experiment. The expert map is build based on the given source-code.

sian, which translate as follows: Q1. Using the CRS concept map would enable me to understand the source-code more quickly; Q2. Using the CRS concept map would enable me to understand the concepts of OOP more easily; Q3. Using the CRS concept map would enable me to understand the relationship among OOP concepts more easily; Q4. Using the CRS concept map would enhance my effectiveness in studying the programming classes; Q5. Overall, the CRS concept map is useful in this class.

Procedure

A control group was needed to create a baseline for the comparison of the results of the CRS method. In the first class of the course, the class teacher administered a test to evaluate students' prior knowledge about programming. Students were divided into two groups, control and experiment (45 per condition), based on their scores on the test, such that experienced students would be distributed equally between the conditions. Such a distribution of the two conditions was later confirmed by conducting the pre-test. The experiment was conducted in the class during the regular class schedule using a tool specifically developed for the experiment. Each student had a separate account to access the tool online. The tool featured the experiment tasks in sequence according to the student's condition, with each task limited by an automatic timer. When a task was finished, the next task was automatically loaded. The students were informed about the sequence of the required tasks and the time allowed for each task. If students did not complete a task within the specified time, the tool automatically disregarded their results. Therefore, they were advised to stay focused on the experiment and not switch to external tasks.

Following the instructions, the tool displayed the slides prepared for the class, which students could read through for 30 minutes, followed by the after-reading comprehension test (pre-test). The students were required to answer the questions by drawing on their understanding during the reading phase. Afterward, students were given 10 minutes of rest time as required by the class teacher. The break time helped refresh the students after one hour of active reading and answering the pre-test questions.

Next, the treatment phase started for 60 minutes. The CRS condition students were given the source-code and the kit of disassembled concepts & links to recompose based on the expert map. On the other hand, the SUM condition was given access to the material slides again, including the same source-code as in CRS condition, and was required to write about 250-word summary describing the source-code in terms of the OOP concepts learned in the presentation slides.

Following the treatment phase, the participants answered the after-treatment comprehension questions (post-test), which consisted of the same questions as in the pre-test. Finally, the questionnaire about the CRS concept map recomposition experience was given to the students in the experiment condition to measure their perceived usefulness toward using this new approach to support their study of OOP.

5.2.2 Results

From the total of 90 enrolled students, 15 were excluded from the analysis due to absences or failure to complete the experimental tasks within the allotted time. As a result, data were collected from 75 students using the provided tool, with 34 and 41 students in the control and experimental conditions, respectively. Statistical tests were conducted at $\alpha = 0.05$ to address research questions. Although there are various methods for normality testing, for a small sample size ($n<50$) , the Shapiro–Wilk test is said to have more power to detect the non-normality, and this is the most popular and widely used method Mishra et al. (2019). Therefore, the Shapiro-Wilk test was used to test for the normality of the user data, and the result showed no evidence of non-normality. To confirm the homogeneity of the conditions, we used Bartlett's test of homogeneity of variances on the pre-test score. The test revealed no significant difference in variances between control and experimental conditions *(Bartlett's K-squared = 0.027, df = 1, P = 0.87)*.

To answer our second research question in this experiment, "What is the effect of integrating the two main aspects of OOP using CRS in a concept map activity on OOP comprehension in an actual class setting compared to the conventional method?", we analyzed the comprehension scores of the after-reading comprehension test (pre-test) and the after-recomposition comprehension test (post-test). We performed the dependent sample t-test for CRS condition. Table 5.1 shows the mean and standard deviation of the comprehension scores and the normalized change score for both conditions. The results revealed a significant increase in the test score from the pre-test score (M=10.2, SD=3.54) to the post-test score (M=12.7, SD=4.10); $t(40) = 4.48, P < .001$ with an effect size of $d = 0.66$ which translates to a medium-sized effect according to Cohen (2013). To understand the learning gain of the proposed method, we calculated the *normalized change* score and compared it against the baseline condition's normalized change score using an independent-samples t-test. The normalized change score measures the proportion of improvement or declines in academic achievement relevant to the maximum of what can be improved or lost, thus avoiding the pre-test score bias Marx and Cummings (2007); Perdana and Azhari (2017); Setiawan and Kudus (2020).

Table 5.1 Mean and standard deviation of after-reading comprehension test (pre-test) score, after-recomposition comprehension test (post-test) score, and the normalized change along with the statistical test result

Group	N	Pre-test M (SD)	Post-test M (SD)	Normalized change M (SD)
SUM	34	11.1 (3.43)	12.1 (3.29)	0.12 (0.23)
CRS	41	10.2 (3.54)	12.7 (4.10)	0.26 (0.35)

Figure 5.6 compares the average normalized change for both groups in a boxplot. The independent sample t-test revealed a significant difference in the normalized change score of the CRS condition (M=0.26, SD=0.35) compared to the control condition (M=0.12, SD=0.23); $t(69.88) = 2.09, P = .039$. The effect size in terms of **probability of superiority** Grissom and Kim (2005) reveals a 63.0% chance that a student picked at random from the CRS group will have a higher score than a student picked at random from the control group. In addition, we fitted the learning gain into the linear regression model, where the recomposition map score (M = 48.78, SD = 28.31) is used as the predictor while controlling for the pre-test score. Table 5.2 shows the

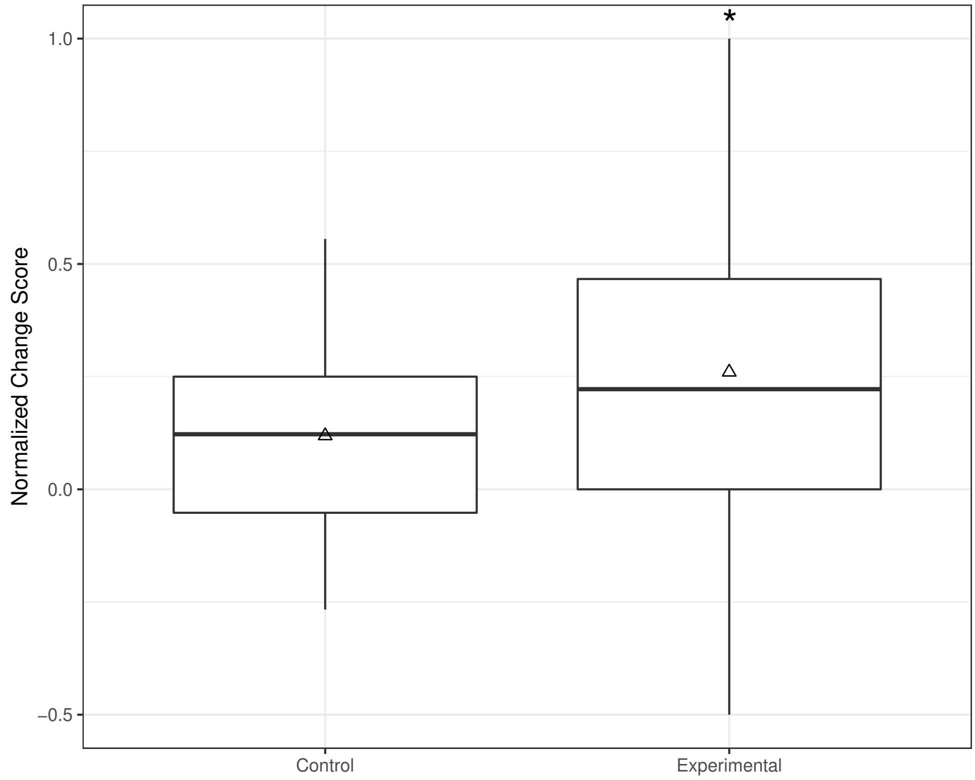

Fig. 5.6 A box-plot comparing the normalized change score of CRS condition to the SUM condition.

results of the linear regression model. The result validates the prediction of the learning gain by the completion degree of CRS map recomposition: $R^2/R^2adj. = .218/0.176, F(2,38) = 5.285, P = .009$.

Table 5.2 Linear regression of learning gain (normalized change) as dependent variable, and CRS map score with pre-test score as independent variables.

	CRS Condition		
Predictors	Estimates	95% CI	p Value
(Intercept)	0.24	-0.07 – 0.55	0.124
Pre-test Score	-0.03	-0.07 – 0.00	0.075
CRS Map Score	0.01 **	0.00 – 0.01	**0.003**
Observations	41		
R2 / R2 adjusted	0.218 / 0.176		

These results of the learning gain analysis suggest that the proposed method positively improves the learning gain of OOP concepts comprehension during the class. The improvement rate is significantly better compared to the conventional method of summarizing the concepts of OOP. The map score analysis indicates that the percentage of successfully recomposing the CRS concept map affects the learning gain positively, thus it is important to focus on supporting students at the recomposition stage in future research.

The results confirm previous findings about using CRS as a method to teach concepts of OOP Khudhur et al. (2021). However, this study confirms that the learning outcome comes from the treatment applied during the experiment. The regression analysis of the recomposition task is consistent with previous studies about using kit-build recomposition, as similar trends have been revealed where the recomposed map score played an important role in the learning activity Andoko et al. (2020); Wunnasri et al. (2017). However, further research is needed to investigate the relationship between the CRS and the concept map recomposition task further.

To address the third research question, "How do the students perceive the proposed method in terms of usefulness for learning OOP?" we analyzed the subjective answers to the perceived usefulness questionnaire. The students responded to the questionnaire after completing the post-test. The inter-reliability of the questions was assessed using Cronbach's Alpha, showing good reliability with a value of $\alpha = 0.88$.

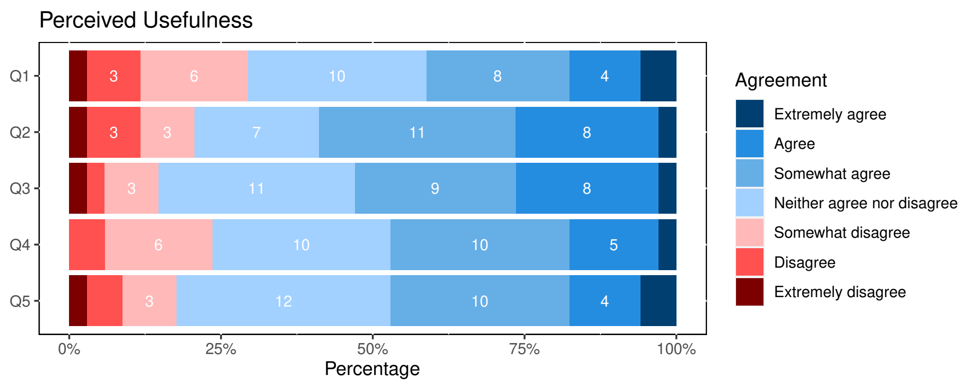

Fig. 5.7 Perceived usefulness questionnaire answers for each question.

The summary of the answers is demonstrated in the stack chart in Figure 5.7, and Table 5.3. Each color in the figure represents one agreement scale. The number inside each color shows the number of students agreeing to the corresponding level. Regarding whether it is faster to use the proposed method to learn concepts of OOP than not, 29% of students have a neutral view, 29% have a negative view, and 41% of students agree with the improved performance. A similar percentage can be seen in questions four and five, where students were asked if the proposed method would enhance

Table 5.3 Distribution of student perceptions regarding the usefulness of the crs method for learning object-oriented programming concepts

Perceived Usefulness	Positive	Neutral	Negative
Question 1	41%	29%	29%
Question 2	59%	20.5%	20.5%
Question 3	53%	32%	15%
Question 4	46%	30%	24%
Question 5	47%	37%	16%
Overall Impression	49%	21%	30%

their effectiveness in studying the programming classes (46% positive, 24% negative, 30% neutral) and their overall impression of the method's usefulness (47% positive, 16% negative, 37% neutral). In questions two and three, a higher percentage of students hold positive views (59% positive, 20% negative, 20% neutral) and (53% positive, 15% negative, 32% neutral), respectively. In these two questions, the students believe that adopting the proposed method makes it easier for them to comprehend each OOP concept and the relationships among these OOP concepts. Approximately half of the students expressed a positive view of using CRS as a learning method. On the other hand, about 21% think neutrally, and less than 30% have a negative impression about using the method as a class learning tool. A high percentage of neutral and negative views can be attributed to the uniqueness of the proposed method for learning programming concepts. We believe that continuous use of the proposed method will enhance students' impressions of using CRS as a learning method in a programming class.

Exploratory Analysis on Long-term Effect of the Treatment Method

Although not part of the main research goal, the students were assessed again after one week using the same pre / post comprehension questions and given the same time limit for the test. In addition, their assignment and mid-term performance were tracked to answer the following exploratory research questions: 1) Compared to the conventional method, can the learning gain of CRS affect the reviewed learning gain after one week? 2) What is the correlation between performance in CRS and performance later in the course activities of assignments and mid-term tests?

The assignment score is the average score of seven consecutive weekly assignments that were part of the regular teaching plan. Each assignment was a practical code-writing activity in which students were asked to code a solution based on a given case. Assignments were submitted weekly before starting the next class, and the content was related to the material studied in the corresponding class. Similarly, the midterm score is the average of six consecutive weekly quizzes in the regular teaching plan. This formative assessment consisted of multiple-choice questions about the content of the corresponding class. The quiz was administered three days after the class in an online form. Given 15 minutes, students were asked to answer all the questions.

To investigate the first exploratory research question, we calculated the delayed normalized change from pre-test to delayed-test for both CRS (M = 0.35, SD = 0.35, N = 39) and SUM (M = 0.27, SD = 0.30, N = 34) conditions. For the delayed test, two students from the experimental condition did not make it to the class that day, so their data were excluded from the analysis. Figure 5.8 shows the change in learning gain from experiment day (post) to one week later (delay). Compared to the post-normalized change score, the learning gain has increased for both conditions without any significant difference. The increase is expected, as the experiment is part of a regular class in which students have a practical session before starting the next class and participate in review studies that are likely to improve their learning.

From the line chart, in addition to the learning gain increase for both conditions, we notice a higher learning slope in the control condition. Thus, we calculated the interaction between condition and time using a two-way Analysis of Variance (ANOVA) with Type III sums of squares, presented in Table 5.4. The result revealed no interaction between time and condition, meaning that continuous class improves students understanding in both conditions similarly without giving an advantage to one condition.

Table 5.4 Anova Table (Type III tests), the response variable is the learning-gain and the predictor variables are time (post/delay), condition (experimental/control), and the interaction between the two predictor variables

	Df	Sum Sq	F value	Pr(>F)
group	1	0.51	5.32	0.0225 *
time	1	0.36	3.73	0.0556 .
condition:time	1	0.06	0.58	0.449
Residuals	142	13.60		

In addition, calculating the linear regression model on the delayed normalized change revealed that for the CRS condition, their delayed learning gain is significantly predicted by their post-learning gain, $R^2/R^2adj. =$

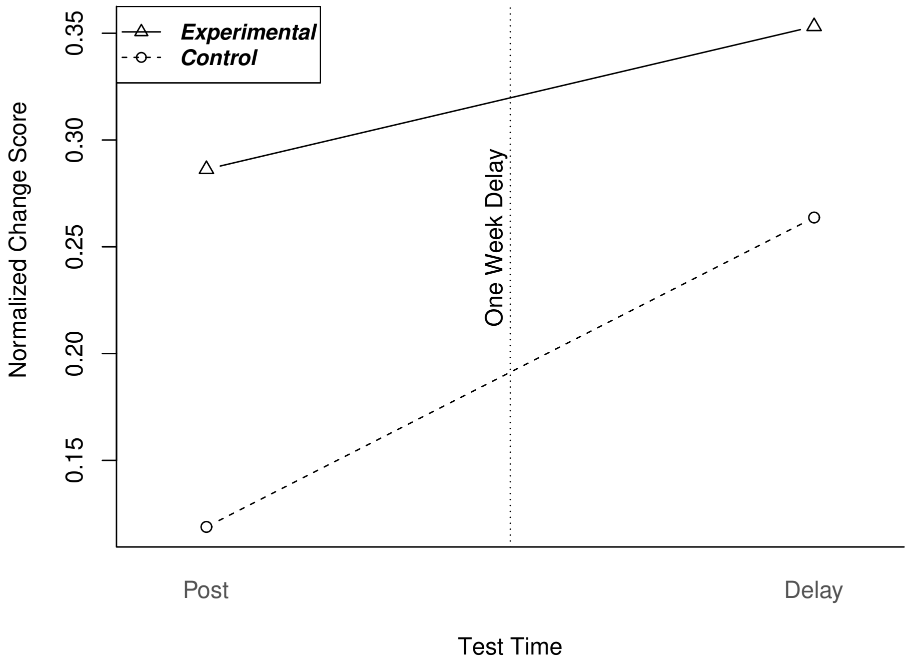

Fig. 5.8 The average normalized change score over a period of one week for both experiment and control conditions.

.319/0.281, $F(2,36) = 8.435, P < .001$. In contrast, the delayed learning gains of SUM condition students were not dependent on their post-learning gains. Tables 5.5 and 5.6 clarify the details of the linear regression model. This result potentially connects learning with the CRS method to the performance of the students during the review process, i.e., supporting the students in their review. It can indicate that if the CRS method is used continuously throughout the course, students will make greater improvements. These interpretations need further investigation, such as monitoring students' review tasks to determine how the learning gained through CRS affects their knowledge and discussion tasks during the review.

To investigate the second exploratory research question, "What is the correlation between CRS performance and later activity performance?" we recorded the test scores for students in the practical assignment activity and the mid-term test.

Both class activity scores were part of the regular class material given by the class teacher. Table 5.7 shows the descriptive analysis of the class activ-

Table 5.5 Linear regression analysis of delayed normalized change as the dependent variable, with CRS post-normalized change and pre-test score as the independent variables

CRS condition	delayed Normalized Change		
Predictors	Estimates	CI	p
(Intercept)	0.10	-0.20 – 0.41	0.501
pre score	0.01	-0.02 – 0.04	0.558
post nc	0.59	0.30 – 0.89	**<0.001**
Observations	39		
R2 / R2 adjusted	0.319 / 0.281		

Table 5.6 Linear regression analysis of delayed normalized change as the dependent variable, with SUM post-normalized change and pre-test score as the independent variables

SUM condition	delayed normalized change		
Predictors	Estimates	CI	p
(Intercept)	0.52	0.16 – 0.87	**0.006**
pre score	-0.03	-0.06 – 0.00	0.088
post nc	0.25	-0.19 – 0.69	0.251
Observations	34		
R2 / R2 adjusted	0.149 / 0.095		

ity scores, in which the control group has a higher mean but without any significant differences.

Table 5.7 Mean and Standard deviation of the class scores

group	N	Assignment M (SD)	Mid-term Score M (SD)
SUM	34	64.68 (31.01)	66.43 (16)
CRS	41	61.9 (30.05)	62.17 (17.10)

We calculated the Pearson correlation coefficient between the post-normalized change score and the assignment or mid-term test scores for both experimental and control conditions. As detailed in Table 5.8, the results indicate a significantly moderate to strong correlation between the assignment and mid-term test scores and the learning gain of the CRS method, respectively. In contrast, there was no significant correlation between the learning gain of the control condition and any of the class activities. This positive correlation for the CRS condition suggests that students who cannot perform well at CRS activities may also fail to perform well in later class activities; thus, it can be used to identify struggling students early in the course, thereby allowing educators to intervene and provide the necessary support to these students so they do not fall behind. Further research is needed to confirm this interpretation of the proposed method and further understand the underlying mechanisms contributing to this correlation.

Table 5.8 Correlation coefficient between post normalized change and class activity scores (assignment and mid-term test)

		Assignment	Mid-term test
Norm. change score for CRS	Pearson Correlation	.48**	.56***
	Sig. (2-tailed)	.0015 (adj: .005)	< .001 (adj: < .001)
	N	41	41
Norm. change score for SUM	Pearson Correlation	.13	.06
	Sig. (2-tailed)	ns	ns
	N	34	34

***, Correlation is significant at the 0.001 level (2-tailed)
ns, Not Significant

Limitations and Future Work

The key to creating an effective CRS concept map is the establishment of strong connections (bridging links) between practical and theoretical knowledge. However, we did not provide clear guidelines for achieving this integration. During the experiment, teachers achieved this through multiple rounds of discussion and revision. In future research, it is imperative to develop a framework for identifying and creating a high-quality CRS concept map with a specific focus on the "bridging links."

In the experiment, we noticed that the student's average rate of recomposition completion was not high; this suggests the difficulty of the recomposition task for the specified time period in the experiment. Therefore, it is necessary to consider the size of the CRS concept map when preparing the activity according to the ability of the students and the available time for the educator. One approach could be breaking down a big CRS concept map into smaller maps and then feeding them to the recomposition task in a scaffolding manner where the student gradually adds to the smaller CRS concept maps until reaching the full ideal map. We leave the investigation of this limitation open for other researchers. Another crucial area for future research is to assess students' misconceptions regarding OOP concepts throughout the course. In doing so, we can determine whether the CRS method is effective in preventing or rectifying these misconceptions. Additionally, examining the role of "bridging links" in this process is essential to understanding the full impact of the CRS method.

5.2.3 Conclusion

In this study, we introduced a new approach to supporting OOP conceptual comprehension by integrating the two main aspects of OOP, theoretical and practical knowledge, in a concept map recomposition activity. The experimental results revealed the following interpretations: 1) An activity using the proposed method in an actual class is practical for an educator; On the other hand, students hold a welcoming view of using the proposed method as a learning tool during their study of OOP. Thus, it gives educators an effective method for conducting activities that promote conceptual comprehension of OOP concepts; 2) The proposed method positively affects OOP concept comprehension during the class. The results reveal the importance of integrating theoretical and practical knowledge for students learning OOP; 3) There is a potential for long-term usage of the proposed method since, under experimental conditions, students showed that the learning gained through the proposed method can significantly explain their review performance over one week, a standard period between classes in educational institutions; 4) Students who are good at the proposed method activity tend to also perform better in the subsequent activities of the class, including code-writing activities, and vice versa. Thus, it helps educators find low-performing students at an early stage of teaching to interfere with and support those students in their learning process.

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Chapter 6

Conclusion

6.1 Improvement to Concept Map Recomposition Activity

The present study aimed to identify strategies for improving concept map recomposition by investigating two aspects: reducing cognitive load and the impact of access to reading material during recomposition on reading comprehension. To address the first aspect, an experimental design was employed using online participants recruited from MTurk. The study proposed a partial decomposition style for generating expert concept map kits, which was compared to the traditional full-decomposition method in a control group. The experiment included a reading task, a pre-recomposition test, and a post-recomposition test. The cognitive load metrics utilized were in four dimensions, two of which were subjective: perceived difficulty and perceived mental effort, while the other two were objective measures: the time spent on the recomposition task and the number of actions required to complete it. In this study, the following research questions were answered:

RQA-1: *Whether the concept map recomposition activity of TSD approach affects the Cognitive load.*

The analysis results of the measured variables demonstrated that the use of the TSD approach significantly reduced cognitive load in all four dimensions (perceived effort, perceived difficulty, time spent on the task, and number of actions needed) compared to the traditional FD approach $F(2.21, 158.9) = 24.2, P < .001$. Further, the RTE analysis revealed a large effect size for the TSD method suggesting that the cognitive load metrics can discriminate one condition from the other almost perfectly in all dimensions.

RQA-2: *Whether the concept map recomposition activity of TSD approach affects the Flow state.*

The self-reported flow state score analysis showed that learners in both conditions TSD and FD perceived similar challenges and confidence in completing the recomposition task ($U = 1300.5, n1 = n2 = 37, P = .35$), indicating that making the task simpler through the TSD method does not make it less interesting for learners. Additionally, it indicated that the subjective self-reports of cognitive load metrics were highly reliable and the difference between the conditions was not due to flow-state.

RQA-3: *Whether the concept map recomposition activity of TSD approach affects the immediate reading comprehension.*

The test scores for pre-test and post-test in both treatment and control conditions were analyzed. Within-group analysis showed a significant increase in both conditions, confirming the positive effect of treatment TSD ($Z = -3.75, P < .001, r = .597$) and FD ($Z = -2.45, P = .01, r = .419$). The results for FD condition align with previous studies where the benefit of KB-CMR recomposition is investigated. Between-group analysis showed no significant difference between the conditions probably due to the possibility of a ceiling effect.

RQA-4: *Whether the concept map recomposition activity of TSD approach affects the retention of reading comprehension.*

The test scores for pre-test and delayed-test in both treatment and control conditions were analyzed. Within-group analysis showed that both conditions' retention performance lowered during the delayed-test which is naturally expected for the gained knowledge to dissipate over time (Condition$_{TSD}$: $Z = 1.29, P = .195, r = .37$; Condition$_{FD}$: $Z = 1.95, P = .051, r = .22$). Between-group analysis did not show any significant difference between the conditions' retention rates.

To address the second aspect, whether to provide or remove access to the reading material during the recomposition considering which best benefits the reading comprehension a similar experimental design was employed. The experiment was conducted online recruiting participants from MTurk.

The treatment group was compared to two control groups, the "recomposition-only" group where they did not have any access to the reading material during the recomposition and the "text-only" group where they did not recompose any map rather they read the material twice. In this study, the following research questions were answered:

RQB-1: *Whether reading time affects reading comprehension.*

Running a linear regression model with the post-test scores as the dependent variable, reading time as the predictor, and pre-test scores as a control variable revealed that reading time can significantly predict immediate reading comprehension (p < 0.001 $R^2 = 0.83$).

RQB-2: *Whether reading time affects retention of reading comprehension.*

Running a linear regression model with the delayed-test scores as the dependent variable, reading time as the predictor, and pre-test scores as a control variable revealed that reading time can significantly predict immediate reading comprehension (p < 0.01 $R^2 = 0.44$).

RQB-3: *What is the effect of having access to the reading material during KB-CMR on immediate learning gain compared to the control conditions.*

Kruskal-Wallis test with normalized change as the dependent variable and condition as the predictor revealed a main effect of condition on normalized change (chi-squared = 9.95, p < 0.01). The post-hoc Dunn's test indicated that having access to the reading material can significantly affect the immediate learning outcome p < 0.001.

RQB-4: *What is the effect of having access to the reading material during KB-CMR on retention of learning gain compared to the control conditions.*

Kruskal-Wallis test with delayed normalized change as the dependent variable and condition as the predictor did not reveal any significant difference among the conditions suggesting similar performance on retention of reading comprehension.

And the following exploratory research questions were explored:

RQBE-1: *Do learners with high reading times while building the map outperform the two control groups in reading comprehension gains.*

After excluding the learners with a low reading time, Kruskal-Wallis test was performed with normalized change as the dependent variable and condition as the predictor. The test revealed a main effect of condition on normalized change, chi-squared = 14.30, $p < 0.001$. Post-hoc Dunn's test revealed that normalized change for the high read learners was significantly higher than learners in "MapOnly" and "Double Text" conditions.

RQBE-2: *Do learners with high reading times while building the map outperform the two control groups in retention of reading comprehension gains.*

After excluding the learners with a low reading time, Kruskal-Wallis test was performed with delayed normalized change as the dependent variable and condition as the predictor. The test revealed a main effect of condition on delayed normalized change, chi-squared = 7.33, $p = 0.03$. Post-hoc Dunn's test revealed that delayed normalized change for the high read learners was significantly higher than learners in "MapOnly" and "Double Text" conditions.

6.2 Extension of Concept Map recomposition to the Procedural Domain

In addition to the improvements of the concept map recomposition task. The extension of this method is investigated with respect to procedural domain conceptual comprehension, specifically in OOP.

A cognitive diagram called Conceptual Representation of the Source-code (CRS) was proposed to create an activity that supported students in conceptual comprehension of both the theoretical and practical aspects of OOP, and to externalize and depict the relationship between these two knowledge bases. The CRS diagram was based on a concept map, and the activity was designed using concept map recomposition. The experiment involved undergraduate students in a real classroom setting. The first experiment was a pilot study examining how the tool could perform in practical use. The second experiment delved deeper into evaluating the effectiveness of the CRS recomposition method in terms of comprehending OOP concepts and the ability of class teachers to create the proposed concept map. The following research questions were addressed in both

RQC-1: *How is the design of CRS incorporated into a concept map recomposition activity in an actual teaching class that integrates theoretical and practical knowledge bases of OOP concepts.*

The characteristics of CRS were determined and successfully incorporated into the KB-CMR recomposition activity in a real class setting. The class teacher satisfied with the activity proposal, thus the study conducted, participating 49 undergraduate third-year students majoring in computer science at Hiroshima Institute of Technology.

RQC-2: *How are the students' likeness towards the proposed KB-CMR activity.*

RQC-3: *How is the students' expectation toward using the proposed KB-CMR activity in their learning of OOP concepts.*

The results of the likeness and expectation questionnaire with average scores of 4.2 and 4.4 respectively, suggest that students perceive the activity as a valuable and effective means of understanding OOP concepts. Additionally, the high expectation scores indicate that students believe the activity will be beneficial in their learning process. Overall, these results indicate that the KB-CMR activity is well-received by students and holds potential as a successful approach to learning in the concepts of OOP.

In the second experiment, the impact of CRS is further investigated to answer the following research questions:

RQC-4: *Can an educator build a practical CRS in concept map according to the characteristics of the CRS in an actual teaching class.*

The experiment was prepared in collaboration with Universitas Yarsi in Indonesia. The characteristics of the CRS were explained to a professional teacher, who then created the expert map. The expert map is then reviewed and approved by the target class teacher and the assistant teacher. The experiment was successfully conducted satisfying the feasibility of an activity adhering to the proposed method.

RQC-5: *What is the effect of integrating the two main aspects of OOP using CRS in a concept map activity on OOP comprehension in an actual class setting compared to the conventional method.*

Collecting data from 75 students in an actual class at university, the learning gain score of CRS recomposition was compared to the learning gain score of a group doing traditional summarization. A significant difference was found between the normalized change scores of the CRS condition (M=0.26, SD=0.35) and the control condition (M=0.12, SD=0.23) according to an independent sample t-test, with a p-value of 0.039. The effect size for this analysis was $d = 0.47$, indicating that there is a 63% probability that a student chosen randomly from the CRS group will have a higher score than a student chosen randomly from the control group.

The results of the linear regression analysis showed that the completion degree of the CRS map recomposition was a significant predictor of learning gain, with an adjusted R^2 value of 0.176 and a P value of 0.009. This indicates that higher completion of the CRS map recomposition is associated with greater learning gain.

RQC-6: *How do the students perceive the proposed method in terms of usefulness for learning OOP.*

Around half of the students believed that the proposed method of learning programming concepts, CRS, was useful. On the other hand, about 21% think neutrally and less than 29% have a negative impression about using the method as a class learning tool. A high percentage of neutral views and negative views can be due to the uniqueness of the proposed method in learning programming concepts. We believe a continuous use of the proposed method will enhance students' impression toward using CRS as a method of learning in programming class.

RQCE-1: *Compared to the conventional method, can the learning gain of CRS affect the reviewed learning gain after one week.*

Students were assessed again after one week of the experiment. Compared to the post-normalized change, students learning gain in delayed-normalized change increased significantly for both conditions. But with-in group comparison did not reveal any difference between the conditions. The increase in the delayed-normalized change is an expected behavior since students are engaged in extra sessions during that week. However, the linear regression result revealed that reviewed learning gain in CRS condition can be predicted by their post learning-gain, $R^2/R^2adj. = .319/0.281, F(2, 36) = 8.435, P < .001$. In contrast, the reviewed learning-gain in SUM condition was not dependent on their post learning-gain.

RQCE-2: *What is the correlation between performance in CRS and performance later in the course activities of assignment and mid-term test.*

Being part of the regular class material, students' data was collected in assignments and mid-term tests. The relationship between students' performance in the CRS activity and their subsequent performance in assignments and mid-term tests were analyzed. Utilizing Pearson's correlation coefficient, a significant and moderate-to-strong correlation was observed between the learning gains achieved through CRS and students' subsequent performance in class assessments. Conversely, no significant correlation was found between learning gains in the control condition and performance in class assessments. These findings suggest students who perform well at CRS activity also perform well at later class activities, in other words, they are good learners and the opposite is true.

6.3 Overall Conclusion and Future Work

Previous studies have shown the usefulness of concept map recomposition as a powerful learning tool for enhancing conceptual understanding. However, there has been a need to improve the task to better support learners, particularly in the procedural domain. In this study, we aimed to address three key issues related to the enhancement of conceptual understanding.

Firstly, we investigated strategies for reducing cognitive load during concept map recomposition. We proposed a partial decomposition style for generating expert concept map kits and compared it to the traditional full-decomposition method in a control group. The results demonstrated that the proposed approach resulted in significantly lower perceived difficulty and mental effort among participants, as well as significantly lower time needed to complete the task and fewer actions required to do so. Importantly, this reduction in cognitive load did not compromise the traditional method's benefits in terms of learning effect and motivation, but rather, further improved retention of learning gains, thus facilitating deeper understanding. This advancement in concept map recomposition allows educators to better control the time and energy required, thereby enabling more customized learning activities that are better suited to the nature of the class.

The second approach investigated the impact of providing or removing access to reading material during recomposition on reading comprehension. It also investigated the relationship between reading time and learning quality. Results showed that allowing access to reading material during recomposition resulted in better reading comprehension gains compared to the recomposition-only group and the text-only group. These findings allow educators to tailor the recomposition activity to the desired outcomes of the class. When long-term comprehension is a goal, it may be beneficial to design the activity such that learners are not only able to refer to the text while completing the recomposition task, but also encouraged to do so.

Lastly, we aimed to extend the application domain of concept map recomposition to the procedural domain. To achieve this, we utilized the improvements in cognitive load and reading material access to support conceptual understanding in the procedural domain of OOP. The study proposed a recomposition-based visualization approach called Conceptual Representation of the Source-code (CRS) that allows for the integration of practical and theoretical knowledge of programming, resulting in a unique conceptual comprehension activity that promotes conceptual understanding of OOP concepts significantly better than the traditional method. The method also allows the educators to potentially track low-performing students in an early stage of their learning and provide sophisticated support that could improve the drop rate of such classes. Future research should continue to explore the potential applications of this approach in other technical subjects.

Overall, the study makes a significant contribution to the field of computer technology in education by providing practical and effective strategies for enhancing conceptual understanding through the application of concept map recomposition. The results of this study have the potential to inform the design of educational materials and support the development of more effective instructional strategies for enhancing conceptual understanding in various fields.

There are several potential areas of future research that can build on the findings of the present study. One area of investigation could be the after-effects of the TSD kit generation approach on self-reflection. Examining how the TSD approach influences the learners' ability to reflect on their own learning process, and how this, in turn, affects the retention of learning gains, would provide valuable insights into the effectiveness of the TSD approach. Another area of study could be the impact of reading encouragement coupled with TSD on learning gain. Investigating how providing guidance and encouragement to learners to refer to the reading material during recomposition affects the learning gain could further enhance the effectiveness of the TSD approach. Additionally, future studies could investigate how the CRS KB-CMR method can be used to address well-known problems in teaching, such as misconceptions. Specifically, exploring how the CRS recomposition approach can help learners overcome common misconceptions about OOP concepts could provide valuable insights into the effectiveness of the CRS approach in the procedural domain. Furthermore, it would be interesting to investigate how the bridging links in the CRS recomposition affected the learning outcome, this could provide an insight on how the CRS approach could be further improved. Research may also continue to explore the potential applications of this approach in other technical subjects.

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Appendices

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Appendix A

Questionnaire Items

A.1 Perceived Effort

The following item was used on a 7-Likert scale ranging from "Very low mental effort" to "Very high mental effort".

- In building the concept map I invested:
  - Very low mental effort
  - low mental effort
  - Rather low mental effort
  - Neither low nor high mental effort
  - Rather high mental effort
  - high mental effort
  - Very high mental effort

A.2 Perceived Difficulty

The following item was used on a 7-Likert scale ranging from "Very Easy" to "Very Difficult".

- I found the task of building the concept map:
  - Very easy
  - Easy
  - Rather easy
  - Neither easy nor difficult
  - Rather difficult
  - Difficult
  - Very difficult

A.3 Flow Short Scale

The following items were used on a 7-Likert scale labeled in the first, middle, and last choices as "not at all", "partly", and "very much" respectively.

- I feel just the right amount of challenge.
- My thoughts/activities run fluidly and smoothly.
- I don't notice time passing.
- I have no difficulty concentrating.
- My mind is completely clear.
- I am totally absorbed in what I am doing.
- The right thoughts/movements occur of their own accord.
- I know what I have to do each step of the way.
- I feel that I have everything under control.
- I am completely lost in thought.

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Appendix B

Source-Code Implemented in CRS

The source-code that is used in the experiments related to CRS.

```
class Circle {

 private double radius;
 protected double pi = Math.PI;

 public Circle() {
    this.radius = 1.0;
 }
 public Circle(double r) {
    this.radius = radius;
 }

 public double getRadius() {
    return this.radius;
 }
 public void setRadius(double r) {
    this.radius = radius;
 }

 /** Returns a self-descriptive String */
 public String toString() {
    return "Circle[radius=" + radius + "]";
 }

 /** Returns the area of this Circle */
 public double area() {
    return radius * radius * Math.PI;
 }
```

```java
}

/**
 * A Cylinder is a Circle plus a height.
 */
class Cylinder extends Circle
{

   private double height;


   public Cylinder() {
      super();
      this.height = 1.0;
   }

   public Cylinder(double h, double r) {
      super(r);
      this.height = h;
   }

   public double getHeight() {
      return this.height;
   }
   public void setSize(double h) {
      this.height = h;
   }
   public void setSize(double h, double r) {
      super.setRadius(r);
      this.height = h;
   }


   public double volume() {
      return super.area()*height;
   }


   public double area() {
      return 2*Math.PI*getRadius()*height + 2*super.area();
   }

   public String toString() {
      return "Cylinder[" + super.toString() + ",height=" + height + "]";
   }
}

//MAIN///////////////
public class OOP_Concept_Test {
```

```
   public static void main(String[] args) {
      Cylinder cy1 = new Cylinder();

      System.out.println("Radius is " + cy1.getRadius()
         + ", Height is " + cy1.getHeight()
         + ", Volume is " + cy1.volume());

      Cylinder cy2 = new Cylinder(5.0, 2.0);
      System.out.println("Radius is " + cy2.getRadius()
         + ", Height is " + cy2.getHeight()
         + ", Volume is " + cy2.volume());
      cy2 = cy1;
      cy2.setSize(34);
      Circle circ = cy2;

   }
}
```

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Abbreviations

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