Supplementary material SM 3

Theoretical foundation of the Concept Maps Trainings

Three types of knowledge in combination (declarative, procedural, and conditional knowledge) need to be provided to enable learners to acquire strategy competence (Weinstein et al., 2000). Declarative knowledge consists of facts and information on the learning strategy itself. Conditional knowledge enables learners to evaluate time and context for the use of a specific strategy (Gu, 2019). Procedural knowledge refers to knowledge about strategy use and includes specific methods and procedures (Alavi and Leidner2001; Gagne et al.1997). Empirical studies showed that the integration of metacognitive and self-regulation strategies into strategy training yield better use of learning strategy and higher learning outcome (e.g., Leopold & Leutner, 2002; Leutner et al., 2001). Additionally, the incorporation of scaffolding (e.g., the use of skeleton maps) and feedback into a concept map construction training was shown to facilitate learning (Authors, 2021). A framework for a structured training program, which allows the inclusion of previous findings, is offered by the cognitive apprenticeship theory (CAT; Collins et al., 1988). Cognitive apprenticeship is a process in which novices learn from more experienced person(s) by continuously increasing active participation until they are able complete a task independently. Over the course of time, tasks increase in complexity and variety, while support and feedback are reduced.

Originally, the CAT is characterized by four phases: *Modeling* (demonstration of the task by the expert), *scaffolding* (supported self-activity), *fading* (reduction of the support by the expert with increasing competence of the learner), and *coaching* (the expert supervises the learning process and provides guidance). A model specifically designed for instruction extends these phases. It recommends *articulation* (learners articulate for example their learning-related knowledge or comment on actions), *reflection* (learners compare their

approaches with that of other learners and experts), and *exploration* (learners are trained to work independently and become experts themselves; see Collins et al., 1991 for an overview).

Regarding the duration of a concept map training, recommendations range from short periods of time (e.g., 5 min, [Blunt & Karpicke, 2014]; 30 min, [Edwards & Fraser, 1983]; 10 min, [Klein et al., 2002 & Karpicke, 2014], 90 min, [Authors, 2021] to several hours, [Gouli et al., 2003] up to several weeks [Quinn et al., 2003]). As we aimed for content coverage and integration of the session into everyday school life, we decided on a total training time of 135 min.

Overview of the Course of the Trainings

As depicted in **Figure S1**, both concept map trainings (CM-c and CM-s training) consist of an introduction and an exercise phase. In the introduction phase, declarative and conditional knowledge is imparted (see **Table S1** for detailed description). In the exercise phase, procedural and conditional knowledge is imparted (see **Table S2 + S3**). The trainings were structured according to the cognitive apprenticeship model proposed by Collins et al. (1991).

The different stages of cognitive apprenticeship were implemented as follows: *Modeling* (e.g., by demonstrating the process of concept map construction), *scaffolding* (e.g., by providing prompts , constant support and feedback), *fading* (e.g., by reducing assistance over time and by providing material for self-regulation), *articulating* (e.g., by implementing group-discussions and collaborative learning with concept maps), *reflection* (e.g., by providing example answers and discussing typical mistakes), *exploration* (e.g., by providing material for self-regulation and enabling self-paced and performance-adapted learning).

In the control training, students were provided with declarative and conditional knowledge in the introduction phase. Instead of acquiring procedural knowledge in the use of concept maps,

they took part in a team building activity which did not include learning with concept maps (see **Table S4**).

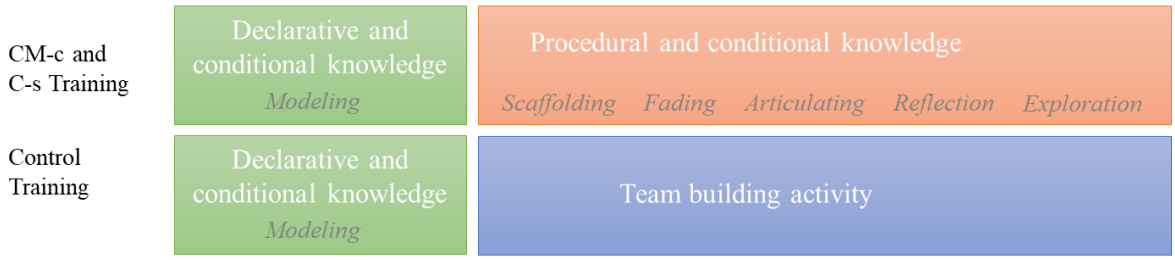

Figure S1: The structure of the different trainings.

The construction training (CM-c training) aims to teach the construction of concept maps based on textual material. The knowledge on constructing concept maps was based on elements, tasks, and social interactions of previously developed concept map trainings (Brüning & Saum, 2007; Chang et al., 2002; Jonassen & Marra, 1994; Novak & Cañas, 2008; Novak & Gowin, 1984; Sumfleth et al., 2010) and introductory recommendations (Authors., 2021) as well as suggestions from Novak and Cañas (2006). Elements such as expanded collaborative learning and half-structured concept maps were integrated (Aguiar & Correia, 2017; Correia et al., 2008). This type of training includes tasks like completion of skeleton concept maps, compiling propositions, adding directions to arrows, evaluating distinct concept maps and self-design concept maps using key words (see **Table S2** for detailed description of the concept map construction training).

The concept map study training (CM-s training) focuses on visual study of expert-designed concept maps. Students for example worked with learning sheets on how to retrieve information from concept maps and corrected concept maps which were incorrect according to the learning text content (see Chang et al., [2002] for a similar approach; see **Table S3** for detailed description of the concept map study training).

All training materials were not related to a school subject but cover various topics (e.g., ‘national economy’ and ‘different states of water’) to avoid confounding test contents. Both training types encompass similar social interactions (e.g., working in peers) and similar contents in order to reduce the amount of confounding variables.

Table S1: Description of the concept map introduction (25 min)

Timeframe	Activity description
10 min	• A student reads a text out loud. • Students select key concepts from the text. • Presentation of a text-based concept map to students (*model*). • Students describe the concept map. • Students make comparisons with other forms of presentation. • Discussion about the proposition structure. • Discussion about the role of focal question.
10 min	• Propositions on the topic 'concept maps' were handed out to the students. • Students read their propositions out loud one at a time. • Trainer constructs a concept map on the blackboard based on the propositions read out. • Trainer explains the procedure, key elements of concept maps as well as discuss typical mistakes. • At the end, the created concept map is compared with an expert concept map. • The students should conclude that there are different concept maps on a topic, which can all be correct.
5 min	• Students read a short guide which summarizes important information and rules. • Students discuss benefits, disadvantages and possible uses of concept maps.

Table S2: Description of the concept map construction training (CM-c; 110 min)

Timeframe	Activity description
40 min	• Students work independently, focusing on the construction of concept maps. • They receive help cards and feedback from the trainer. • They can compare their final solutions with expert solutions. • One worksheet is worked on in partnership for sharing ideas and discussing in pairs. • Students who are finished early get extra tasks and are encouraged to help others. • **Focus**: Identification of key concepts and relations from texts, compiling propositions, organize new information, planning of the mapping process and controlling it.
5 min	• Classroom discussion: For a vote, all students receive a yellow and a green card. • Various examples consisting of two propositions are shown. Either the proposition shown in green or the proposition shown in yellow is correct. • Students use their cards to guess which variant is correct. • Concept map rules and mistakes are discussed. • **Focus**: Identification of concept map mistakes and internalization of concept map rules.
45 min	• Finally, students should create a concept map themselves based on a text. • For this purpose, small stickers with concepts were provided to promote and simplify the construction of concept maps. • **Focus**: The mapping process should have been internalized here to such an extent that the students can concentrate on the learning context.
20 min	• Peer review: Finally, the students discuss on their concept maps in groups of up to four, chose the best concept map, change / improve it together. • These collaborative concept maps were hung up and all students discuss and choose the best three from these. • **Focus:** Self-reflection and self-questioning, identification of knowledge gaps, troubleshooting

Table S3: Description of the concept map study training (CM-s; 110 min)

Timeframe	Activity description
40 min	• Students work independently on worksheets focusing on the study of concept maps. They receive help cards and feedback from the trainer. They can compare their final solutions with expert solutions. • One worksheet is worked on in partnership for sharing ideas and discussing in pairs. Students who are finished early get extra tasks and are encouraged to help others. • **Focus**: Identification of key concepts and relations in concept maps, identify reading directions, getting familiar with concept map structure, find information and answer questions using concept maps
5 min	• Classroom discussion: For a vote, all students receive a yellow and a green card. • Various examples consisting of two propositions are shown. Either the proposition shown in green or the proposition shown in yellow is correct. • Students use their cards to guess which variant is correct. • Concept map rules and mistakes are discussed. • **Focus**: Identification of concept map mistakes and internalization of concept map rules.
45 min	• Finally, the students should transfer a complex concept map into a text. • One text is read out loud and discussed. • Trainer gives feedback on all texts. • **Focus**: The process of map study should have been internalized here to such an extent that the students can concentrate on the learning context. Self-reflection and self-questioning, identification of knowledge gaps, troubleshooting
20 min	• Students receive a Concept map and 10 min time to memorize/understand it. • Concept maps were collected and a questionnaire is handed out. • **Focus**: Consolidation of map study abilities

Table S4: Description of the control training (Control; 110 min)

Timeframe	Activity description
40 min	• Trainer tells the story of a researcher who found a prehistoric egg which needs to be recovered from a high tree to initiate the following task. • Students should create a craft from provided materials that will protect a raw egg when dropped from 4 meters high (‘egg drop challenge’). • Trainer divides students into heterogeneous and randomly selected groups of up to four students.
20 min	• Students are provided with material and work on the task together.
30 min	• The construction of each group was tested one after another.
20 min	• Students reflect and discuss their teamwork. • Goals for future group work are formulated.

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