Learning by Teaching: The Effects of Individual Versus Collaborative Preparation

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Abstract

Aiming to replicate and extend the results of Kobayashi's (2021) research, this study assessed collaborative versus individual preparation effects in a learning by teaching context, focusing on a practical classroom setting. Participants were recruited from the Dutch Army Artillery school and the sample ($N = 24$) included predominantly male participants with a relatively high age and diverse educational background. While results mirrored the original study, showing no significant differences in conceptual knowledge and transfer medium effect sizes were observed. Collaborative preparation significantly boosted intrinsic motivation compared to individual preparation ($p = .022$, $d = 1.007$). Cognitive load differences were not significant but the near significance and effect size hint at potential implications. A non-significant positive correlation was found between learning outcome and collaboration quality. However, limitations, including the study's specific context, small sample size and demographics, may have influenced the results. Practical implications include the potential benefits of incorporating collaborative preparation in educational settings to enhance motivation. Future research should focus on the nuances of collaborative dynamics and the potential influence of external factors on learning outcomes. In conclusion, while collaborative preparation did not significantly outperform individual preparation in terms of learning outcomes, its impact on motivation and the observed trends in cognitive load underscore its potential value in educational contexts.

Introduction

Learning by teaching is a popular learning activity that is widely used in education due to its effectiveness and flexible application (Kobayashi, 2021). In this learning activity, the students act as teachers and explain previously learned material face-to-face (Bargh & Schul, 1980), developing teaching material (Ribosa & Duran, 2022) or teach peers on camera (Fiorella & Mayer, 2013; 2014). Over the past five decades, a large body of research has emerged on learning by teaching focusing primarily on the individual benefits of this learning activity (Allen, 1976; Duran, 2017; Kobayashi, 2019). However, studies examining the effects of collaboration within learning by teaching are relatively scarce, despite evidence supporting the benefits of collaborative learning (Laal & Ghodsi, 2012). Some of this evidence can be found in the context of making instructional videos with a group of students (Gold et al., 2015; Orús et al., 2016; Zahn et al., 2014), but these studies are not comparable due to the different samples, procedures, and measurements. It therefore remains largely unclear what the most effective strategy for teachers is to apply learning by teaching in combination with collaborative learning.

However, one recent study by Kobayashi (2021) examined the effects of collaborative versus individual preparation on learning by teaching, showing that students who collaboratively prepare teaching: (1) learned more and (2) provided higher quality teaching explanations. Despite these promising results, one study is not enough to provide guidelines to teachers for the optimal application of learning by teaching. Moreover, the study of Kobayashi (2021) had limitations that needed to be addressed (e.g., measure collaboration separately and replicate in a more educational setting). Therefore, this study aimed to replicate the promising results of Kobayashi (2021) on the one hand and addressed some of these limitations on the other hand.

Learning by Teaching

Learning by teaching is a learning activity in which students act as teachers and explain previously learned material to their peers (Kobayashi, 2019), also known as "peer tutoring" (Roscoe & Chi, 2007). This method has been found to be more effective than traditional learning activities such as studying for a test (Benware & Deci, 1984; Duran, 2017; Lachner et al., 2022) or restudying the same material (Fiorella & Mayer, 2014; Hoogerheide et al., 2019b). Research on learning by teaching dates back to the 1970s (Allen, 1976; Cohen et al., 1982) and has demonstrated its effectiveness in various settings, including one-on-one peer tutoring (Roscoe & Chi, 2007) and teaching without an audience through video recordings (Fiorella & Mayer, 2013; Hoogerheide et al., 2019a; Lachner et al., 2022).

Learning by teaching is typically segmented into three phases: preparation, teaching, and interaction (Bargh & Schul, 1980; Fiorella & Mayer, 2014; Ribosa & Duran, 2022). In the preparation phase, students must first master the study material so that they can teach it to their peers (Kobayashi, 2021). This process of mastering the material is one of the essential factors that makes the learning by teaching activity so effective, since the students involved are expected to learn the subject matter in a relatively short time before they have to teach their peers (Bargh & Schul, 1980; Kobayashi, 2019; Ribosa & Duran, 2022).

Research on the effects of this preparatory learning process has identified *teaching expectancy* as an important factor in the preparation phase (Benware & Deci, 1984; Fiorella & Mayer, 2013, 2014). Teaching expectancy, also known as 'preparing-to-teach', refers to students having the expectation to teach others about the learning material and provide them with explanations (Kobayashi, 2019). A meta-analysis by Kobayashi (2019) of 28 studies found that priming students with a teaching expectancy resulted in an increase in both surface and deep learning, with a small-medium effect size ($g = 0.35$). However, the high heterogeneity of the results ($I^2 = 76\%$) makes it difficult to determine the exact cause of this positive effect (Kobayashi, 2019). A likely explanation could be found in the generative and constructive learning hypotheses, which suggest that students who prepare for teaching activate generative processes, such as selecting the most relevant information, creating a comprehensive narrative, monitoring their own comprehension, and integrating new knowledge with existing prior knowledge (Fiorella & Mayer, 2015; Hoogerheide, 2019b; Roscoe, 2013).

In addition, the research by Kobayashi (2019) has revealed that the expected audience also affects students' learning outcomes when they are primed with teaching expectancy. Specifically, students who were expecting to teach a real-life audience (also know as an interactive setting) showed larger learning effects compared to those who expected to explain the material on camera or on paper (also know as a non-interactive setting). The most likely explanation for this seems to be the social presence hypothesis; which suggests that the awareness of an audience can activate arousal and trigger motivational and metacognitive processes, fostering a more thorough preparation for teaching (Benware & Deci, 1984; Hoogerheide, 2019a; Lachner et al., 2022). Overall, teaching expectancy has been shown to be a powerful mechanism for promoting learning in the preparation phase of learning by teaching, but simply evoking teaching expectancy is not sufficient to ensure higher learning outcome (Kobayashi, 2019).

Collaborative Learning

While studies on learning by teaching have traditionally focused more on individual preparation (Fiorella & Mayer, 2013, 2014; Kobayashi, 2019), the large body of research on collaborative learning suggests that collaborative preparation could improve learning outcomes of learning by teaching. Collaborative learning occurs when students work together in a group setting, actively engaging and interacting with the intention of establishing a common focus and achieving a common goal (Kirschner et al., 2011; 2018). However, simply putting students together in a group is not enough; the key to successful collaborative learning lies in the co-construction of knowledge (Gillies, 2016; Kirschner et al., 2008; Roschelle, 1992). A critical precondition for collaboration is therefore qualitative interaction, where all participating students have equal talking time, are equally engaged, and actively discuss the learning material to effectively process the learning material together (Chi & Wylie, 2014; Roschelle, 1992). This interaction triggers generative and metacognitive learning processes, resulting in more effective learning compared to individual learning activities (Fiorella & Mayer, 2016; Roscoe & Chi, 2007).

An additional explanation for the effectiveness of collaborative learning is that the cognitive load of individuals can be shared in a collective working memory when working with other individuals or computers (Kirschner et al., 2011; 2018). This way, the burden of processing information and completing tasks is shared, leading to more efficient and effective learning. When students prepare for teaching together, they could benefit from this collective working memory (Kirschner et al., 2008; 2018).

Furthermore, collaborative learning has been shown to boost student motivation, increase self-efficacy, promote a learning goal orientation, and enhance academic performance, all of which are beneficial in the preparation phase of learning by teaching (Bargh & Schul, 1980; Loes, 2022; Lowyck & Pöysä, 2001). In summary, the positive results of collaborative learning should be applicable in the preparation phase of learning by teaching, increasing the effectiveness of learning by teaching.

Collaborative Versus Individual Preparation

Kobayashi's (2021) pioneering study investigated the impact of collaborative versus individual preparation on learning by teaching, employing the ICAP framework (Interactive, Constructive, Active, Passive) proposed by Chi and Wylie (2014) to examine the differences in learning processes. The ICAP framework identifies four modes of engaging in learning activities: passive, active, constructive, and interactive. For Kobayashi’s study, the focus was on the constructive and interactive modes, linked with higher-order learning processes.

The constructive mode refers to activities in which students engage in higher-order learning through the construction of new knowledge using prior knowledge as an individual (e.g., self-explaining or summarizing text in their own words). The interactive mode, however, is solely triggered by qualitative interaction among two or more learners (e.g., constructively criticizing and elaborate on each others ideas), resulting in more deeper learning (Chi & Wylie, 2014). This aligns with the examined research on collaborative learning; when students are actively involved in discussions and thus co-construction of knowledge, they activate deeper generative processes (Razmerita, & Kirchner, 2014; Roscoe & Chi, 2007).

Kobayashi (2021) used this information to hypothesize that collaborative preparation fosters more learning (hypothesis 1), promotes higher quality explanations due to the deeper processing of knowledge (hypothesis 3), and that the quality of instructional explanations predict the outcome of learning (hypothesis 4). Additional hypotheses were centered around the belief that collaborative preparation would lead to higher intrinsic motivation and a differential cognitive load experience between the two conditions. The hypotheses were tested by dividing participants into two groups, each comprising two students: one for individual preparation and another for collaborative preparation. Both conditions were instructed that each student should prepare to explain learning material on camera, but a random participant from each pair would teach on camera, thus evoking teaching expectancy. After the preparation, the participants within each condition was split into two roles: half of the students presented on camera, the other half listened and rated the explanation of the other student. Kobayashi's research outcomes indicated that participants in the collaborative group showed increased performance in comprehension tests (hypothesis 1) and delivered more coherent explanations (hypothesis 3). Notably, the quality of these explanations was found to be a robust predictor of the learning outcomes (hypothesis 4). In addition, the collaborative condition showed significantly increased intrinsic motivation and inference knowledge compared to the individual condition. However, it is important to underscore that the study did not show any significant results between the two conditions regarding transfer, conceptual knowledge and cognitive load. These results show the necessity for further research, as Kobayashi (2021) mentioned.

Another argument to further investigate these findings is that Kobayashi (2021) used surveys to measure conceptual knowledge, transfer and inference after the teaching phase, sidelining the preparation phase, thus making it harder to detect the precise factors that cause the observed differences between the conditions. This element, alongside the fact that Kobayashi (2021) did not measure the quality of the collaboration, should be addressed in future studies.

Present study

The current study aims to expand the research on learning by teaching by partly replicating Kobayashi's (2021) study. Given that Kobayashi's original research was pioneering in comparing collaborative versus individual preparation, the current study intended to further validate and strengthen these findings, providing clearer guidelines for teachers in applying learning by teaching effectively. Therefore, the main aim of this study was to replicate the findings of Kobayashi (2021) by comparing collaborative versus individual preparation on learning by teaching. The present study differed from the original study by focussing only on the preparation phase, excluding the teaching phase in order to determine how the preparation phase influences learning, intrinsic motivation and cognitive load. It was key that while excluding the teaching phase, participants were primed with the teaching expectancy in both conditions to generate reliable results. The instruments to measure learning (conceptual knowledge and transfer), intrinsic motivation (interest and enjoyment) and cognitive load were as similar to the original study of Kobayashi (2021) as possible, despite using different learning text.

Since the participants in this study also deviated from the original study, a more generic learning material was used. The used learning material included surveys to measure learning (conceptual knowledge and transfer), however no surveys to measure inference knowledge existed and was therefore excluded from this study. In line with Kobayashi (2021), this study hypothesized that the collaborative condition would outperform the individual condition on conceptual knowledge, transfer (hypothesis 1 & 2) and intrinsic motivation (hypothesis 3). It was also expected that the cognitive load would be higher for participants preparing individually compared to those preparing collaboratively (hypothesis 4).

The second aim of this study was to address the limitations of Kobayashi's original study, by validating if participants in the collaborative condition were actively involved in active collaborative learning instead of merely working together. Therefore the quality of collaboration was measured, showing if the participants were involved in the interactive mode instead of the constructive mode during their collaboration (Chi & Wylie, 2014). Thus for the final hypothesis, it was predicted that there was a positive relation between a higher quality of collaboration and learning outcomes (hypothesis 5).

Method

Participants and Sampling Procedure

Participants were recruited from the Dutch Army, specifically within the Artillery school. The personnel of the Artillery school were first informed about this study via their managers and subsequently received an invitation to participate via email a week later (see Appendix A). This email included information about the study, the informed consent form, and guidelines of the university regarding privacy of the participant and data handling. Those who responded positively to the email were individually approached to join one of the five experiment sessions, utilizing a convenience sampling method. The inclusion criterion for this study was therefore 1) working for the military and 2) be willing and able to participate in the planned timeframe. No specific exclusion criteria were applied, aiming for a sample that is diverse and representative of the population within the organization.

Despite the aim for diversity, the sample of $N = 24$ was predominantly male (95.80%), mirroring the gender distribution within the Dutch Army (Ministerie van Defensie, 2023). Participants' ages ranged from 25 to 58 years ($M = 41.30$, $SD = 9.90$). The rather high mean age can be attributed to the requirement for personnel at the Artillery school to possess relevant military practical experience. Additionally, a more detailed look into the participants' education shows that only 29.20% of the participants completed higher education. This can be explained by the composition of the staff at the school, which primarily consists of instructors with practical training, with relatively few higher-educated officers present. A detailed overview of the participant characteristics, including gender, age, and education level, is provided in Table 1.

All participants provided informed consent, and confidentiality was maintained throughout the study by using randomly assigned participant numbers. Participant numbers and conditions for each session were predetermined, with prenumbered envelopes placed on the tables where participants were seated. Participants chose their seating spot voluntarily, unaware of the corresponding participant number and condition. Sessions were scheduled over a period of five weeks, contingent upon the availability of classrooms within the Artillery school and the schedules of the participants and the researcher. No payments were made to participants for their involvement in the experiment. The study received ethical approval from the Faculty Ethical Review Board (FERB) of the Faculty of Social and Behavioural Sciences at Utrecht University.

Table 1

Participant Demographics

Category	**Frequency**	**Percentage**
Gender		
Male	23	95.80
Female	1	4.20
Age Range (Years)		
20-29	4	16.70
30-39	6	25.00
40-49	9	37.50
50-59	5	20.80
Education Level		
Secondary Vocational Education	11	45.80
Higher General Secondary Education	6	25.00
University (of Applied Sciences)	7	29.20

Design and Power Analysis

This study employs a between-subjects experimental design and serves as a conceptual replication study, aiming to validate the principal findings of Kobayashi (2021) within a more practical context. A priori power analysis was conducted using G*Power 3.1.9.7 to determine the required sample size for this study. Based on the study of Kobayashi (2021) the same expected power of $d = 0.74$ was used for an a priori two-tailed independent samples t-test in G*Power with a predicted power of 0.80 and $\alpha = 0.05$, resulting in a total suggested sample size of $N = 60$ participants ($N = 30$ per group). However, only $N = 24$ participants were recruited, impacting the study's power and the results. This was corroborated by a post-hoc power analysis using G*Power (3.1.9.7), incorporating the results of the analysis of the first hypothesis (N = 12 for both groups, a Cohen's d of 0.57, and an α of 0.05). The post-hoc analysis revealed an achieved power of 0.26, indicating a 26% probability of correctly rejecting the null hypothesis given the observed effect size and sample size, underscoring the need for caution in interpreting the results (Cohen, 1992).

Materials And Measures

Materials

Unlike Kobayashi's study (2021), this research employed more generalized learning materials for the task. The frequently used materials on "the formation of lightning" (Harp & Mayer, 1997; Shangguan et al., 2020) were translated into Dutch and subjected to a face validity check by three peers. Following their feedback, the Dutch learning text was expanded by a total of 99 words (see Appendix C). The measuring instruments, derived from Shangguan et al. (2020), remained largely unaltered.

Prior Knowledge

Assessing prior knowledge is necessary as it can influence cognitive load, learning, and motivation (Bittermann et al., 2023; Ormrod, 2019). This study employed the two instruments from Shangguan et al. (2020): a four-item self-report checklist with a four-point Likert scale (e.g., "I know how lightning is formed", 1 = "I don't understand anything about this topic" – 4 = "I fully understand this topic") and five multiple-choice questions (e.g., "How is a cloud created?", A = "Airflow rises", B = "Temperature drops ", C = "Water vapour condenses into water droplets", D = "I don't know"). Consistent with previous studies utilizing these instruments, learners' prior knowledge was calculated by summing the scores of the self-assessment (each item scored between 0 to 4, with a maximum of 16 points) and the multiple-choice questions (each item scored either 0 or 1, with a maximum of 5 points), yielding a range from 0 to 21 points (Shangguan et al., 2020).

Learning outcomes

The conceptual knowledge test and the transfer test both combined resulted in the total learning outcome score, based on the products of Shangguan et al. (2019). The items were translated to Dutch, resulting in the conceptual knowledge test consisting of nine multiple-choice questions (e.g., “How is lightning formed?”, A = “Positive charge moves upward”, B = “Negative charge moves downwards”, C = “Positive and negative charges meet”, D = “I don’t know”). The conceptual knowledge score was calculated by summing the total correct answers, with each correct answer awarded one point, yielding a range between 0 and 9 points. The transfer test, designed to measure the learners’ ability to apply acquired knowledge in new contexts, consisted of three open questions (e.g., “Explain the influence of indoor temperature in the forming of lightning?”), with points assigned for each correct element of the answer, resulting in a total range from 0 to 7 points (refer to Appendix C for detailed guidelines).

The total learning outcome was derived by adding both scores, resulting in a range from 0 to 16 points. To ensure interrater reliability for the transfer items, a second rater evaluated 50% of the answers, with each condition equally represented. After scoring the items, the scores were compared with rather small differences except for two items. The raters calibrated the answers, with one rater adjusting the answers after reaching an agreement on the interpretation. Subsequently the Cronbach’s Alpha was calculated, resulting in $\alpha = 0.86$, indicating a high level of agreement between the raters.

Intrinsic Motivation

In the study conducted by Kobayashi (2021), two items were used to measure the interest and enjoyment of the participants since it can influence learning by preparing to teach; however, these items lacked theoretical grounding. To address this limitation, the current study employs items from the Intrinsic Motivation Inventory (IMI). The IMI is a well-validated instrument, demonstrating Cronbach's α values ranging from 0.82 to 0.95 and consistent convergent validity across various studies, with correlations between 0.41 and 0.69 (Gillet et al., 2012; McAuley, Duncan, & Tammen, 1987). The IMI encompasses four categories, each measuring different aspects of intrinsic motivation, including a category specifically for “interest and enjoyment”. Within this category, four items were selected to align with the learning task in this study (e.g., “While preparing the presentation, I noticed that I was enjoying it.”, 1 = “Completely disagree”, 7 = “Completely agree”). These items were translated into Dutch and underwent a face validity check by two peers, which concluded that no adjustments were necessary. The intrinsic motivation score was calculated as the mean of all item scores, with item 2 (“The topic of the presentation did not hold my attention at all”) being reverse scored.

Cognitive Load

Evaluating cognitive load is crucial in this study to understand the cognitive demands placed on participants during the learning task, as it may influence the learning outcomes of working either individually or collaboratively (Kirschner et al., 2008; 2018). In alignment with Kobayashi (2021), this study employed the Paas mental-effort rating scale to measure cognitive load (Paas, 1992). This scale consists of a single-item questionnaire, translated into Dutch, which asks about the mental effort expended on the learning task, rated on a nine-point scale (1 = “Very, very little effort”, 9 = “Very, very much effort”). Consistent with Kobayashi (2021), this questionnaire was administered immediately after the learning task to enhance the accuracy of the measurement (DeLeeuw & Mayer, 2008).

Quality of Collaboration

Evaluating the quality of collaboration is pivotal for understanding the interactive dynamics and synergies in learning processes, hypothesized to correlate with higher learning outcomes in hypothesis 5. To measure collaboration, this study utilized the Teamwork Skill

Scale (TSS), specifically focusing on the ‘teamwork behaviour’ factor. This scale, validated in vocational education contexts with a Cronbach's Alpha of $\alpha = 0.80$ (De La Guardia et al., 2022; Lower et al., 2017), is particularly relevant to the demographics and context of this study. The TSS was translated into Dutch and comprised 6 items (e.g., “I communicated well with my teammate”), utilizing a seven-point Likert scale ranging from 1 = “Completely disagree” to 7 = “Completely agree”. The mean score was calculated for the quality of collaboration score.

Circumstances

Given that this study was conducted in a practical classroom setting, the environmental conditions could potentially influence the results. For instance, if participants found the learning environment too noisy to concentrate, it could impact the outcomes. To control for the learning environment setting, an additional single-item survey was created (“Were conditions calm enough to concentrate well on preparing the presentation?"), utilizing a seven-point Likert scale (1 = “Completely disagree”, 7 = “Completely agree”). The mean score from this item could be used to explain potential anomalies in learning results or to reinforce the anticipated outcomes.

Data collection

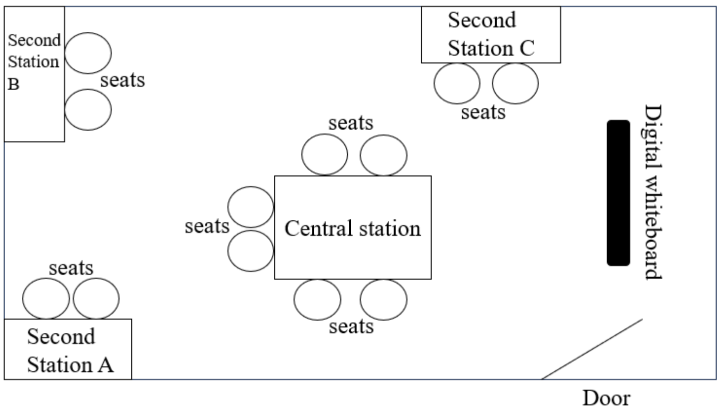
Data collection occurred over five sessions, each accommodating up to six participants due to practical constraints, and all data were collected using hard copy instruments within a classroom at the Artillery school. The experiment, designed to last approximately 60 minutes, was based on timings from previous research; for instance, Harp and Mayer (1997) reported a reading time of approximately 6.5 minutes for their text, which informed the time allocation for this phase. The first two sessions served as pilot sessions to validate the timings for both conditions and ensure the smooth flow of the experiment, with notes on timings, potential improvements, and critical observations recorded by the researcher during each session. These initial sessions were crucial for refining the experiment's structure, resulting in minor adjustments like extending the learning task by five minutes (from 15 to 20 minutes).

Procedure

The experiment was conducted during five sessions where participants could subscribe for these sessions. Based on these subscriptions, the conditions were randomly divided for each session and participant numbers were generated. The experiments were conducted within a classroom that was organized with several participant stations (see Figure 1). Before each session, participants were assembled in a briefing room at the Artillery school for an introduction to the study's essential aspects (see Figure 2, phase 1). They were reminded about the objectives, data storage and privacy details and informed about the procedural flow, ensuring transparency. The emphasis during this briefing was placed on preparing a presentation as learning task in order to prime teaching expectancy correctly. This briefing also allowed participants to clarify any doubts, fostering open communication.

Figure 1

Classroom Overview

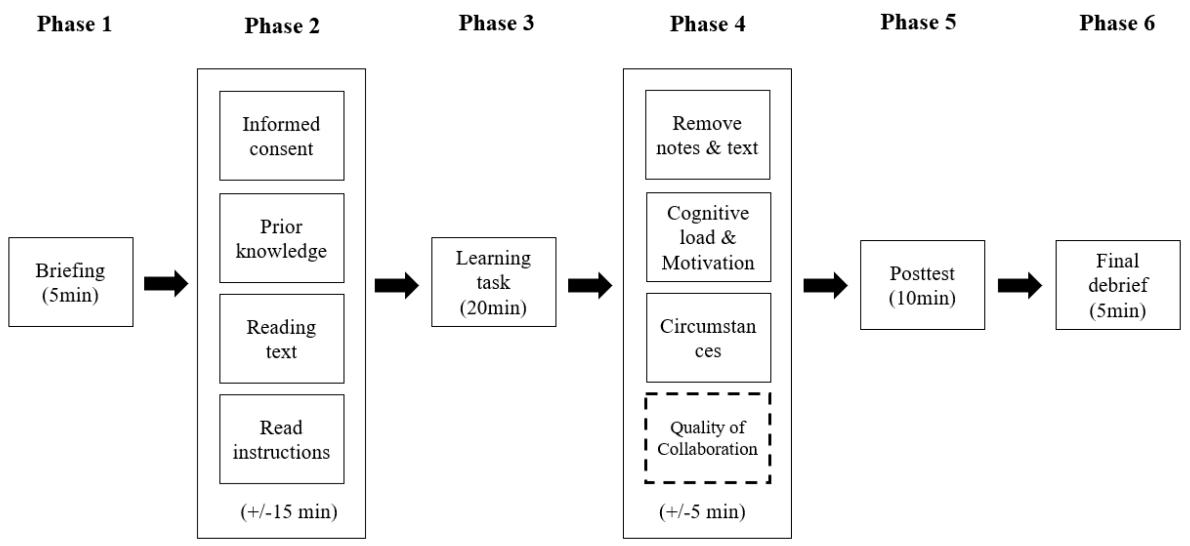


After the briefing, the participants were guided to the prepared classroom (Figure 1). Upon entering the classroom, the participants were asked to take a seat on the central station where numbered envelopes and informed consent forms awaited (see Figure 2, phase 2). The random seating determined the participant number and condition. The participants were instructed to fill in the informed consent form and then put these in the envelope. Once all informed consent forms were filled in, participants filled in the self-assessment form and the prior knowledge tests, followed by an acquaintance with the learning text. Subsequently, the participants were handed instructions that corresponded with their condition. The individual condition received instructions where they were explicitly instructed to prepare the presentation individually (e.g., “You will prepare an individual presentation that you will later give to a number of participants”) whereas the collaborative condition got specific instructions to prepare together (e.g., “Prepare the presentation together so that you can give the presentation well prepared.”).

To ensure priming for both teaching expectancy and the right condition, the digital whiteboard, placed prominently in the classroom, was pointed out as a tool to support the individual presentation that was prepared alone or together. When there were no questions, the learning task started (Figure 2, phase 3).

Figure 2:

Procedure Overview



Participants were then relocated to the second stations (see Figure 1) aligning with their assigned condition where the preparation for the presentation started. During the learning task, the researcher encouraged the collaboration when necessary. Three minutes before the end of phase 3, the participants were notified that time was almost due. After the 20 minutes of the learning task passed, the participants were asked to gather at the central station, starting phase 4. First, the notes and learning text were put in the envelopes. Subsequently, the surveys for cognitive load, intrinsic motivation and circumstances were filed in. For the collaborative condition, the quality of collaboration survey was filled in as well.

When finished, all surveys were put in the envelopes, initiating phase 5. This phase started with a short debrief clarifying the exclusive focus of the experiment on the preparation phase and informing the participants that they would not conduct the individual presentations. Participants then completed the knowledge tests assessing conceptual knowledge and transfer knowledge. The last phase was the final debriefing, where participants' reactions were gathered, and appreciations were extended for their participation, concluding the experiment.

Data Storage

Data acquired in this study was managed and stored in strict adherence to the 'Research Data Storage Protocol' of Utrecht University. Given the utilization of hard-copy forms for data collection, a secure transportation and subsequent digitization of these forms was imperative before any analysis could commence. The envelopes containing the hard-copy data were immediately digitized by photo after the experiment. Subsequently, the envelopes were then sealed and locked in an office cabinet for the duration of the day. After the day ended, the envelopes were then stored in a locked vault at the home of the researcher. The digital storage platform Yoda was employed to ensure the secure and organized storage of the digital data, in accordance with institutional guidelines. Besides the raw data, additional products like the coding sheet for the participants with their participant number were also stored securely online and/or offline in sealed envelopes in a locked vault.

Data Analysis Procedure

Data analysis was performed using SPSS statistical software. Initially, the data were digitized into Excel before being transferred to SPSS, where the necessary additional variables were created and calculated (e.g., to measure the prior knowledge, the sum of the self-assessment score and the prior knowledge test was used to create the "prior knowledge total score" variable). Following this, the interrater reliability score and the assumptions of normality, linearity, and homogeneity of variances were evaluated. Given the comparative nature of the research question, the primary analysis was conducted using two-tailed independent samples *t*-tests to address the main hypothesis. However, hypothesis 5 was assessed through correlational analysis, as it examines the positive relation between collaboration and learning outcome, making an independent samples *t*-test inappropriate. Lastly, effect size and power analysis were computed to understand the magnitude of the observed differences and to evaluate the adequacy of the sample size and the potential risk of type I and type II errors.

Results

Descriptive Statistics

Before delving into the descriptive statistics, the assumptions of normality, linearity, and homogeneity of variances were verified, revealing one detected violation pertaining to linearity. One outlier was found, showing that a participant within the first condition scored a 2 out of 7 within the circumstance variable, suggesting that the conditions of the learning task were not calm enough to concentrate on the learning task. This suggested that this participant might also have had aberrant scores in other variables; however, this participant showed no other deviating results on cognitive load, intrinsic motivation, conceptual knowledge and transfer. To ensure there was no effect of this participant's score, all analyses were conducted with and without this participant, showing no significant differences for all hypotheses (e.g., for intrinsic motivation, p = .022 with the participant and p = .038 without the participant). Therefore, in this study, all reported outcomes included all participants (N = 24). Following these adjustments, descriptive statistics were obtained for all outcome variables per condition (Table 2).

Table 2

Descriptive Statistics per Condition

Variable	**Condition**	***N***	***M***	***SD***
1. Prior Knowledge	Individual	12	10.92	1.93
(Range 0 = Low, 21 = High)	Collaborative	12	11.50	2.39
2. Conceptual Knowledge	Individual	12	6.33	1.16
(Range 0 = Low, 9 = High)	Collaborative	12	7.00	1.21
3. Transfer	Individual	12	3.04	1.57
(Range 0 = Low, 7 = High)	Collaborative	12	3.54	1.01
4. Intrinsic Motivation	Individual	12	4.58	1.07
(1 = Low, 7 = High)	Collaborative	12	5.56	0.86
5. Cognitive Load	Individual	12	5.83	1.53
(1 = Very low, 9 = Very high)	Collaborative	12	4.50	1.89
6. Quality of Collaboration	Individual	-	-	-
(1 = Low, 7 = High)	Collaborative	12	5.57	1.03
7. Circumstances	Individual	12	5.75	1.36
(1 = Not Good, 7 = Good)	Collaborative	12	6.17	0.58

Overall, the individual condition demonstrated an average score in prior knowledge (M = 10.92), above-average scores in conceptual knowledge (M = 6.33), intrinsic motivation (M = 4.58), and a relatively high cognitive load (M = 5.83). However, the individual condition scored below average in transfer (M = 3.04). The collaborative condition, on the other hand, exhibited slightly higher than average in prior knowledge (M = 11.50), average scores in transfer (*M* = 3.54) and cognitive load (*M* = 4.50), and consistently above-average scores in conceptual knowledge (*M* = 7.00), quality of collaboration (*M* = 5.57), and intrinsic motivation (*M* = 5.56). Both conditions showed very small differences in the average score of circumstances (*M* = 5.75 and *M* = 6.17), suggesting that both conditions experienced similar favourable circumstances while preparing their presentations.

Before conducting the main analyses, two independent samples *t*-test were conducted to check for prior knowledge and circumstances. Results indicated no significant difference in prior knowledge, $t(22) = -0.66$, $p = .518$, with a small negative effect size ($d = -0.27$, 95% *CI* [-1.07, 0.54]). Similarly, no significant difference was found in the circumstances, $t(22) = -0.98$, $p = .338$, with a small to medium negative effect size ($d = -0.40$, 95% *CI* [-1.20, 0.41]). These findings suggest that both conditions had comparable levels of prior knowledge and were subjected to similar external conditions, thereby supporting the comparability of the two groups.

Main Findings

The hypotheses were tested subsequently by conducting independent samples *t*-tests (see Table 3) and a correlation analysis. The first hypothesis posited that the collaborative condition would yield higher scores in conceptual knowledge compared to the individual condition. Descriptive statistics showed a mean score of 6.33 for the individual condition and 7.00 for the collaborative condition. This indicated a small potential advantage in conceptual knowledge for the collaborative condition. However, an independent samples *t*-test revealed no significant differences between the two conditions, $t(22) = 1.38$, $p = .181$. Despite the lack of statistical significance, a medium effect size of $d = 0.57$ was noted with a 95% confidence interval between -0.33 and 1.67, indicating a moderate difference in favour of the collaborative condition. However, the confidence interval included zero, which implied that the true effect might be negligible or even non-existent. Given these findings, the first hypothesis was not supported.

The second hypothesis stated that the collaborative condition would achieve higher scores in transfer compared to the individual condition. The descriptive statistics showed a slightly higher transfer score for the collaborative condition (*M* = 3.54) compared to the individual condition (*M* = 3.04).

Table 3

Main Findings

Hypothesis	***t***	***df***	***p***	**Cohen's *d***	**95% *CI* for *d***		**Result of Hypothesis test**
					Lower	**Upper**	
H1: Conceptual Knowledge: Collaborative > Individual	1.38	22	.181	0.57	-0.33	1.67	Rejected
H2: Transfer: Collaborative > Individual	0.93	22	.364	0.38	-0.62	1.62	Rejected
H3: Intrinsic Motivation: Collaborative > Individual	2.47	22	.022	1.01	0.16	1.83	Accepted
H4: Cognitive load: Individual > Collaborative	1.91	22	.070	0.78	-0.12	2.79	Rejected

This indicated a potential small advantage in transfer scores for the collaborative group. Nonetheless, the independent samples *t*-test yielded no significant differences between the two conditions $t(22) = 0.93$, $p = .364$. While the results were not statistically significant, it's worth noting a small to medium effect size of $d = 0.38$ was observed, with a 95% confidence interval ranging from -0.62 to 1.62. However, the confidence interval included zero, which implies that the true effect might be negligible or even non-existent. Given these findings, the second hypothesis was not supported.

The study's third hypothesis proposed that participants in the collaborative condition would exhibit higher intrinsic motivation than those in the individual condition. Descriptive statistics revealed a mean intrinsic motivation score of $M = 4.58$ for the individual condition and $M = 5.56$ for the collaborative condition. This indicated a potential advantage in motivation for the collaborative group. An independent samples *t*-test found a statistically significant difference between the two conditions, $t(22) = 2.47$, $p = .022$ with a large effect size of $d = 1.01$ combined with a 95% confidence interval ranging from 0.16 to 1.80. This effect size suggested a substantial difference in favour of the collaborative condition. The confidence interval was entirely in the positive range, which implies a the true effect. Given these findings, the third hypothesis was supported.

The fourth hypothesis posited that participants in the individual condition would experience a higher cognitive load compared to the collaborative condition. Descriptive statistics revealed a mean cognitive load score of 5.83 for the individual condition and $M = 4.50$ for the collaborative condition. This indicated a potential higher cognitive load for the individual group, in line with the hypothesis. The conducted independent samples *t*-test however, yielded a result that approached significance but was not statistically significant $t(22) = 1.91$, $p = .070$ with a medium to large effect size of $d = 0.78$ with a 95% confidence interval ranging from -0.12 to 2.79. This effect size suggested a potential difference in cognitive load between the conditions. However, the confidence interval included zero, which implied uncertainty about the true effect. Given these findings, the hypothesis was not supported due the lack of statistical significance.

The fifth hypothesis predicted a positive relationship between the quality of collaboration and learning outcomes for participants in the collaborative condition. To test this hypothesis, a Pearson correlation analysis was conducted, focusing first on the relation of collaboration and the conceptual knowledge total score, resulting in a medium, though non-significant, positive correlation, $r(10) = 0.37$, $p = .240$. Subsequently, the analysis for the correlation between collaboration and the transfer score was conducted, revealing a small, non-significant positive correlation, $r(10) = 0.18$, $p = .576$. Given the variations between the conceptual knowledge and transfer scores, a control correlation analysis was performed using the combined total scores of both variables to derive a comprehensive 'learning score'. This analysis yielded similar non-significant results, $r(10) = 0.35$, $p = .266$, with a medium positive correlation between the quality of collaboration and the combined learning score. Given these findings, the fifth hypothesis was not supported.

Discussion

Interpretation of Main Findings

This study sought to replicate and extend Kobayashi's (2021) research on the effects of collaborative versus individual preparation in learning by teaching. Kobayashi's research highlighted that collaborative preparation enhanced learning, motivation, and reduced cognitive effort. The current study builds on these findings in three ways: (1) by conducting the research within a classroom setting, (2) by measuring the immediate effects of preparation for learning by teaching after the preparation phase, and (3) by assessing the quality of collaboration. It was hypothesized that participants in the collaborative condition would demonstrate enhanced learning (hypotheses 1 and 2) and higher intrinsic motivation (hypothesis 3), while experiencing a lower cognitive load (hypothesis 4). Additionally, it was posited that a higher perceived quality of collaboration would correlate positively with learning outcomes (hypothesis 5).

Given the small sample size ($N = 24$) resulting in low statistical power ($d = 0.26$), interpretations of the findings of this study should be approached with caution. The limited sample size heightens the risk of type I and type II errors, potentially impacting the study's reliability as noted by Cohen (1992). The following section will explore potential interpretations of the results, considering both effect sizes and descriptive statistics for a broader understanding. However, it is essential to note that these interpretations are tentative and future research with larger samples is necessary for more definitive conclusions.

Conceptual Knowledge and Transfer

In line with Kobayashi's (2021) findings, this study did not observe statistically significant differences in conceptual and transfer knowledge scores between collaborative and individual conditions. However, an in-depth analysis reveals a modest edge in mean scores for participants in the collaborative condition. This trend mirrors the slight advantage reported in Kobayashi's original study. The effect sizes however, present a notable contrast: this study reported a medium effect size ($d = 0.57$), in contrast to Kobayashi's negligible effect ($d = -0.07$). A possible explanation for this difference in effect size could be moment of measurement: the current study only focused on measuring the effect of the preparation phase, while Kobayashi's study measured the effect of both the presentation and teaching phase. Kobayashi suggested that providing instructional explanations during the teaching phase might not have been beneficial for learning. In contrast, the effect size in this study supports the notion that collaborative preparation positively impacts learning, consistent with prior research on learning by teaching (Kobayashi, 2019). Nevertheless, the lack of statistical significance necessitates a cautious interpretation.

Regarding transfer, both studies report minor difference in mean scores. However, a closer examination of the effect sizes showed a small to medium effect, favouring the collaborative condition in the current study, whereas Kobayashi (2021) noted a medium effect. The original study's larger effect sizes might be explained by the generative and elaborative learning processes activated during the subsequent teaching phase. However, the small positive effect on transfer that collaborative preparation seems to have compared to individual preparation when only the preparation phase is measured, can be considered as a cautious contribution to the findings of the original study (Kobayashi, 2021). This suggests that collaborative preparation could have a beneficial, albeit limited, impact on transfer knowledge, highlighting the need for further investigation in this area.

Intrinsic Motivation and Cognitive Load

Intrinsic motivation and cognitive load are key factors influencing collaborative learning and teaching (Kirschner et al., 2008; Loes, 2022; Lowyck & Pöysä, 2001). This study found significantly higher intrinsic motivation in the collaborative condition compared to the individual condition, aligning with the findings of the original study (Kobayashi, 2021). In addition, both studies reported similar large effect sizes, with $d = 1.01$ for this study and $\eta_p^2 = .190$ for Kobayashi's (2021) study (Cohen, 1992). A possible explanation for these comparable findings could be the increased sense of social interdependence among participants, since they were explicitly instructed to collaborate during the preparation phase (Loes, 2022). Increased self-efficacy from perceived peer support might have also contributed to greater enjoyment of the learning task (Laal & Ghodsi, 2012; Lowyck & Pöysä, 2001), suggesting that collaborative learning environments might offer more engaging experiences. However, future research should explore the dynamics of collaborative learning in more practical contexts more profoundly.

Regarding cognitive load, according to the Collaborative Cognitive Load theory of Kirschner and colleagues (2008; 2018), collaboration when performing a complex task is more effective compared to individual learning. The results of this study, while not significant ($p = .070$), showed lower perceived cognitive load in the collaborative condition compared to the individual condition. This contrasts with Kobayashi's original study, which showed slightly higher scores for the collaborative condition. These differences are further emphasized by the effect sizes, with a medium to large effect of *d* = 0.78 for this study, compared to a small effect in Kobayashi's study (η_p^2 = .040) (Cohen, 1992). A possible explanation could be the perceived task complexity. Kirschner and colleagues (2011) found that perceived complexity was a precondition for more effective learning when collaborating, thus leading to the perception of a lower cognitive load while collaborating compared to individuals. By comparing the relative mean scores (total mean score of all participants divided by maximum mean score), the participants of this study scored lower on conceptual knowledge and transfer (74% and 47%) compared to the original study (79% and 59%), which could indicate that the task was perceived by the participants of this study as more complex. This could have influenced participants' cognitive load, potentially making collaborative efforts more effective in managing this load.

Additionally, factors as circumstances and prior knowledge could have influenced the perceived cognitive load (Bittermann et al., 2023; Ormrod, 2019). The current study tried to control for this factor by incorporating the circumstances survey ("Were conditions calm enough to concentrate well on preparing the presentation?), however, the results showed no statistical significance, difference in numerical score, nor effect size. Comparable with Kobayashi's original study, the results of the prior knowledge measurements also showed no significant effects either. Given these observations, future research should delve deeper into these aspects, particularly the role of task complexity and participant background, to better understand cognitive load dynamics in collaborative settings.

Quality of Collaboration and Learning Outcomes

This study found no correlation between the quality of collaboration and learning outcomes of conceptual knowledge and transfer. This finding contrasts with several studies on collaborative learning, such as those by Chi and Wylie (2014), Roschelle (1992), and Roscoe and Chi (2007), which suggest that qualitative interaction during collaboration should enhance generative learning processes. A potential reason for this discrepancy could be the method used to measure collaboration quality. Although the study employed a validated Teamwork Skill Scale (TSS) survey (De La Guardia et al., 2022; Lower et al., 2017), focusing on interaction quality, it might not have captured crucial aspects of interaction like discussion and collaborative problem-solving, which are vital for activating generative learning (Chi and Wylie, 2014; Razmerita & Kirchner, 2014).

Additionally, the lack of correlation might be influenced by the participants' demographics. Since all participants came from a military background, they likely had substantial experience in collaboration, a common aspect of military work. This experience might have contributed to the uniformly high collaboration scores. Furthermore, as all participants were colleagues at the same school, potentially having prior collaborative experiences, it could have further influenced these high scores.

In summary, while this study did not establish a significant correlation between collaboration quality and learning outcomes, it builds upon Kobayashi's (2021) research. It underscores the importance of more nuanced measures of collaboration quality and suggests that factors like participant demographics and prior collaboration experience could significantly influence learning outcomes in collaborative preparation for teaching.

Limitations and Practical Implications

While this study offers valuable insights into collaborative versus individual preparation in learning by teaching, it has notable limitations. The most significant is the small sample size, necessitating future research with larger participant groups. Additionally, the demographic composition of the sample, predominantly male participants (95.80%) from the Dutch Army Artillery school, poses a limitation. This homogenous group, including a broad range of educational levels and a high mean age with significant dispersion (M = 41.30, SD = 9.90), might have impacted the results and perceptions of collaboration quality. Future studies should intentionally include a more gender-diverse and demographically varied group to enhance generalizability.

Another limitation concerns the learning materials and instruments used. Originally designed for middle school students (Shangguan, 2020), these tools might not have aligned perfectly with the educational level of this study's participants. Nevertheless, the relatively low mean scores of conceptual knowledge and transfer suggested that the learning material was appropriately challenging. The study’s reliance on a specific survey to measure collaboration quality requires refinement for more accurate future measurements. Incorporating qualitative data collection methods like observations and open-ended questions could provide a deeper understanding of collaboration dynamics (Dobrovolny & Fuentes, 2008). The study's setting, a more "naturalistic" environment as suggested by Kobayashi (2021), introduced unique variables that could influence outcomes. This study attempted to control these through a circumstances survey, which showed no significant differences between groups, enhancing result reliability. However, the study’s focus on pairs rather than larger groups, as recommended by Gillies (2016), might not have been ideal. Future research with groups of three to five students could yield more favourable results for collaborative learning.

In terms of practical implications, this study suggests that collaborative preparation in educational settings can positively influence student motivation and potentially reduce cognitive load without negatively impacting learning outcomes. These findings support the integration of collaborative methods in teaching practices, particularly in settings similar to those of this study. However, due to the study's limitations, including the unique military context and potential bias in self-reporting methods, these conclusions should be viewed as preliminary. Further research is necessary to confirm these findings in broader and more diverse settings, exploring the role of task complexity and participant background in collaborative learning.

Conclusion

In conclusion, this study aimed to contribute to the research on learning by teaching, particularly by examining the effects of collaborative versus individual preparation. Previous studies have highlighted a connection between motivation, collaboration, and learning outcomes in learning by teaching contexts. However, little research has been conducted on the effects of collaborative preparation compared to individual preparation. This study aimed to replicate and extend the findings of Kobayashi (2021) in a more practical context. However, the results need to be interpreted carefully due the small sample size.

The results suggest an increase in motivation when students prepare collaboratively for teaching in a classroom setting, a finding that aligns with Kobayashi’s (2021) study. Additionally, this study observed a trend towards reduced cognitive load in collaborative settings, with a medium to large effect size, although this was not statistically significant. Consistent with Kobayashi's (2021) findings, non-significant learning outcomes in conceptual knowledge and transfer were found, showing a minor differences favouring collaborative preparation. Additionally, this study found no significant correlation between the quality of collaboration and learning outcomes. Possible explanations for these non-significant results include the small sample size, the homogeneous nature of the sample in terms of gender, the size of the groups involved, the measurement of quality of collaboration and perceived task complexity. Despite these limitations, practical implications of this study suggest that instructors, when given the choice, should encourage students to prepare for learning by teaching in groups of two or more. This approach could enhance motivation, and potentially, indirectly reduce cognitive load and learning outcomes compared to individual preparation.

These findings underscore the potential of collaborative preparation in learning by teaching contexts, particularly in enhancing motivation and possibly reducing cognitive load. Future research should address these aspects with larger and more diverse samples, improved collaboration quality measures, and a broader range of educational settings. Such research would help confirm these findings and further clarify the role of collaborative preparation in enhancing the teaching and learning process.

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Appendices

Appendix A: Invitation For Participants

Beste collega,

We nodigen u uit om deel te nemen aan een afstudeeronderzoek genaamd "Leren door Presenteren: Optimaliseren van Leeruitkomsten en Motivatie". Dit onderzoek is gericht op het begrijpen hoe we leren wanneer we ons voorbereiden op het presenteren van informatie. Eerder onderzoek laat zien dat dit een effectieve werkvorm is, maar het is nog niet duidelijk onder welke omstandigheden dit het meest effectief is. Het onderzoek vindt plaats tussen 26 juni en 21 juli op de Vuursteunschool.

Deelnemen biedt een mooie gelegenheid om nieuwe kennis en inzichten te verkrijgen in een relevant wetenschappelijk onderzoek. Daarnaast kan dit onderzoek mogelijk nieuwe, bruikbare inzichten opleveren die door u tijdens de lessen kunnen worden toegepast.

Wat houdt het onderzoek in? Tijdens het onderzoek wordt van u verwacht dat u een tekst doorneemt en op basis van deze informatie een korte presentatie voorbereidt. Hierna wordt u gevraagd de presentatie te geven en de presentaties van anderen te beoordelen. Tussendoor zijn er korte vragenlijsten om in te vullen die bijvoorbeeld uw voorkennis over het onderwerp testen of uw mening vragen over het voorbereiden van de presentatie. De totale tijdsbesteding voor deelname aan dit onderzoek is maximaal 60 minuten.

Bij dit onderzoek respecteren we uw privacy volledig. Alle gegevens die tijdens het onderzoek worden verzameld, worden veilig en volgens de huidige wetgeving opgeslagen. Tijdens het onderzoek worden er geen audiovisuele opnames gemaakt en alle verzamelde informatie wordt anoniem gerapporteerd zodat de resultaten niet herleidbaar zijn naar u als deelnemer.

Mocht u tijdens of na het onderzoek niet meer willen deelnemen, dan hoeft u dit alleen maar aan de onderzoeker te melden. Tot 3 maanden na het onderzoek kunt u besluiten om uw deelname te beëindigen en worden uw resultaten en gegevens aansluitend vernietigd.

Op de volgende bladzijde vindt u aanvullende informatie en contactgegevens voor als u verdere vragen heeft over dit onderzoek.

Deelname aan dit onderzoek is geheel vrijwillig. U kunt op elk gewenst moment besluiten om te stoppen zonder dat dit gevolgen voor u heeft. Als u vragen heeft, stuur dan een e-mail naar ….

Dank u voor uw tijd en overweging.

Met vriendelijke groet,

Bert van der Meer

Contactadres voor aanvullende vragen en/of klachten
Algemene vragen of opmerkingen over het onderzoek kunt u richten aan [redacted] of [redacted]

Indien u contact wilt opnemen met een onafhankelijk onderzoeker over dit onderzoek dan kunt u een mail sturen naar [redacted].

Als u een officiële klacht heeft over het onderzoek, dan kunt u een mail sturen naar de klachtenfunctionaris via [redacted]
Als u vragen heeft over de verwerking van uw persoonsgegevens kunt u deze richten aan [redacted]. Graag verwijs ik u naar de algemene privacyverklaring van de UU: Privacyverklaring Universiteit Utrecht - Organisatie - Universiteit Utrecht (uu.nl).

Universiteit Utrecht

Appendix B: Informed Consent Form

Algemene informatie:

Datum: ____

Naam: ____

Leeftijd: ____

Geslacht: ____

Hoogst genoten opleiding: _________________________________

Toestemmingsverklaring

Hierbij verklaar ik de informatiebrief m.b.t. onderzoek "Leren Door Presenteren: Optimaliseren van Leeruitkomsten en Motivatie" gelezen te hebben en akkoord te gaan met deelname aan het onderzoek.

Dit betekent dat ik instem met:

1) Deelname aan het onderzoek

2) Verzamelen van mijn gegevens

3) Verwerken en gebruiken van mijn geanonimiseerde data

Handtekening

____

Verder Onderzoek

Het kan zijn dat er op basis van dit onderzoek in de toekomst verder onderzoek wordt gedaan naar dit onderwerp. De anonieme data uit dit onderzoek kunnen dan worden gebruikt in vervolgonderzoek.

A) Ik geef toestemming dat mijn gegevens worden gebruikt voor dit onderzoek en eventueel onderzoek dat qua opzet en doeleinde in lijn ligt met dit onderzoek. Mijn gegevens worden veilig en anoniem opgeslagen en ik ben als deelnemer op geen enkele manier herleidbaar naar aanleiding van de resultaten.

   Ja / Nee[1]

B) Ik ga ermee akkoord dat de voor het onderzoek verzamelde onderzoeksgegevens mogen worden gepubliceerd of beschikbaar gesteld, mits mijn naam of andere identificerende informatie niet wordt gebruikt.

   Ja / Nee

C) Ik begrijp dat de onderzoeksgegevens, zonder enige persoonlijke informatie die mij zou kunnen identificeren (niet aan mij gekoppeld), met anderen mogen worden gedeeld.

   Ja / Nee

[1] Streep door wat NIET van toepassing is

Appendix C: Research Products

Learning text

Bliksem kan worden gedefinieerd als de ontlading van elektriciteit die voortvloeit uit het verschil in elektrische lading tussen de wolk en de grond.

Wanneer het aardoppervlak warm is, wordt vochtige lucht dicht bij het aardoppervlak verwarmd en stijgt deze snel op. Hierdoor ontstaat er een opwaartse luchtstroom tot hoog in de lucht. Naarmate de lucht in deze opwaartse stromingen afkoelt, condenseert waterdamp tot waterdruppels en vormt een wolk. De top van de wolk strekt zich uit tot boven het vriespunt, waardoor kleine ijskristallen ontstaan.

Na verloop van tijd groeien de waterdruppels en ijskristallen in de wolk door de aanvoer van koude lucht. Hierdoor worden ze te zwaar om door de luchtstroom in de bovenste delen van de wolk te blijven zweven. Ze vallen dan naar het onderste deel van de wolk, waarbij ze lucht vanuit de wolk naar beneden trekken. Dit veroorzaakt een neerwaartse luchtstroom die uiteindelijk het aardoppervlak bereikt. Wanneer deze koude neerwaartse luchtstromen de grond raken, verspreiden ze zich in alle richtingen en veroorzaken ze vlagen van koele wind. Dit wordt vaak gevoeld vlak voordat de regen begint.

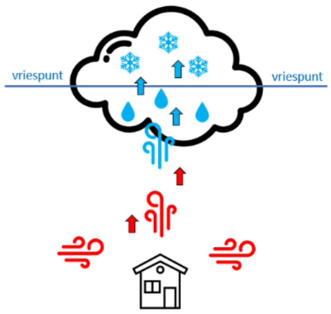
Binnen de wolk ontstaan elektrische ladingen door de bewegende luchtstromingen, hoewel wetenschappers nog niet volledig begrijpen hoe dit proces precies plaatsvindt. De meeste wetenschappers geloven dat de lading wordt veroorzaakt door de botsing tussen lichte, opstijgende waterdruppels en kleine ijsdeeltjes in de wolk met hagel en andere zwaardere, vallende deeltjes. De negatief geladen deeltjes dalen naar de bodem van de wolk, terwijl de meeste positief geladen deeltjes naar de top stijgen.

De stapsgewijze ontlading, ook bekend als trage ontlading, is het eerste stadium van een wolk-naar-grond bliksemflits. Hierbij beweegt de bliksemflits in een zigzaggend patroon naar beneden in een reeks stappen. Wetenschappers geloven dat dit proces wordt geactiveerd door een vonk tussen de gebieden met positieve en negatieve ladingen binnen de wolk. Elke stap van de stapsgewijze ontlading duurt ongeveer 1 miljoenste van een seconde, met een korte pauze van ongeveer 50 miljoenste van een seconde tussen elke stap. Terwijl de stapsgewijze ontlading de grond nadert, stijgen vanuit de grond opwaarts bewegende ontladingen op van objecten zoals bomen en gebouwen om de negatieve ladingen te ontmoeten. Meestal is de opwaarts bewegende ontlading van het hoogste object de eerste die de stapsgewijze negatieve ontlading ontmoet en een pad voltooit tussen de wolk en de aarde. De twee ladingen ontmoeten elkaar ongeveer 50 meter boven de grond. Negatief geladen deeltjes snellen dan als eerste van de wolk naar de grond langs het pad dat door de ontladingen is gecreëerd. Deze ontlading langs het pad van de stapsgewijze ontlading wordt de bliksemflits.

Naarmate de stapsgewijze ontlading de grond nadert, wekt het een tegengestelde lading op in de grond, waardoor positief geladen deeltjes van de grond snel omhoog stromen langs hetzelfde pad. Deze opwaartse beweging van de stroom wordt de retourslag genoemd en bereikt de wolk in ongeveer 70 microseconden. De retourslag produceert het heldere licht dat mensen opmerken bij een flits van bliksem. Door de snelheid van dit proces kan deze opwaartse beweging niet worden waargenomen. Tijdens de retourslag worden er miljoenen volts aan energie geproduceerd waardoor er veel hitte vrijkomt hitte. De lucht langs het bliksemkanaal wordt hierdoor in een korte tijd tot een zeer hoge temperatuur verhit. Zo'n intense verhitting veroorzaakt een explosieve uitbreiding van de lucht, wat een geluidsgolf produceert die we donder noemen.

Bijgevoegde Afbeeldingen met Tekst (96 woorden)

Figuur 1: Ontstaan van bliksem door de ontlading van elektriciteit die voortvloeit uit het verschil in elektrische lading tussen de wolk en de grond.

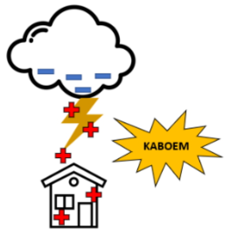


Figuur 2: Warme vochtige lucht stijgt snel op, waardoor er een opwaartse luchtstroom ontstaat die condenseert in de wolk.

Figuur 3: De vorming van veel waterdruppels en ijskristallen zorgen voor een neerwaartse luchtdruk met een koele wind tot gevolg.

Figuur 4: Ontstaan positieve ladingen bovenin de wolk, en onderin de negatieve ladingen.

Figuur 5: De getrapte ladingen ontmoeten elkaar vlak boven de grond.



Figuur 6: De retourslag produceert een helder licht (bliksem) en het kort verhitten van de lucht veroorzaakt een harde geluidsgolf (donder).

Prior Knowledge Test

Hier zijn enkele vragen over de vorming van bliksem. Geef aan wat je kennis is op deze onderwerpen.

	Ik begrijp niets van dit onderwerp	Ik begrijp dit onderwerp een klein beetje	Ik begrijp dit onderwerp goed	Ik begrijp dit onderwerp volledig
	1	2	3	4
1. Ik weet hoe wolken zich vormen	O	O	O	O
2. Ik kan uitleggen hoe lading en stroom bewegen	O	O	O	O
3. Ik weet wat verdamping, condensatie, en stolling is	O	O	O	O
4. Ik weet hoe bliksem ontstaat	O	O	O	O

Meerkeuzevragen Voorkennis

1. Hoe ontstaat een wolk?

   A. Luchtstroom stijgt　　B. Temperatuur daalt

   C. Waterdamp condenseert tot waterdruppels　　D. Weet ik niet

   Het juiste antwoord is C. 1 punt.

2. Hoe vormen kleine ijskristallen boven in een wolk?

   A. Temperatuur is hoger dan het vriespunt　　B. Temperatuur is lager dan het vriespunt

   C. Temperatuur is gelijk aan het vriespunt　　D. Weet ik niet

   Het juiste antwoord is B. 1 punt.

3. Vul deze zin aan: *Wanneer regendruppels en ijskristallen uit de wolken vallen, wordt (...) luchtstroom gegenereerd.*

   A. Neerwaartse　　B. Opwaartse

   C. Geen　　D. Weet ik niet

   Het juiste antwoord is A. 1 punt.

4. Vul deze zin aan: *Nadat de ijskristallen in de wolk zijn gevormd, vallen deze (...) geladen deeltjes naar de bodem van de wolk.*

   A. Positief　　B. Negatief

   C. Positieve en negatief　　D. Weet ik niet

   Het juiste antwoord is B. 1 punt.

5. Hoe ontstaat bliksem?

   A. Positieve lading beweegt naar boven

   B. Negatieve lading beweegt naar beneden

   C. Positieve en negatieve lading komen elkaar tegen

   D. Weet ik niet

   Het juiste antwoord is C. 1 punt.

Conceptual Knowledge Test

Kennisvragen

1. Hoe wordt bliksem gevormd?
    A. Positieve lading beweegt naar boven
    B. Negatieve lading beweegt naar beneden
    C. Positieve en negatieve lading ontmoeten elkaar
    D. Weet niet

    Het juiste antwoord: C. 1 punt.

2. Welk antwoord geeft een juiste verklaring voor het ontstaan van wolken?
    A. Wanneer vochtige koude lucht nabij een wolk heet wordt, verandert het in waterdamp en stijgt het op
    B. De opstijgende waterdamp wordt waterdruppels in de lucht als het afkoelt
    C. Wanneer de hete lucht in de lucht de grond nadert, vormen er waterdruppels wanneer het afkoelt
    D. Geen van bovenstaande is waar

    Het juiste antwoord: B. **1 punt.**

3. Welk antwoord geeft een juiste verklaring voor de vorming van ijskristallen in een wolk?
    A. De temperatuur aan de onderkant van de wolk moet lager zijn dan de temperatuur aan de top van de wolk
    B. De hoogte van de top van de wolk moet het ijsoppervlak overschrijden
    C. Temperatuur is hoger dan het vriespunt
    D. Geen van bovenstaande is waar

    Het juiste antwoord: B. **1 punt.**

4. Welk antwoord over het begin van de bliksem is waar?
    A. De vochtige en koude lucht die van de grond opstijgt, wrijft tegen de deeltjes in de wolk
    B. De opwaarts bewegende warme lucht in een wolk wrijft tegen de deeltjes in de wolk
    C. IJskristallen in de wolk bewegen naar boven en wrijven tegen deeltjes in de wolk
    D. De positieve en negatief geladen deeltjes in de wolk zorgen voor een vonk

Het juiste antwoord: D. **1 punt.**

5. <u>Welk antwoord over de positieve en negatief geladen deeltjes in de wolk is waar?</u>
   A. Positieve lading beweegt naar de onderkant van de wolk, negatieve lading beweegt naar de top van de wolk
   B. Positieve lading beweegt naar de top van de wolk, negatieve lading beweegt naar de onderkant van de wolk
   C. Zowel positieve als negatieve ladingen bewegen naar de top van de wolk
   D. Zowel positieve als negatieve ladingen bewegen naar de onderkant van de wolk

Het juiste antwoord: B**. 1 punt.**

6. <u>Vul deze zin aan: *Nadat de stapsgewijze ontladingen elkaar ontmoeten, beweegt de stapsgewijze ontlading met (...) lading als eerste naar beneden.*</u>
   A. Positieve
   B. Negatieve
   C. Zowel positieve als negatieve
   D. Geen van bovenstaande is waar

Het juiste antwoord: B. **1 punt.**

7. <u>Welke uitspraak over de stapsgewijze ontladingen is waar?</u>
   A. De positieve lading aan de onderkant van de wolk beweegt naar de grond en ontmoet de negatieve lading in de lucht
   B. Als de lading aan de onderkant van de wolk naar de grond beweegt, geeft het een licht af dat bekend staat als retourslag
   C. De negatieve lading aan de onderkant van de wolk beweegt naar de grond en ontmoet de positieve lading in de lucht
   D. Geen van bovenstaande is waar

Het juiste antwoord: C. 1 punt.

8. <u>Welke uitspraak over de retourslag is niet waar?</u>
   A. De negatieve lading op de grond wordt aangetrokken en beweegt omhoog
   B. De retourslag beweegt omhoog vanaf de grond
   C. De retourslag heeft meestal een spanning van enkele miljoenen volt
   D. De positieve lading op de grond wordt aangetrokken en beweegt omhoog

Het juiste antwoord: A. 1 punt.

9. <u>Welke uitspraak over de vorming van bliksem is niet waar?</u>
    A. De lucht krijgt door de retourslag een hoge temperatuur. De hete lucht zet hierdoor explosief uit, waardoor er donder ontstaat
    B. De negatieve lading aan de onderkant van de wolk vormt een sterk elektrisch veld met de positieve lading op de grond
    C. In de top van de wolk is de temperatuur boven het vriespunt waardoor de ijskristallen onder in de wolk blijven
    D. De negatieve lading aan de onderkant van de wolk beweegt naar de grond onder de druk van een sterk elektrisch veld

Het juiste antwoord: C. 1 punt.

Knowledge Transfer Test.

Transfer Vragen

1. Kun je uitleggen waarom je soms wolken in de lucht ziet, maar geen bliksem waarneemt, door de principes van bliksemvorming toe te passen die je zojuist hebt geleerd?

o Correcte vermelding dat onweerswolken met sterke opwaartse en neerwaartse luchtstromen nodig zijn voor het ontstaan van bliksem, hier is warme lucht voor nodig (2 punten)

Beperkte uitleg:

o Als de wolk niet boven het vriespunt komt ontstaat er geen bliksem. (1 punt)

o Er is beweging in de wolk nodig tussen de geladen deeltjes, indien dit door bovenstaande zaken niet voorkomt is er geen bliksem. (1 punt)

Maximaal 2 punten

2. Leg uit wat de invloed is van de temperatuur binnen in het ontstaan van bliksem?

o Correcte vermelding dat de luchttemperatuur aan de top van de onweerswolk onder het vriespunt is (1 punt)

o Correcte uitleg dat vervolgens de ontstane ijskristallen en waterdruppels botsen en elektrische ladingen opbouwen waardoor bliksem ontstaat (1 punt)

Beperkte uitleg:

o Uitleg dat door temperatuurverschillen in de wolk de verschillende geladen deeltjes met elkaar botsen en hierdoor kunnen zorgen voor een vonk waardoor bliksem ontstaat (1 punt)

Maximaal 2 punten

3. Je wordt gevraagd om advies hoe de impact van bliksem kan worden geminimaliseerd voor personen en gebouwen. Noem drie (bekende) maatregelen die je kan treffen om de schade van bliksem te minimaliseren. Licht de werking van deze maatregelen kort toe.

   Benoemen valide maatregel = 0,5 punt (max 3)

Benoemen bijbehorende uitleg = 0,5punt (max 3)

Voorbeelden:

o bliksemafleiders/ bliksemdetectiesystemen (0.5 punt)

Correcte uitleg dat bliksemafleiders de elektrische lading van bliksem naar de grond geleiden (0.5 punt)

o Gebruik isolatie (rubber) voor tegengaan geleiding (0,5punt)

o Kooi van Faray (schuilen in een auto) (0,5pnt)

o Correcte uitleg dat bliksemdetectiesystemen/ weersvoorspelling / koude wind kunnen helpen bij het voorspellen van bliksem (0.5 punt)

uitleg dat je dan op tijd kan gaan schuilen (0,5punt)

o Correcte vermelding dat je niet het hoogste punt in de omgeving moet zijn of moet opzoeken om te schuilen (0.5 punt)

o Uitleg dat het hoogste punt een grote kans heeft om de connectie te zijn tussen de positieve en negatief geladen deeltjes en dus door de bliksem kan worden getroffen (0.5 punt)

Maximaal 3 punten

Intrinsic Motivation Test

Intrinsieke Motivatietest

Beoordeel de volgende uitspraken op basis van uw ervaring tijdens de voorbereiding van de presentatie. Gebruik een schaal van 1 (Helemaal niet mee eens) tot 7 (helemaal mee eens).

	V olledig niet mee eens			**N eutraal**			**V olledig mee eens**
	1	**2**	**3**	**4**	**5**	**6**	**7**
1. Tijdens de voorbereiding van de presentatie merkte ik dat ik er plezier in had.	O	O	O	O	O	O	O

2. Het onderwerp van de presentatie hield mijn aandacht helemaal niet vast (R).	O	O	O	O	O	O	O
3. Ik zou het onderwerp van de presentatie als "zeer interessant" omschrijven.	O	O	O	O	O	O	O
4. Ik vond het erg leuk om de presentatie voor te bereiden.	O	O	O	O	O	O	O

Cognitive Load and Concentration Questionnaire

Please choose the category (1, 2, 3, 4, 5, 6, 7, 8, or 9) that applies to you:

9-point Likert Scale (1 = very, very low mental effort; 2 = very low mental effort; 3 = low mental effort; 4 = rather low mental effort; 5 = neither low nor high mental effort; 6 = rather high mental effort; 7 = high mental effort/ 8 = very high mental effort; 9 = very, very high mental effort This questionnaire was translated to Dutch and tailored to the learning task (preparing to teach).

Percieved Cognitieve Load Survey

Beoordeel de volgende uitspraken op basis van uw ervaring tijdens de voorbereidingsfase van het lesgeven.

	Zeer, zeer weinig moeite				Niet weinig en niet veel moeite				Zeer, zeer veel moeite
	1	2	3	4	5	6	7	8	9
Moeite	O	O	O	O	O	O	O	O	O

Circumstances

Beantwoord de volgende vraag met een schaal van 1 (volledig mee oneens) tot 7 (volledig mee eens).

	Volledig niet mee eens			**Neutraal**			**Volledig mee eens**
	1	**2**	**3**	**4**	**5**	**6**	**7**
Waren de omstandigheden rustig genoeg om je goed te kunnen concentreren op het voorbereiden van de presentatie?	O	O	O	O	O	O	O

Collaboration Test

Beoordeel de volgende stellingen op een schaal van 1 (helemaal niet mee eens) tot 7 (helemaal mee eens) op basis van uw ervaring tijdens het gezamenlijk voorbereiden van de presentatie.

	Helemaal niet mee eens			Neutraal			Helemaal mee eens
	1	2	3	4	5	6	7
Ik heb tijdens de voorbereiding van de presentatie mijn mening kunnen geven zonder gevoelens van mijn teamgenoot te kwetsen.	O	O	O	O	O	O	O
Ik heb tijdens de voorbereiding van de presentatie gevraagd naar de mening van mijn teamgenoot.	O	O	O	O	O	O	O
Ik heb tijdens de voorbereiding van de presentatie moeite gedaan om mijn teamgenoot te betrekken.	O	O	O	O	O	O	O
Ik waardeer de bijdrage van mijn teamgenoot in de voorbereiding van de presentatie.	O	O	O	O	O	O	O
Ik behandelde mijn teamgenoot als mijn gelijke tijdens het voorbereiden van de presentatie.	O	O	O	O	O	O	O
Ik communiceerde goed met mijn teamgenoot.	O	O	O	O	O	O	O

Task Instruction per Condition

Individuele conditie

Wie:

- Individueel

Wat:

- U bereidt zo een individuele presentatie voor die u straks gaat geven aan een aantal participanten.
- De presentatie mag niet langer zijn dan 5 minuten.
- Het is de bedoeling dat u de inhoud van de leertekst uitlegt aan de toehoorders waarbij de vraag wordt beantwoordt: hoe ontstaat bliksem?
- U mag hiervoor uw eigen aantekeningen gebruiken tijdens de presentatie. Verder heeft u tijdens de presentatie een (digitaal)whiteboard met stiften ter beschikking.

Waar:

- Voorbereiden hier in het lokaal aan uw bureau. De presentatie zal ook in dit lokaal worden gegeven.

Wanneer:

- U krijgt 15 minuten de tijd om de presentatie voor te bereiden. Wanneer 12 minuten zijn verstreken krijgt u elke minuut een tijdswaarschuwing.

Hoe:

- Bestudeer de leertekst zodat u de inhoud ervan zodanig begrijpt dat u er een presentatie over kan geven. U mag gebruik maken van een aantekeningenblad.
- De doelgroep van de presentatie is een publiek dat niets weet over het onderwerp.
- Doe de voorbereidingen individueel en in stilte.
- Nadat de 15 minuten voorbereidingstijd voorbij zijn wordt u gevraagd een aantal vragenlijsten in te vullen. Hierna vangen de presentaties aan. Wie begint met presenteren wordt dan pas bekend gesteld.
- U wordt gevraagd de presentaties van anderen te beoordelen op inhoud. Uw presentatie wordt ook beoordeeld op inhoud door de andere deelnemers.
- Indien u vragen heeft over de leertekst of over de procedure dan kunt u deze stellen aan de aanwezige begeleider.

Succes!

Collaboratieve conditie

Wie:

- In tweetallen

Wat:

- U bereidt zo in tweetallen een presentatie voor die u straks gaat geven aan een aantal participanten.
- De presentatie mag niet langer zijn dan 5 minuten.
- Het is de bedoeling dat u de inhoud van de leertekst uitlegt aan de toehoorders waarbij de vraag wordt beantwoordt: hoe ontstaat bliksem?
- U mag hiervoor uw eigen aantekeningen gebruiken tijdens de presentatie. Verder heeft u tijdens de presentatie een (digitaal)whiteboard met stiften ter beschikking.

Waar:

- Voorbereiden hier in het lokaal aan uw bureau. De presentatie zal ook in dit lokaal worden gegeven.

Wanneer:

- U krijgt 15 minuten de tijd om de presentatie voor te bereiden. Wanneer 12 minuten zijn verstreken krijgt u elke minuut een tijdswaarschuwing.

Hoe:

- Bestudeer de leertekst zodat u de inhoud ervan zodanig begrijpt dat u er een presentatie over kan geven. U mag gebruik maken van een aantekeningenblad.
- De doelgroep van de presentatie is een publiek dat niets weet over het onderwerp.
- Bereid samen de presentatie voor zodat jullie goed voorbereid de presentatie kunnen geven.
- Let op, de presentatie wordt niet samen gegeven, maar individueel!
- Nadat de 15 minuten voorbereidingstijd voorbij zijn wordt u gevraagd een aantal vragenlijsten in te vullen. Hierna vangen de presentaties aan. Wie begint met presenteren wordt dan pas bekend gesteld.
- U wordt gevraagd de presentaties van anderen te beoordelen op inhoud. Uw presentatie wordt ook beoordeeld op inhoud door de andere deelnemers.
- Indien u vragen heeft over de leertekst of over de procedure dan kunt u deze stellen aan de aanwezige begeleider.

Succes!