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Expert examples and prompted reflection in learning with self-generated concept maps

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Abstract

Background: Creating concept maps can help students overcome challenges of accurate knowledge monitoring and thus foster learning. However, students' knowledge often contains gaps and misconceptions, even after concept map creation. Theoretically, students could benefit from additional support, but it is unclear whether this might also be the case for (more practical-oriented) secondary vocational students.

Objectives: This study investigated whether the effectiveness of concept maps for learning could be improved by providing students with expert examples and reflection prompts in addition to their self-generated concept maps.

Methods: First-year secondary vocational students ($N = 91$, $M_{age} = 17.3$ years) participated in this study, which utilized a pretest-intervention-posttest design. Regarding the intervention, students worked in two successive online learning environments, in which they had to present their knowledge in concept maps. After creation, students' concept maps were, depending on condition, supplemented with (1) an expert example with comparative feedback (a combined concept map) and related reflection prompts, (2) the combined concept map only, or (3) no combined concept map and no prompts.

Results and Conclusions: Analyses based on students' domain knowledge demonstrate that students significantly increased their knowledge in all conditions. Data indicate that there was no significant difference in knowledge gain between conditions. Further analysis showed that students in the experimental conditions demonstrated higher learning gains if they consulted the combined concept map more often than their peers.

Implications: Access to an example in addition to students' self-generated concept maps seems promising in fostering their knowledge acquisition. However, secondary vocational students might need additional ways of support to guarantee higher learning gains. Avenues to increase the effectiveness of support are discussed.

KEYWORDS
concept maps, expert examples, feedback, prompts, reflection

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1 | INTRODUCTION

Professions for which students are prepared within secondary vocational education are and will be subject to change in the upcoming years. The changing nature and content of students' future jobs (e.g., car mechanics and electrical engineers) implies that the knowledge that students acquire during their training is less tenable (Christoffels & Baay, 2016). Instead of bringing acquired knowledge to the work field, it becomes increasingly important for students to develop necessary skills that will help them to continuously develop themselves and their knowledge. Adequately preparing students for their future role in society requires a different approach, which for example is also apparent from a shift from teacher-centred towards more student-centred learning within secondary vocational education (Christoffels & Baay, 2016); instead of knowledge being mainly transferred from teachers to students, students are increasingly responsible for regulating their own learning to successfully improve their learning performance. Especially within the context of, rather practical-oriented, secondary vocational education, teachers are looking for ways to properly support students in this process (e.g., de Bruijn & Leeman, 2011).

Effective self-regulated learning requires students to monitor their knowledge (Isaacson & Fujita, 2006; Zimmerman, 2002). However, students' knowledge monitoring is often inaccurate. For example, many students tend to overestimate their level of knowledge (Dunlosky & Lipko, 2007; Dunlosky & Rawson, 2012; Isaacson & Fujita, 2006) and are unaware of gaps and misconceptions often present in their knowledge (Ellis et al., 2004). This is problematic, as this kind of inaccurate knowledge monitoring makes it difficult to further improve learning; students might not reliably estimate their current level of understanding and, in consequence, would not see the need to extend or reconsider their knowledge.

Externalizing knowledge and therefore making it explicit can foster knowledge monitoring and potentially benefit students' awareness of what they do and do not know (Rodríguez-Triana et al., 2017). Concept map construction has been shown to effectively facilitate externalization of knowledge (Cañas et al., 2012; Cimolino et al., 2003; Ifenthaler, 2010; Novak & Cañas, 2008) and many studies have shown positive effects of concept mapping on learning (e.g., Nesbit & Adesope, 2006; Schroeder et al., 2018). However, research has also shown that gaps and misconceptions often persist, even when students construct concept maps (Cimolino et al., 2003; Novak, 2002; Roberts, 1999). A possible cause could be the general absence of appropriate feedback when constructing concept maps (Kinchin, 2014; Morse & Jutras, 2008). Comparing a self-generated concept map with an expert example might offer a non-intrusive solution, as this can give students insight into their knowledge level and possible gaps and misconceptions (Kao et al., 2008; Novak, 2005; O'Donnell et al., 2002).

Differences between the expert example and their own product should elicit reflection which, in turn, improves both students' conception of what they know and do not know (i.e., knowledge monitoring and awareness) and their understanding of the content (i.e., more deeply rooted knowledge). However, reflection is a demanding activity and students' reflection often lacks the qualities needed for positive effects (Bannert, 2006; Kori et al., 2014). To support students' reflection, prompts can be offered that structure the reflection process and improve its effectiveness by directing students' attention to the most valuable information (Berthold et al., 2009; Chi, 2009; ter Vrugte & de Jong, 2017). Based on the aforementioned theories, the current study sets out to explore the potential of expert examples and supported reflection to contribute to concept map utility for education.

1.1 | Concept maps to improve knowledge acquisition

Concept maps are widely used in educational settings and often studied in relation to knowledge acquisition. A concept map has been defined as 'a schematic device for representing a set of concept meanings embedded in a framework of propositions' (Novak & Gowin, 1984, p.15). A proposition consists of two concepts connected by a linking label that indicates their underlying relationship. An example of a proposition would be, matching the context of this study's overall topic 'electricity', '*total voltage* is calculated with $U_1 + U_2 + U_x$', or '*cable length* influences *cable resistance*'. This relatively simple grammatical structure makes them easier to create and process than equivalent learning products that consist of relatively large pieces of text and fully written sentences (such as note-taking or writing a summary) (Adesope & Nesbit, 2013; Haugwitz et al., 2010; Schroeder et al., 2018). It also makes concept maps particularly suitable for students who may find it challenging to express themselves verbally (Nesbit & Adesope, 2006) such as, for example, many students in secondary vocational education (e.g., Slaats et al., 1999).

Research has shown that both constructing and studying concept maps make a unique contribution to students' learning outcomes (e.g., Adesope & Nesbit, 2013; O'Donnell et al., 2002; Ritchhart et al., 2009). Based on their meta-analysis, Schroeder et al. (2018) concluded that, although constructing concept maps was preferable to merely studying concept maps, both studying and constructing concept maps were more effective for students' learning outcomes compared to other instructional strategies, such as constructing or studying texts or attending lectures. These findings are in line with a meta-analysis conducted by Nesbit and Adesope (2006), who found similar positive effects of creating concept maps on students' domain knowledge retention and transfer.

Despite the clear potential that concept maps have for learning, there is no uniform explanation for their generally positive effects (Kinchin, 2014; Schroeder et al., 2018). Nevertheless, from prior studies, two main reasons can be identified. *First*, constructing a concept map requires students to structure their knowledge (verbally and spatially), by creating representations of meaningful concepts and underlying links and, ideally, connecting them to their prior knowledge. This process of integrating new knowledge with information that is already known fosters meaningful learning, which takes place when students deliberately seek to relate and assimilate new concepts with prior knowledge within a systematic structure (Novak, 2002). Having new knowledge be anchored to an existing knowledge network results in knowledge that is more deeply rooted, and therefore facilitates retention (Novak et al., 2005; Romero et al., 2017).

Second, and the main focus of the current study, making knowledge explicit facilitates students' knowledge monitoring (Davis, 2003). Generally, students tend to overestimate their own level of understanding and lack awareness of gaps and misconceptions (Kori et al., 2014; Novak, 2002). This results in an *illusion of knowing* (Bjork, 1999; Isaacson & Fujita, 2006), which hampers learning. Making knowledge explicit may contribute to students' accurate representation of knowledge and fosters their knowledge monitoring. Accurate knowledge monitoring, in turn, is essential for effective self-regulated learning, as students can adapt their focus and effort after realizing what they already know and what still needs more attention (Isaacson & Fujita, 2006). Especially when it comes to the domain of 'electricity', students' knowledge often contains misconceptions (Andre & Ding, 1991; Kollöffel & de Jong, 2013; Reiner et al., 2000). For a proper understanding of this domain, not only knowledge about the various separate concepts (e.g., current, voltage and resistance), but in particular knowledge about how these are related to each other is important (Streveler et al., 2008). Concept map creation can help students explicate such relationships and has already been employed successfully in several studies for the electricity domain (e.g., Austin & Shore, 1995; van Boxtel et al., 2002).

Although a concept map can be a fruitful means to foster knowledge externalization and could aid knowledge monitoring and learning, even when students construct concept maps, unawareness of gaps and misconceptions in their knowledge often persist (Cimolino et al., 2003; Novak, 2002; Roberts, 1999; van Boxtel et al., 2002). Providing feedback can offer a solution for inadequate knowledge monitoring, as it can help students to increase their awareness of their understanding (Isaacson & Fujita, 2006). There is evidence that feedback on students' concept maps is needed to realize an effect on students' learning (Chang et al., 2002; Morse & Jutras, 2008). Hence, feedback can foster the effectiveness of concept maps and might even be crucial for learning. Providing students with an example concept map could offer a meaningful solution. An example concept maps allows for offering feedback on students' conceptual knowledge as presented in their concept map, therewith also giving insight into their possible gaps and misconceptions.

1.2 | Expert examples as feedback

In general, feedback can be described as 'information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding' (Hattie & Timperley, 2007, p. 81). For students to gain insight into their understanding, this feedback should include a standard to which their knowledge can be compared (Kluger & DeNisi, 1996).

This norm or reference level can be provided by means of an expert example. A significant body of research studying expert examples and their effectiveness has focused on worked-out examples. A worked-out example provides a step-wise procedure for solving a particular problem or demonstrating a specific skill, which helps students to complete essential steps or elicit relevant principles (e.g., Atkinson et al., 2000; Hilbert & Renkl, 2009; van Gog & Rummel, 2010). It has generally been found that studying such examples benefits students' learning outcomes (e.g., Atkinson et al., 2000; ter Vrugte et al., 2017; van Gog & Rummel, 2010; van Merriënboer & Kester, 2005). These examples are mostly offered prior to a task, as this enables students to internalize a particular procedure or strategy that can be applied when performing the task. They can also be used as feedback after a learning task (Paas, 1992; Paas & van Merriënboer, 1994; van Gog, 2011). When used in this way, through comparison of the example with their own performance, the worked-out example helps students identify whether and where their performance or knowledge is lacking, after which the example can be used to improve their learning on these specific points (Reisslein et al., 2006; van Gog, 2011). Similar to worked-out examples, an (expert) example concept map can facilitate students' learning (Novak & Cañas, 2008; O'Donnell et al., 2002).

However, from studies of worked-out examples it can be deduced that students might fail to use the example constructively, not recognizing which part of the example they need to pay attention to (van Gog et al., 2011). Feedback that points out possible gaps or misconceptions could help overcome this problem. This is in line with earlier definitions of feedback that stressed the importance of including information about the gap between an accepted reference level and students' knowledge (Ramaprasad, 1983; Sadler, 1989). For example, in the context of concept maps, the students' concept map could be mapped onto an expert or example concept map with overlaps and differences highlighted and/or colour-coded. The colour codes could direct students' attention to the relevant information, hence providing comparative feedback. An example of such an approach was studied by Kao et al. (2008). In their study, students' concept maps were combined into integrated concept maps, containing concept maps of peers. Differences between students' own and the rest of the concept maps were highlighted. Their findings showed that this approach could serve as an aid to broaden students' knowledge (getting insight into new ideas and finding other relations between concepts). Though successful, Kao et al. (2008) also reported that only a minority of the participants indicated that the integrated concept maps helped them in detecting mistakes or misconceptions. They, therefore, suggest to create an integrated concept map by combining the students' map with an expert example, instead of the peers' concept maps, as they did. The expert example could possibly provide more objective feedback, valued more valuable by the students and thus improve the effectiveness of the approach.

Though providing students with an expert example and pointing out the relevant information provides an objective norm from which knowledge gaps and misconceptions can be deduced, as with all feedback, the effectiveness of the approach depends on what students do with the information provided. For this approach to be effective, the information should be processed and reflected upon (Gabelica et al., 2014; Hattie & Timperley, 2007; Renkl, 2005). Reflections have particular added value if students must draw inferences or give justifications in cases where these are not provided by the text or example (Wylie & Chi, 2014). Therefore, reflection and concept maps could be an especially fruitful combination. For instance, when students compare their concept map to an expert map, propositions and underlying relations in the expert example are given, but a concept map does not provide detailed (contextual) information, meaning that more specific information has to be inferred from the example. The success of reflection in combination with concept maps was also substantiated by Hilbert and Renkl (2009), who found that students who both received an example of how to construct a concept map and were also prompted to reflect on these examples obtained better scores than students who only received the example. However, students rarely reflect spontaneously and when they do, their reflections are generally too superficial or incomplete to be effective (Bannert, 2006; Renkl, 1997; ter Vrugte & de Jong, 2017). Supporting and directing students' reflections via prompts is therefore recommended (Bannert, 2006; Chi et al., 1994; Davis, 2003).

1.3 | Reflection prompts

Reflection requires students to (1) collect information, (2) interpret this information, and (3) set goals for future action (Rogers, 2001). This metacognitive process (i.e., acquiring insight, in this case, into one's own knowledge) is often perceived by students as difficult or unnecessary (Xie et al., 2008), leading them not to perform all three steps or to process the provided information or feedback at only a superficial level. Students are, therefore, likely to benefit from guidance during these steps in order to improve their reflections (Rogers, 2001). As discussed, comparative feedback can foster students' collection of relevant information (Step 1). However, to improve effectiveness, students also need to interpret (Step 2) and set goals based on this information (Step 3).

Reflection prompts are a widely studied approach to support reflection, and in general, researchers have endorsed their effectiveness (Davis, 2000, 2003; Kori et al., 2014). They can be described as instructional methods to stimulate and support students' reflection by asking them to carry out specific actions (Bannert, 2006), and they typically have in common that they direct students' attention to their own understanding and stimulate them to execute the necessary reflection steps (Davis, 2000, 2003; Lin & Lehman, 1999). Regardless how specific they are (i.e., generic vs. directive reflection prompts), providing students with reflection prompts generally has been found to have a positive effect on their learning outcomes (Davis, 2003; Ge & Land, 2003; Kori et al., 2014).

The optimal level of specificity depends on the context and intended goal (Davis, 2003; Kori et al., 2014). Considering comparative feedback, reflection prompts should aim at improving students' knowledge monitoring and knowledge acquisition through getting them to actively process the information offered by the comparative feedback. Research has demonstrated that directive reflection prompts can be successful in supporting students to make connections between two sources by comparing and contrasting the provided information (Gadgil et al., 2012), which meets the need for interpreting the collected information (Step 2). Based on this acquired insight, students can then be asked to formulate goals for the improvement of their understanding (Step 3).

1.4 | Current study

From the above it can be stated that concept maps are a fruitful means for having students externalize and structure their knowledge (Novak & Cañas, 2008), which, in turn, can foster their knowledge acquisition (Nesbit & Adesope, 2006; Schroeder et al., 2018). However, research has also shown that students often have difficulties with identifying gaps and misconceptions in their knowledge and, as a result, may have no insight into how to make improvements themselves, even in the situation when they have made a concept map. Helping students overcome this problem is likely to positively affect the usefulness of concept maps for education. It is assumed that providing students with an expert example and comparative feedback could improve the effectiveness of concept maps. Reflection prompts that help students to make sense of, consider the implications of, and use this feedback could further enhance their effectiveness. Based on the above it is, however, unclear whether this support might also be beneficial for students in secondary vocational education, who in general have a more practical focus and are less inclined to reflect on their behaviour and understanding (de Bruijn & Leeman, 2011; Slaats et al., 1999).

To investigate the benefits of an expert example and reflection prompts as additions to concept maps, a tool was designed that enabled the student to map their concept map onto an expert example (i.e., a combined concept map). The differences between the two concept maps were colour coded (providing students with comparative feedback). In addition, reflection prompts were added to help students reflect on the information they could deduce from the combined concept map. In line with Rogers' (2001) breakdown of reflection, the prompts supported students' (1) collection of information, (2) interpretation of this information, and (3) goal setting. All support was integrated within two online learning environments. In the online learning environments, students independently studied topics related to electricity and electric power transmission and created concept maps about their knowledge. To investigate the effect of the described support on students' knowledge acquisition, students were divided across three conditions. The learning environments were the same for all conditions, but in two conditions students' created concept maps were supplemented with either a combined concept map with reflection prompts or a combined concept map without reflection prompts; in the third condition, students received no combined concept map and no reflection prompts (=control). Based on the discussed research on concept mapping, expert examples and reflection, two hypotheses were formulated. First, it was expected that providing students with the expert example and comparative feedback (as embedded in the combined concept map) would, when used actively, on average, result in higher learning gains compared to the control situation in which students merely created a concept map. Second, it was anticipated that the addition of reflection prompts would help students process the information in the combined concept map. It was, therefore, assumed that reflection prompts would enhance the effect of the expert example and comparative feedback and lead to even higher learning gains.

2 | METHOD

2.1 | Participants

An initial total of 197 secondary vocational education students (193 males, four females), participated in this study. Participants were first-year students from nine classes divided over three schools for secondary vocational education (in Dutch: MBO) in the Netherlands. These schools prepare students for their role as a vocational professional (e.g., car mechanic and electrical engineer).

The inclusion criteria for participants' data were based on students' attendance and loggings of their time spent working with the concept mapping tool, combined concept map and reflection prompts. Based on the attendance criteria, from the initial sample of 197 students, 79 students were excluded from the final dataset because they did not attend all four sessions. Based on the time-spent criteria, an additional 27 students were removed from the analysis. These were students who, according to the log files, spent no time examining the concept mapping tool, and/or combined concept map, and/or reflection prompts while they did have access and were expected to do so based on their condition. This has resulted in a final sample of 91 students (all males), with a mean age of 17.3 years ($SD = 0.88$): 28 in the combined concept map with reflection prompts condition, 32 in the combined concept map condition and 31 students in the control condition.

The relative high drop-out rate should be seen in the context of the ‘qualification duty’ (in Dutch: kwalificatieplicht) that students have in the Dutch system for secondary vocational education. This implies that they have a certain degree of freedom when it comes to obligatory school attendance and, as a consequence, irregular school attendance is not exceptional.

Participants in the current study were enrolled in a technical training programme that includes electrical engineering as a fundamental part of the curriculum and has a total duration of 4 years. When comparing the participants in our final sample to students in similar technical secondary vocational educational programmes in the Netherlands, they can be considered rather similar (i.e., most students in our sample (93%) have followed a prevocational track (in Dutch: VMBO) prior to their current training programme; also the majority of the total population (86%) hold a prevocational diploma when starting their technical secondary vocational track. In addition, although our final sample only consisted of male students (i.e., the four female students dropped out), the vast majority of students (96%) enrolled in technical programmes are male (Platform Talent voor Technologie, n.d.).

2.2 | Design

This study utilized a pretest–intervention–posttest design. Within each class, the students were assigned to one of the following conditions: the combined concept map with reflection prompts condition, the combined concept map only condition, or the control condition. Other than these differences, the conditions were identical in terms of learning material (i.e., the online learning environment). In vocational training, students' capabilities within one class can be very diverse. Therefore, in order to ensure that students' average pretest scores were equally distributed among the three conditions, students within each of the nine classes were ranked on their average pretest score and alternately assigned to the different conditions. Students who did not complete the pretest were randomly distributed among conditions.

2.3 | Materials

2.3.1 | Online learning environments

The two successive online learning environments were adapted from the learning environments designed by Eshuis et al. (2019) and both contained two online labs, a series of assignments, and instructive multimedia material related to electricity and electric power transmission. They were designed with the Go-Lab ecosystem (de Jong et al., 2021), and both included nine assignments each. The first environment addressed basic principles of electricity (i.e., current and voltage) and basic elements of electric power transmission (e.g., efficiency, transformers and cable resistance). The second environment expanded further on the basic principles of electricity (i.e., equivalent resistance) and electric power transmission (e.g., cable design, costs and high current). Both environments were structured by means of tabs at the top of the screen. The first tab opened an introduction, which briefly explained the purpose of the learning environment and provided an overview of the learning goals, thereby indicating how these were connected to the upcoming assignments (2–8). The introduction was followed by the first assignment, in which students had to map their prior knowledge of the domain in a concept map by using the provided concept mapping tool. To help students determine relevant prior knowledge concerning the upcoming learning environment that should be included in their concept map, they were again provided with the learning goals that should be reached by the end of that learning environment. Within the concept mapping tool, students could insert concepts, either by typing them themselves or by clicking on one of the predefined concepts (i.e., key concepts indicated as bolded text in the learning goals and formulas), and connect them by drawing a line between them. To indicate the relation, they then had to name the line. Figure 1 provides a picture of the online learning environment displaying the first assignment with the

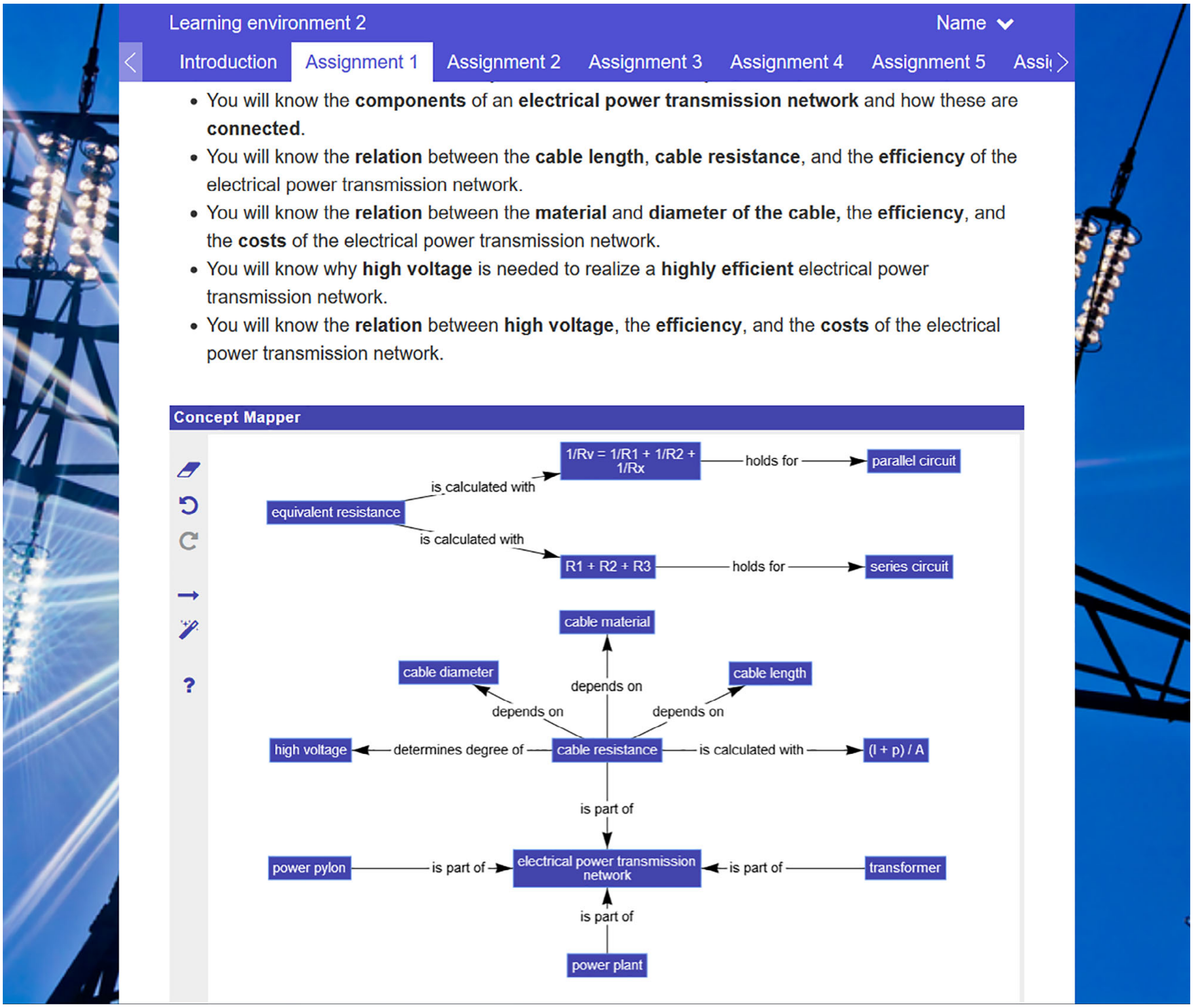


FIGURE 1 Screenshot of the second online learning environment (translated from Dutch), with the concept mapping tool in the centre

concept mapping tool. The concept map presented concerns a fictitious one (i.e., students' actual self-generated concept maps in Assignment 1 were in general less extensive).

The remaining tabs contained a series of assignments that were connected to one of the online labs. For the final assignment in each learning environment, students were again provided with the concept mapping tool, which showed their initial concept map. They were asked to update it to match their current knowledge and understanding.

Assignments 2–8, that students worked on in between both concept mapping assignments, revolved around two labs: The Electricity Lab and the Electric Power Transmission Lab. In the Electricity Lab, students could create electrical circuits based on direct or alternating current, perform measurements on them, and view measurement outcomes. Figure 2 displays an example of an electrical circuit in progress, composed of various components that could be dragged and dropped from the left menu. Various metres are presented in the right menu. An example of an assignment connected to the Electricity Lab was: (a) create a parallel circuit with a power source and three light bulbs; (b) Use the ammeter to find out the values of the total current (It) and partial currents (Ix) of your parallel circuit. Enter your findings below; (c) Describe in your own words how in a parallel circuit total current can be calculated from partial currents; (d) Provide the formula that is used to calculate the total current (It) in a parallel circuit based on partial currents (Ix). Demonstrate the correctness of the formula by entering the measured values from your parallel circuit.

In the Electric Power Transmission Lab students could design a transmission network by choosing different power plants and cities, and by varying different components within the network (e.g., properties of the power line and the voltage). Figure 3 displays an example of a created transmission network, with the power line menu being opened in which cable material and area could be varied and changes in cable costs and efficiency could be observed. An example of an assignment connected to the Electric Power Transmission Lab was: (a) Vary the

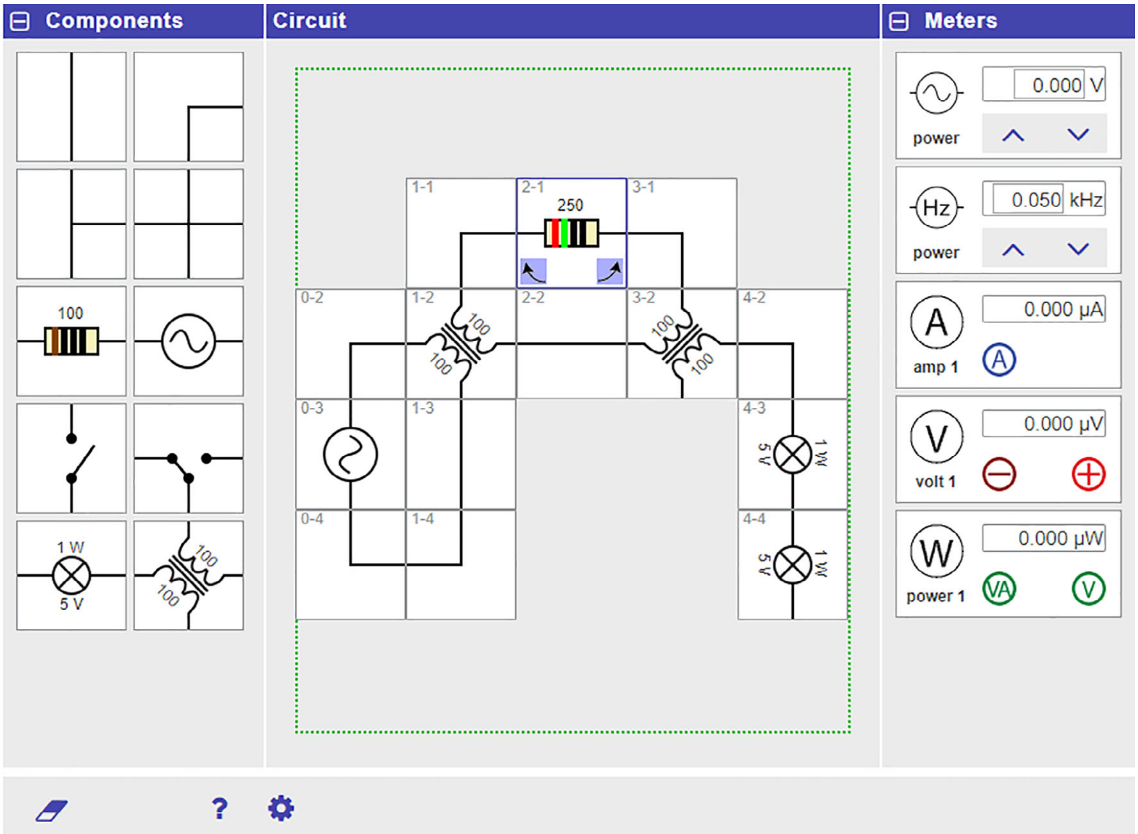


FIGURE 2 The Electricity Lab (translated from Dutch)

cable area within the lab and enter three random values with their corresponding cable resistance in the table below; (b) Based on the values in your table, you can determine the relationship between the cable area and cable resistance. Describe below how much the cable resistance (in ohm) goes up if you increase the cable area with a certain factor.

2.3.2 | Combined concept map

For students in two conditions, the concept mapping tool in the final assignment was supplemented with a combined concept map feature, which students could (de)activate by clicking a button. In the corresponding assignment they were instructed to activate and examine the combined concept map after they had finished their own concept map. The combined map feature allowed students to map their concept map onto an expert example. In the combined map, differences and commonalities between the expert map and the student's concept map were indicated with colours and line weights (see Figure 4): concepts and lines that were unique to the expert concept map were displayed in orange, those that were unique to the student's concept map were displayed in purple; concepts that were present in both concept maps were shown as a purple box with an orange border, while links that were present in both concepts maps were represented by a thick (i.e., thicker than the unique links) purple line. This comparative feedback aimed at helping students to use the provided example constructively, by directing their attention to the relevant parts (i.e., missing and/or incorrect knowledge).

2.3.3 | Reflection prompts

Students in the reflection condition were provided with a set of reflection prompts that were located under the concept mapping tool in the final assignment. They were instructed to answer these prompts after they had examined the combined concept map. The prompts were designed in such a way that they would not require extensive cognitive effort (i.e., concisely phrased prompts—the most textual part of the prompts concerns the spelled out learning goals, but students were already familiar with those at that point—that allow for short answers: check boxes and open-ended prompts only when additional information should be provided). The choice of offering highly directive prompts is further justified by Wylie and Chi (2014), who argued that when students must compare and contrast more information sources—similar to the task in the current study (i.e., their own and the example concept map)—they benefit from more directive (compared to more generic) prompts.

The set of prompts involved two parts (see Figure 5), based on the essential steps for the process of reflection as stated by Rogers (2001): collecting and interpreting information and setting goals

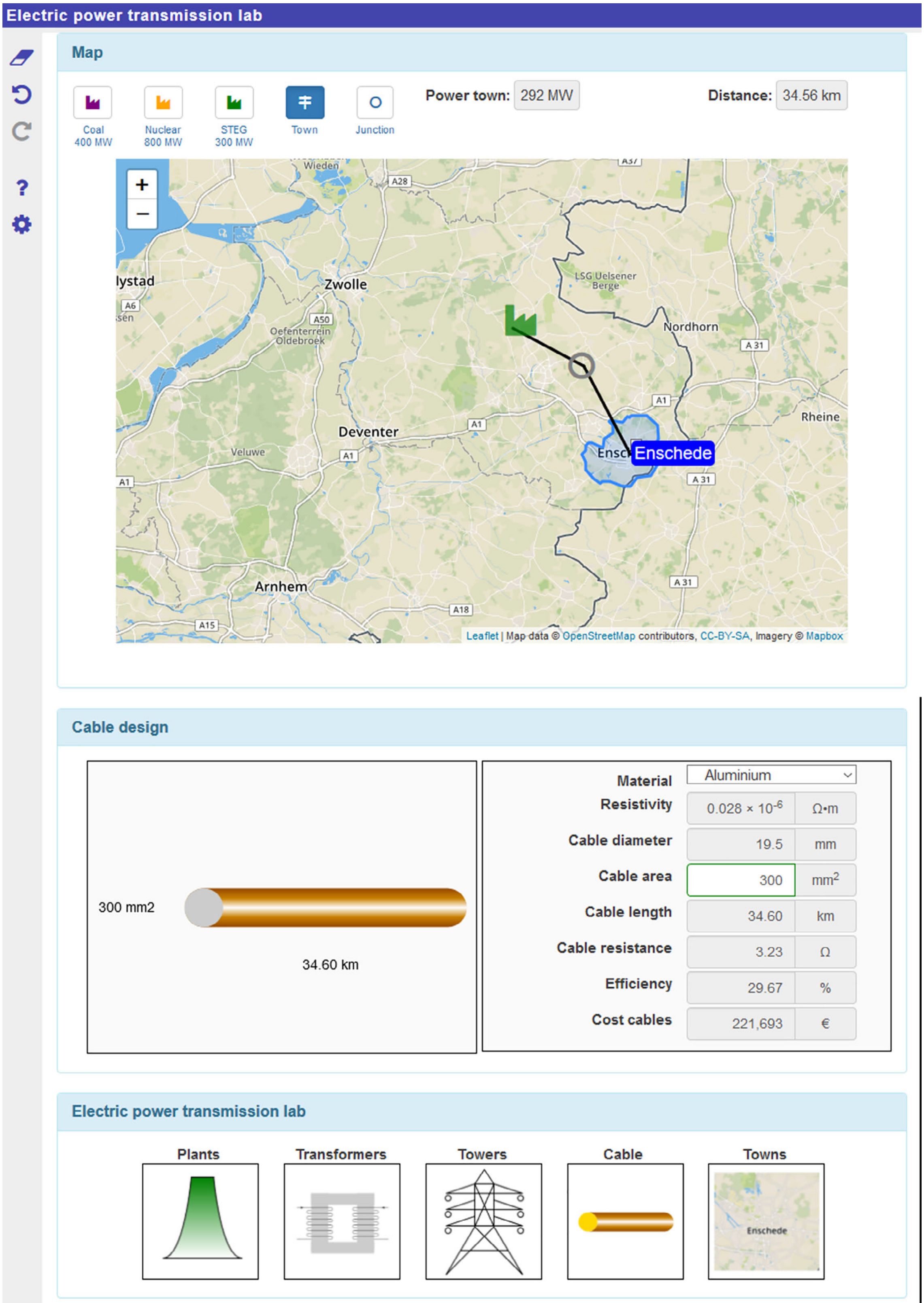


FIGURE 3 The Electric Power Transmission Lab (translated from Dutch)

for future action. Hence, in the first part students had to indicate missing information and provide a reason for not including this information (i.e., 'forgotten', 'insufficient knowledge' or 'other'). For the second part, students had to estimate how they would score on a test about topics addressed in the current learning environment and had to indicate what learning goals they still should work on.

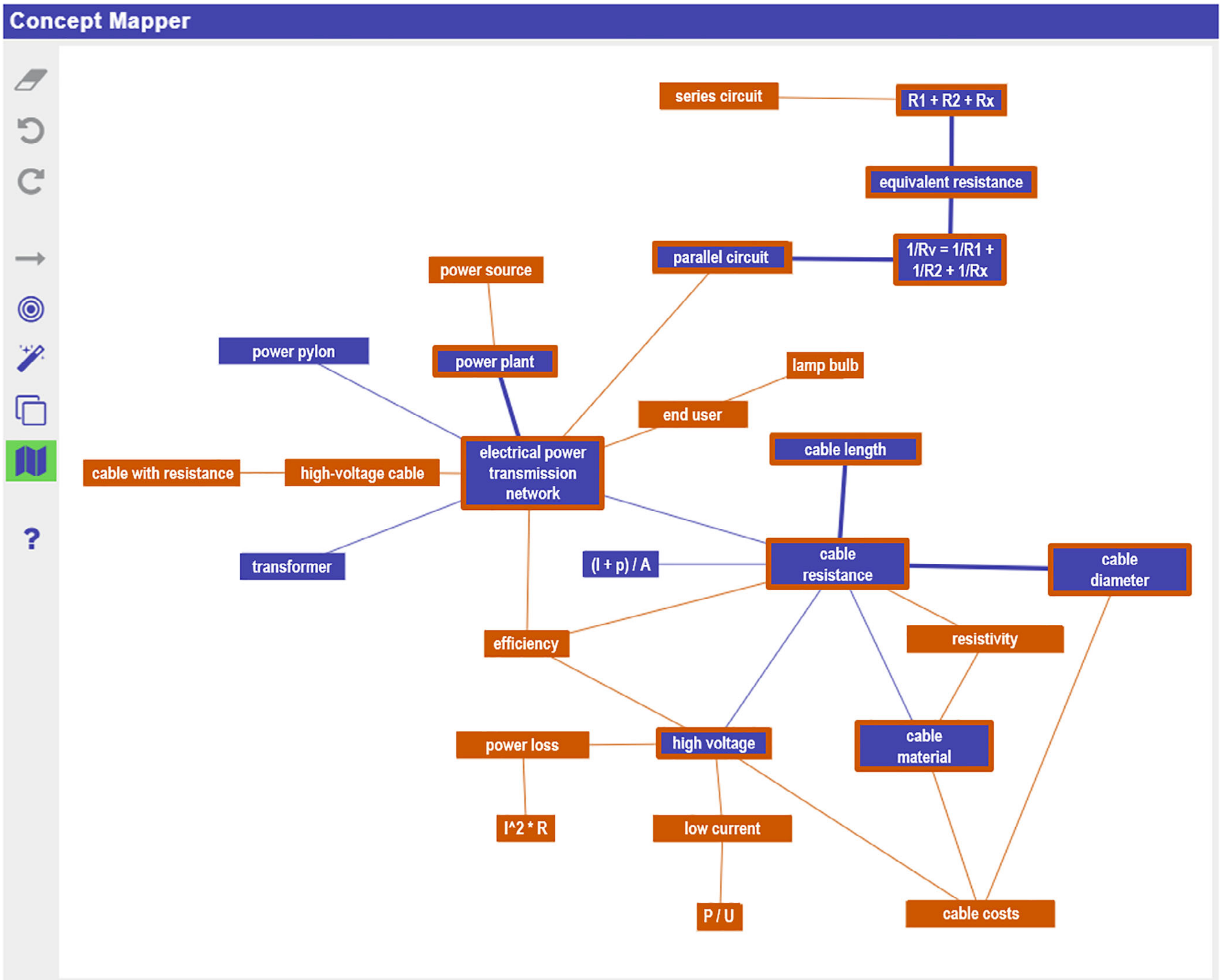


FIGURE 4 Concept mapping tool with combined concept map activated (translated from Dutch)

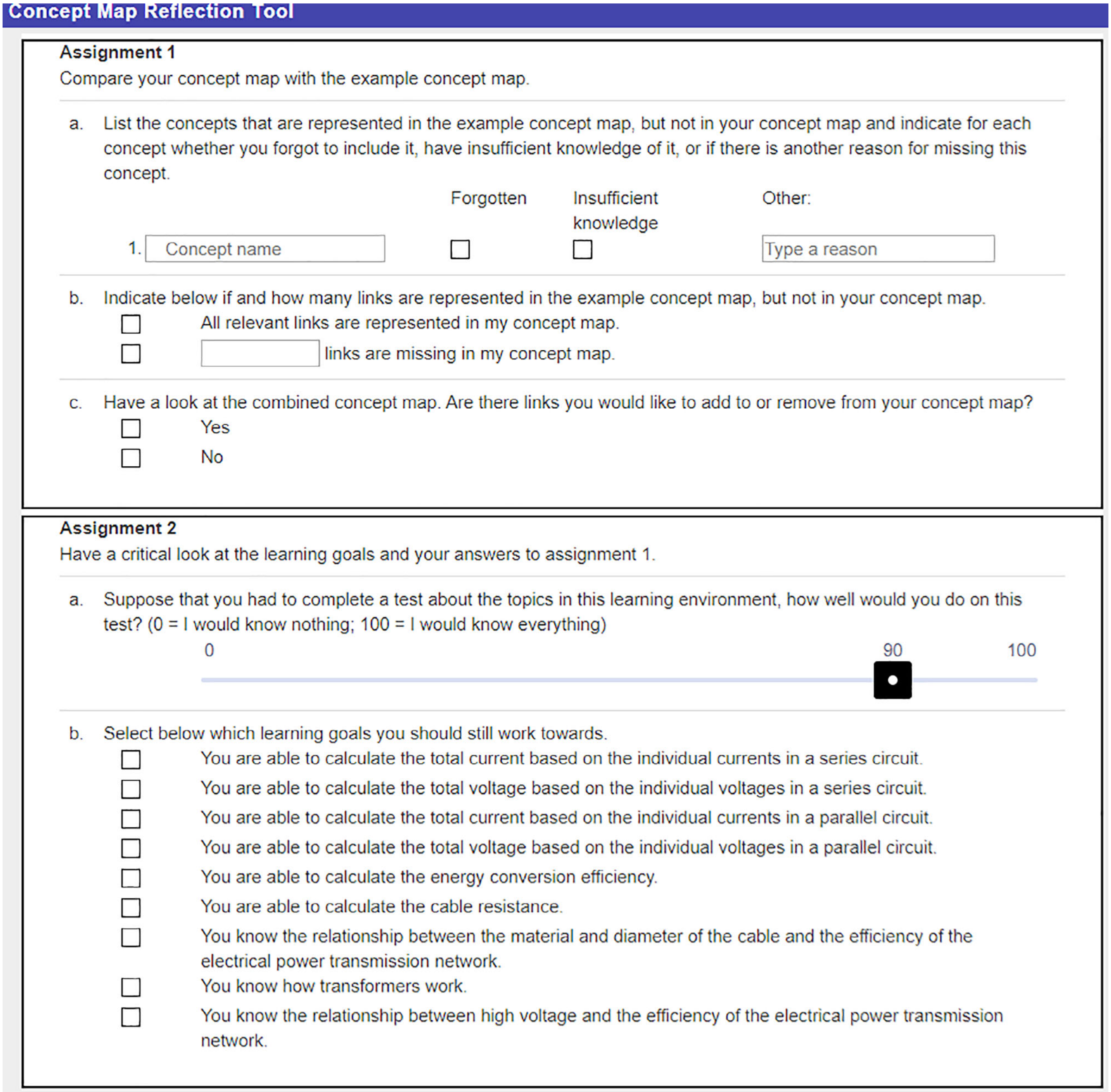
2.4 | Measurements

2.4.1 | Domain knowledge tests

Two parallel paper-and-pencil tests were used to measure students' domain knowledge—as specified in the learning goals—on the topics of the online learning environments, both before and after the intervention. The parallel items assessed similar knowledge but differed from each other in context or formulation. Counterbalancing was used to prevent order effects. That is, approximately 50% of the students in each condition received Version A as pretest and Version B as posttest, while the remaining students received Version B as pretest and Version A as posttest. In addition to their answers to the questions, students were asked to write down some personal information, namely their name, date of birth, gender, school, class and prior training trajectory.

The domain knowledge tests were based on the tests developed by Eshuis et al. (2019) and adapted to align with the topics of the online learning environments. Therefore, items that did not match one of the topics were either removed or rephrased. This resulted in 11 open-ended questions per test. Each question contained one sub-question that assessed knowledge at the conceptual level (e.g., recalling a definition or formula) and one sub-question that assessed knowledge at the application level (e.g., applying a formula or explaining a particular principle), for example: Question 1: (a) Provide the formula that is used to calculate the equivalent resistance in the circuit below, (b) What is the value of the equivalent resistance in the circuit below? Please show how you came up with your answer; Question 2: (a) The figure below presents a picture of a dynamo. Please indicate, by using two arrows, where both the magnet and the coil are located, (b) Provide a clear description of how alternating current is generated in a dynamo.

A rubric was used to score the tests. Per test, a maximum of 22 points could be earned. A second rater scored 26% of the tests independently, which resulted in an interrater reliability (Cohen's Kappa) of 0.87 for the pretest and 0.90 for the posttest. Reliability was measured using both Cronbach's alpha ($\alpha = 0.66$ for the pretest



Concept Map Reflection Tool

Assignment 1

Compare your concept map with the example concept map.

a. List the concepts that are represented in the example concept map, but not in your concept map and indicate for each concept whether you forgot to include it, have insufficient knowledge of it, or if there is another reason for missing this concept.

Forgotten | Insufficient knowledge | Other:

1. Concept name ☐ ☐ Type a reason

b. Indicate below if and how many links are represented in the example concept map, but not in your concept map.

☐ All relevant links are represented in my concept map.

☐ ____ links are missing in my concept map.

c. Have a look at the combined concept map. Are there links you would like to add to or remove from your concept map?

☐ Yes

☐ No

Assignment 2

Have a critical look at the learning goals and your answers to assignment 1.

a. Suppose that you had to complete a test about the topics in this learning environment, how well would you do on this test? (0 = I would know nothing; 100 = I would know everything)

0 90 100

b. Select below which learning goals you should still work towards.

☐ You are able to calculate the total current based on the individual currents in a series circuit.

☐ You are able to calculate the total voltage based on the individual voltages in a series circuit.

☐ You are able to calculate the total current based on the individual currents in a parallel circuit.

☐ You are able to calculate the total voltage based on the individual voltages in a parallel circuit.

☐ You are able to calculate the energy conversion efficiency.

☐ You are able to calculate the cable resistance.

☐ You know the relationship between the material and diameter of the cable and the efficiency of the electrical power transmission network.

☐ You know how transformers work.

☐ You know the relationship between high voltage and the efficiency of the electrical power transmission network.

FIGURE 5 Reflection prompts (translated from Dutch)

and 0.69 for the posttest) and McDonald's omega ($\omega = 0.74$ for the pretest and $\omega = 0.75$ for the posttest).

2.4.2 | Log files

Log files were consulted to capture indicators related to how individual students (in both combined concept mapping conditions) have used the combined concept map. Active use of the combined concept map may involve students going back to their self-generated concept map after examining the combined concept map and maybe adapting their own concept map. This requires them to (de)activate the combined concept map and to perform particular actions in their own concept map after activation. Therefore, *consultation frequency* (i.e., the total number of times a student activated the combined concept map) and the *number of actions* a student performed in their own concept map (e.g., clicking, adding, dragging, typing) *after the first time the combined concept map was activated* were logged. It was assumed that the higher these numbers, the more actively students have used the combined concept map.

2.5 | Procedure

The experiment took place in a real school setting during scheduled classes within regular school hours, meaning that students' presence was expected. In addition to a researcher, a teacher was present during all sessions to facilitate classroom management (they were instructed not to answer any possible content-related questions of their students). Prior to the experiment, a letter was sent to the students and their parents containing information about the purpose and procedure of the upcoming experiment that their school engaged in. They were given the option to indicate any objections regarding the processing of their data before the start of the experiment.

The experiment comprised four sessions to be completed within 2 weeks; the first and the last session took a maximum of 60 min each, while the second and third took 90 min each (see Table 1). Prior to each session, students were informed about the maximum time they could spend on the task at hand and that content-related questions would not be answered by either the teacher or the researcher. In addition, they were instructed to work individually (i.e., independent, without communication). To discourage interaction, students sat at separated tables during each session.

The first session started with a short introduction during which students were informed about the upcoming lessons. Subsequently, students were given the domain knowledge pretest, which they had to complete within a maximum of 40 min. At the start of the second session, the online learning environments with the labs were introduced. Students were also briefly instructed about what a concept map entails (i.e., that a concept map is a network of concepts and links that provides a means to represent one's knowledge). Differences between concepts and links were explained (and were illustrated by showing an example concept map of a different domain), and instructions were provided on how to create a concept map with the concept mapping tool. After these instructions, students received a piece of paper giving the URL of the learning environment, a login code, and brief instructions on the online labs and concept mapping tool. Students in the combined concept map conditions received additional information about the combined concept map (including a key indicating how to interpret the combined concept map). Thereafter, they started working in the first learning environment. For the duration of the session, students had access to the entire first online learning environment, but they were instructed to proceed through the learning environment in consecutive order. To ensure that students in all conditions would have enough time to complete the final assignment (including the intervention), they were told to stop working on their current assignment after 60 min, and move on to the final assignment (i.e., updating their initial concept map and, depending on their condition, examining the combined concept map and filling out the reflection prompts). All students were allowed to work another 15 min on their final assignment. All in all, the total maximum time they could have spent in the entire learning environment was similar for all conditions. The third session, during which students only had access to and worked in the second learning environment, followed the same procedure as session two. In the fourth session, students completed the domain knowledge posttest within a maximum of 40 min. All sessions took place within a maximum time span of 2 weeks, with Sessions 3 and 4 being completed in the same week.

3 | RESULTS

Inclusion criteria were used to select data for analyses (see Participants section). To check whether drop-out (i.e., students excluded from analyses) was more or less random, mean scores of available pretests (i.e., $n = 170$, based on attendance of Session 1) of students who dropped out ($M = 6.38$, SD $= 3.24$) were compared to those of students who were included in the final sample ($M = 6.43$, SD $= 3.28$). Results of an independent samples t-test showed that these mean scores did not differ significantly from each other ($t(8) = 0.52$, $p = 0.619$), which suggests that, in terms of prior knowledge, drop-out was random.

The three conditions in the final dataset were comparable regarding students' age ($F(2, 88) = 1.15$, $p = 0.323$). Table 2 presents an overview of the mean pretest scores, posttest scores and learning gains (posttest scores − pretest scores) for each condition. Univariate analysis of variance indicated no significant difference in pretest scores between conditions, $F(2, 88) = 0.27$, $p = 0.762$, $\eta_p^2 = 0.006$, which demonstrates that the conditions were also comparable—even after drop-out—in terms of students' prior knowledge.

To assess whether students' domain knowledge improved after the intervention, a paired samples t-test, comparing pre- and posttest scores, was performed for each condition. Results showed that

TABLE 1 Overview of main activities per session (with max. time in minutes per action between brackets)

Session 1	Sessions 2 and 3			Session 4
	Condition			
All	Combined concept map + reflection prompts	Combined concept map	Control	All
Introduction of sessions *(10)*	Instruction of online learning environment with labs and concept mapping tool *(10; only session 2)*			
Pretest *(40)*	Students work individually in the online learning environment *(60)*			Posttest *(40)*
	Students individually update their concept map of their knowledge			
	Students process the combined concept map			
	Students continue processing the **combined concept map** with the help of **reflection prompts** *(15)*	Students continue updating their concept map and processing the **combined concept map** *(15)*	Students continue updating their concept map *(15)*	

TABLE 2 Mean pretest scores, posttest scores and learning gains (max = 22) by condition

		Pretest		Posttest		Gain	
Condition	*n*	M	SD	M	SD	M	SD
Combined concept map with reflection prompts	28	6.04	3.37	8.41	3.17	2.37	3.03
Combined concept map	32	6.57	3.56	9.10	4.26	2.53	2.77
Control	31	6.62	2.95	8.30	2.83	1.67	2.52
Total	91	6.43	3.28	8.61	3.48	2.19	2.77

TABLE 3 Correlations between learning gain and use of combined concept map ($n = 60$)

	1	2	3
1. Learning gain	–		
2. Consultation frequency of the combined concept map	0.254*	–	
3. Number of actions in own concept map after activation of combined concept map	0.219	0.839**	–

*$p < 0.05$; **$p < 0.01$.

TABLE 4 Means and standard deviations regarding consultation frequencies of the combined concept map (of both learning environments) by condition

		Consultation frequency of the combined concept map	
Condition	*n*	*M*	SD
Combined concept map with reflection prompts	28	7.07	5.99
Combined concept map	32	10.56	11.04
Total	60	8.93	4.57

posttest scores were significantly higher than pretest scores in all three conditions (combined concept map with reflection prompts condition: $t(27) = 4.14$, $p < 0.001$, $d = 0.78$; combined concept map condition: $t(31) = 5.15$, $p < 0.001$, $d = 0.91$; control condition: $t(30) = 3.69$, $p = 0.001$, $d = 0.66$). This indicates that, on average, students in each condition did learn; effect sizes were medium to large. Although the data suggest a trend that the support conditions were more favourable for knowledge gain, an analysis of covariance with posttest scores as dependent variable, pretest scores as covariate and condition as independent variable revealed that learning gains did not differ significantly between conditions, $F(2, 87) = 0.83$, $p = 0.442$, $\eta_p^2 = 0.019$.

To explore whether students' interaction with the combined concept map affected their knowledge acquisition, a backwards stepwise regression analysis with indicators of students' use of the combined concept map (consultation frequency of the combined concept map and number of actions in their own concept map after activation of the combined concept map) as possible predictors and their learning gain as the outcome was performed. Correlations of the included variables are reported in Table 3. To check the assumption of no multicollinearity, VIF and tolerance statistics were consulted. These values (VIF = 3.38 and tolerance = 0.30) indicated no cause for concern.

Results of the regression analysis indicated a significant model (adjusted $R^2 = 0.048$), $F(1, 58) = 4.007$, $p = 0.050$, in which the consultation frequency of the combined concept map was a significant predictor of learning gain ($B = 0.080$). These results imply that the more often students activate the combined concept map, the higher their learning gain is. Table 4 presents an overview of the means and standard deviations regarding consultation frequency of the combined concept map for both combined concept map conditions.

4 | DISCUSSION AND CONCLUSION

Results of the current study revealed that on average all students, regardless of the support they received, did learn. The domain knowledge test measured whether students had reached the learning goals that they could work on in the learning environments. An average posttest score of 8.61 and an average learning gain of 2.19 on a test where a maximum of 22 points could be acquired can be considered as relatively low; it indicates that students, on average, have not yet fully mastered the domain. Ideally, the development of knowledge acquisition would be more substantial than was demonstrated in the present study. However, the outcomes are in line with expectations when taking into consideration that secondary vocational students vary widely in their didactical abilities, the time spent in the current learning environments was rather short (two times 75 min)—learning materials in vocational education are usually offered repeatedly over a longer period of time—, students did not receive a grade for the tests, and they were not given the opportunity to study prior to the test.

Contrary to what was expected, data from students' domain knowledge tests did not indicate a significant difference in knowledge gain between conditions. Yet, analysis on students' interaction with the combined concept map (for students who received it) revealed that students' consultation frequency of the combined concept map was a significant predictor of their learning gain. Based on these findings we carefully conjecture that access to the combined concept map can foster learning, but that the current implementations did not guarantee effective use of the combined concept map (an indication for individual differences in use is the spread in 'consultation frequency' which was the predictor of learning gain). It could be that not all students used the combined concept map in a manner that would facilitate their learning; they might not have actively processed or reflected upon the provided information or their reflections could have been too superficial. The current data does, however, not allow us to determine what students exactly did after activation of the combined concept map or what their motivation was for doing so. Future research can add to our understanding as to which student behaviours underlying these observed actions would possibly be beneficial for students' learning. More insight into these behaviours can, for example, be acquired by distinguishing between different actions in students' own concept map (i.e., from the current study we do know that students' total number of actions in their own concept map after activation of the combined concept map did not significantly correlate with learning gains, but more detailed analyses potentially provide more information), by using a thinking aloud approach or having students work together and in this way gain insight into their interactions.

Based on prior research it was anticipated that reflection prompts might remedy possible passive use of the combined concept map and, in turn, aid its effectiveness for learning. However, contrary to our expectations, the results revealed that adding reflection prompts to a combined concept map did not help students to improve their learning. These students' learning gains were similar to the learning gains of the students who received the combined concept map without the reflection prompts.

Based on the above, it appears that presenting an expert concept map in combination with a self-generated concept map may have potential, but that additional measures are needed to fully exploit this. From the current data, some indications can be derived that possibly explain why not all students who interacted with the combined concept map, whether provided with the reflection prompts or not, have benefited from the intervention. One issue that may need to be addressed is the large difference in structure between many of the student-generated concept maps and the expert map. Casual observations revealed high diversity in terms of students' concept map structure (e.g., students often used concepts and linking labels interchangeably or used no linking labels at all and therefore failed to create meaningful propositions). As a consequence, when a concept map that was not constructed according to the intended structure was combined with the expert concept map, differences between the two concept maps were less conceptually meaningful, making the comparison less useful as a starting point for students' reflections.

The structural issues that appeared in students' concept maps are not unique to the current study. Related research has indicated that, in general, students experience difficulties managing the linking structure (i.e., distinguishing between concepts and links and determining proper linking labels to create correct, meaningful propositions) when creating a concept map (Cimolino et al., 2003; Novak & Cañas, 2008). Though the observed structural issues in this study may have partly resulted from the open-endedness of the task, the choice not to direct students in constructing their concept maps was well-advised. Directing students could disrupt their reasoning and result in a concept map that does not represent their own knowledge, which, in turn, could hamper reflection (Gouli et al., 2003; Ruiz-Primo et al., 2001). That said, it would be interesting to investigate whether higher quality concept maps, constructed according to the intended structure, would increase the effectiveness of the feedback (i.e., the comparison with the expert example) and reflection prompts.

Based on literature two ways to increase the quality of students' concept maps stand out: restricting the task and training the students. Creating concept maps from scratch has often been compared to more 'restricted' concept mapping tasks (e.g., where students have to complete incomplete concept maps or where they have to construct a concept map with only predefined concepts and linking labels) (e.g., Cañas et al., 2012; Gouli et al., 2003; O'Donnell et al., 2002; Ruiz-Primo et al., 2001; Strautmane, 2012). The degree of restrictiveness influences the way students structure their concept map and may affect their knowledge acquisition: the more restricted the task, the more likely that students produce higher quality concept maps that resemble the intended structure (Cañas et al., 2012; Ruiz-Primo et al., 2001). Another way to reduce the structural issues in students' concept maps is to train students in creating a concept map (e.g., by introducing the use of concept maps, explaining how to construct propositions and how to relate them, letting them practice the construction of a concept map and discussing students' own concept maps (see, e.g., Ruiz-Primo et al., 2001); or by learning students how to construct a concept map, how to use it, to evaluate it, and to revise it (see, e.g., Quillin & Thomas, 2015). Related research substantiates the positive effects of training on students' concept map quality and related learning gains (Chang et al., 2002; Hilbert & Renkl, 2008; Ruiz-Primo et al., 2001). Additionally, improving the quality of the student-generated concept maps makes the differences between student and expert map more conceptually meaningful. In turn, this is likely to positively affect the effectiveness of the reflection prompts.

Another adaptation that may help to increase the effectiveness of the reflection is the phrasing of the prompts. The prompts in this study mainly aimed to improve students' knowledge monitoring by helping them to identify weaknesses in their knowledge (e.g., by asking them to indicate differences between their concept map and the expert version and to state whether these differences were due to insufficient knowledge). Although proper knowledge monitoring involves awareness of possible gaps and misconceptions (Linn, 1995), as discussed by Davis (2003), students' reflections may benefit from prompts that are phrased more positively (e.g., 'what can be improved' instead of 'what is missing'). This is in line with findings from Dekker et al. (2013), who found that feedback comments phrased in a positive tone stimulated reflection more than those with a negative tone, as well as findings that students prefer positively phrased feedback (Pitt & Norton, 2017), while negatively worded feedback can cause students to be reserved in their reaction or respond in a negative way (Poulos & Mahony, 2008; Weaver, 2006). Moreover, the level of specificity may have affected the effectiveness of the reflection prompts. Although a relatively high level of specificity is needed to steer students' attention towards particular information, it can be that the reflection prompts in the current study contained too many 'check the box' items. This might have inhibited students' critical thinking and reasoning (Wylie & Chi, 2014). Hence, it would be interesting to see how the phrasing and focus of the prompts affect the effectiveness of the reflection support.

The fact that findings of the current study do not seamlessly align with findings from prior studies could be seen in relation to the population. Secondary vocational students, a rarely targeted population, might need different support than other students. Regarding their learning, vocational students often encounter motivational problems (Meijers, 2008) and in a more practically than theoretically oriented educational setting, they are not commonly used to reflect upon their behaviour (Slaats et al., 1999). Besides, these students can be considered as rather divers with respect to their learning capabilities, which is, among others, evidenced by the divergent preparatory training trajectories they followed and the rather high variances in learning outcomes of the current study. We, therefore, see our results as an encouragement to seek for additional ways to support our target group. As indicated above we suppose improvements can be found in training concept map creation or restricting this process and phrasing reflection prompts in a more generic and positive way.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Research data are not shared.

ETHICS STATEMENT

The procedures used in this study were in accordance with the ethical standards of and approved by the BMS Ethics Committee of the University of Twente.

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