Immersive technology in the training of manual skills: A pilot study with commercial off-the-self devices in military training*

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Abstract

This pilot study investigated the maturity and functionality of virtual and augmented reality technologies in manual skills training. In the experiment, 32 reserve officer students participated in a heavy machine gun maintenance and handling lesson, the treatment group (n = 16) used virtual and augmented reality tools, and the control group (n=16) was instructed in traditional lesson with manual and PowerPoint presentation. After the lesson, everyone did a timed and scored maintenance disassembly with a real machine gun. The group that studied with VR and AR technologies performed better on the disassembly task and their own assessments of the accumulation of competence was more positive. In addition, the treatment (VR/AR) group felt that the teaching material supported learning better than in the group studying with more traditional methods. After the training, the VR/AR group also rated the training as more interesting than the other group. The results suggest that VR/AR technologies can be effectively used in training of manual skills even if the learners have no prior expertise in these technologies.

Keywords

virtual reality, augmented reality, military, training, education

1. Introduction

1.1. Virtual and augmented reality in training and education

Virtual reality technologies can be utilized in enhancing traditional class-room based education or in creating new types of learning settings in various fields of education, for review, see [1]. Virtual reality (VR) refers commonly to an environment where one is fully immersed and able to interact with, whereas in augmented reality (AR) real, physical, environment is augmented with computer graphic -generated virtual objects [2]. Both the VR and AR technologies have been used in training and education in various contexts with promising results. For example, in a review of previous studies the using of AR in training and performance was found to reduce time and errors of performing skilled tasks and produce more permanent learning compared to other alternatives [3]. Also, various other types of effects have been reported. It has been shown, for example, that when compared to traditional text-based and video material, the using of VR learning material may evoke higher engagement and increased positive and decreased negative emotions among the learners [4].

Learning objectives can be classified into six increasingly more cognitively complex categories: *Remember, Understand, Apply, Analyse, Evaluate*, and *Create*, according to the widely used Bloom's taxonomy [5]. In a revised version of the taxonomy, four categories for types of knowledge are added: *Factual, Conceptual, Procedural, and Metacognitive* [6]. In a recent review it was found that the pedagogical goals in previous studies on use of AR in education varied with the *Understand* and *Apply* as the most prominent targeted cognitive dimensions [7]. In addition to cognitive

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dimensions or skills, the VR has been successfully utilized in the training of various psychomotor skills [8]. In the current study we examine the using of VR/AR technologies in training of procedural manual skills.

The effects that VR/AR have been observed to have on learning may be due to the possibility to build realistic and vivid multimedia learning experiences that support in constructing more comprehensive mental models of the learned topic [9]. Immersive and interactive VR/AR learning environments are also suited for supporting learning by doing [10] and inquiry-based learning, where the students actively hypothesize and explore [11], thus evoking engagement of the students. However, VR/AR training effectiveness may be challenged by various human-factors and usability issues. For example, VR and AR sickness may severely affect the use experience of the learning environment [12, 13].

Although there is already vast amount of studies on using VR in the education and training of various skills, concerns on e.g. the lack of information on the used pedagogical delivery methods, limited number of study participants and assessment methods have been raised [14, 8]. Another concern is expressed as the notion of paucity of VR studies that would have measured transfer of training in addition to various subjective measures [15]. In the military context, especially within those armed forces using the conscript system, the training of large groups poses challenges for education methods. It is suggested, that VR and AR could be utilized in this task. These technologies offer novel ways to include training sessions to those moments where otherwise the conscripts would have to spend their time waiting for their turn to use the actual training devices or high-fidelity simulators. In this study the using of VR and AR is examined in the teaching of the basics of disassembling heavy machine gun, a weapon that each soldier in the studied armed force should be able to use.

1.2. VR and AR in military training and education

There are many examples of using commercial-off-the-shelf digital games in military training [16, 17] and the increased interest in the consumer market towards VR technologies has contributed also to the interest towards commercial VR devices in the fields of military and security training.

VR can be utilized in the training of the basic skills of a dismounted soldier, such as shooting skills, but also in the training of stress management and decision making, for example [18, 19, 20, 21, 22]. Virtual reality applications can enhance military training by enabling repetitive training of scenarios economically and in a safe environment with possibility for collecting vast amounts of data for analysis and feedback.

In addition to the beneficial effects of VR and AR in enhancing training effectiveness, these technologies may also enable effective training of certain scenarios in military context that would otherwise be difficult, dangerous, or costly to train with other methods [e.g., 15, 8]. These include various types of complex and cooperative tasks [23].

It is also suggested that when training large masses (e.g. conscripts) with limited number of devices or weapon systems, a VR or AR application could be used by those who wait for their turn to use the more high-fidelity simulator or the actual device or weapon system that is being studied. One important function that VR learning environments may have in such instances is to reduce performance anxiety, stress and workload that is related to the performance of a criterion task or when using a real weapon or device, when compared to training with more traditional methods [24]. This could potentially enhance the effectiveness of training by familiarizing and preparing the students and trainees more effectively with the forthcoming live performance or criterion task. This could potentially save time and resources.

Also relevant for the military context, virtual training environments enable secure and discrete training of procedures that want to be kept secret [25].

2. Current study and research questions

The purpose of the current study was to examine the using of VR and AR in enhancing military training, specifically training of procedural skills needed in weapon handling. The current study also aims to contribute to the field of VR/AR training human factors and human-computer interaction studies by providing evidence on learning effects that are observable on actual behavior with objective measures in the physical world, not just in the VR/AR environment. As shown by Kaplan and colleagues [15] there is paucity of such studies. Thus, the main research question of the current study was:

RQ1: What effects the using of VR and AR technologies have on learning effectiveness for manual disassembly task in military context, when compared to more traditional classroom teaching?

Using of new technologies may increase interest towards the teaching and in the case of technologies such as VR and AR, even a wow-effect [26], and experienced interest towards the learning event may contribute to better learning outcomes [27]. Thus, we defined the second research question:

RQ2: What effects the using of VR and AR technologies have on the experienced interest towards the learning event when compared to more traditional classroom teaching?

Self-efficacy refers to a person's belief in their ability to perform a certain task [28] and it has been shown to have a role in learning [29]. Typically, higher sense of self-efficacy is related to better learning outcomes [e.g., 30]. In a recent meta-analysis, it was observed that in language training the using of VR may enhance self-efficacy [31]. Thus, we set the third research question:

RQ3: What effects the using of VR and AR technologies have on the perceived self-efficacy when compared to using of more traditional classroom teaching?

Making of mistakes during training and education may be perceived negatively and this may lead to cognitive load and avoiding of doing mistakes at all costs [e.g., 32, 33]. Virtual and augmented reality technologies make it possible to build learning environments that encourage and support experimenting and playful learning [34]. It is suggested that in such a playful environment the possibility of making mistakes may also lower the anxiety towards making them when performing the real task with real weapons and devices. Thus, we formed the following research question:

RQ4: What effects the using of VR and AR technologies have on the perceived error anxiety when compared to using of more traditional classroom teaching?

3. Methods

3.1. Participants

The participants were 32 conscripts from the Naval Reserve Officer School. The participants were from a selected population, among the conscripts only a selected few are admitted to reserve officer course. The selections are based on psychological and physiological screening and on their performance during the service so far. At the time of the experiment the participants still had 4 months left of their 11,5-month conscript service. All the participants were male and their age varied between 19-23 years. The participants were placed randomly to the two experimental groups. The participants had not used previously the heavy machine gun. Participation was voluntary and there was no monetary or other type of compensation. All the participants gave written informed consent in accordance with the Declaration of Helsinki. The study was carried out in accordance with the ethical principles of research with human participants.

3.2. Procedure

The participants were split to two groups and each was randomly assigned either to treatment group (Group 1, VR &AR) or control group (Group 2, book & projector). After being informed about the session and signing a consent form, each of the groups were held a 60 min lesson on the basic structure and mechanics of the heavy machine gun and how to disassemble it. The content of the lesson was the same for both groups. However, the groups differed in the utilized pedagogical technology.

For the Group 1 the lesson was held entirely in a VR/AR environment so that the participants wore ClassVR (https://www.classvr.com/) VR/AR glasses for the entire 60 min lesson. The lesson was led by the instructor, who dictated the pace by which the contents of the VR/AR environment was studied. There was no audio in the VR/AR environment, so that the students were able to hear the speech of the instructor.

The content of the VR/AR environment consisted of video clips on the using and handling of the weapon, short text pieces describing its' functionality and 3D animations which showed the mechanical functioning of the different parts of the weapon (Figure 1). Most of the material was implemented as VR content, but there was also an AR functionality that utilized a QR cube (Figure 2). By rotating the cube in hands, the participant could move the 3D animation sequence of the weapon that showed how the different parts move in relation to others. The animation showed the disassembly sequence of the weapon that was later done with a real weapon as a timed and scored performance test.

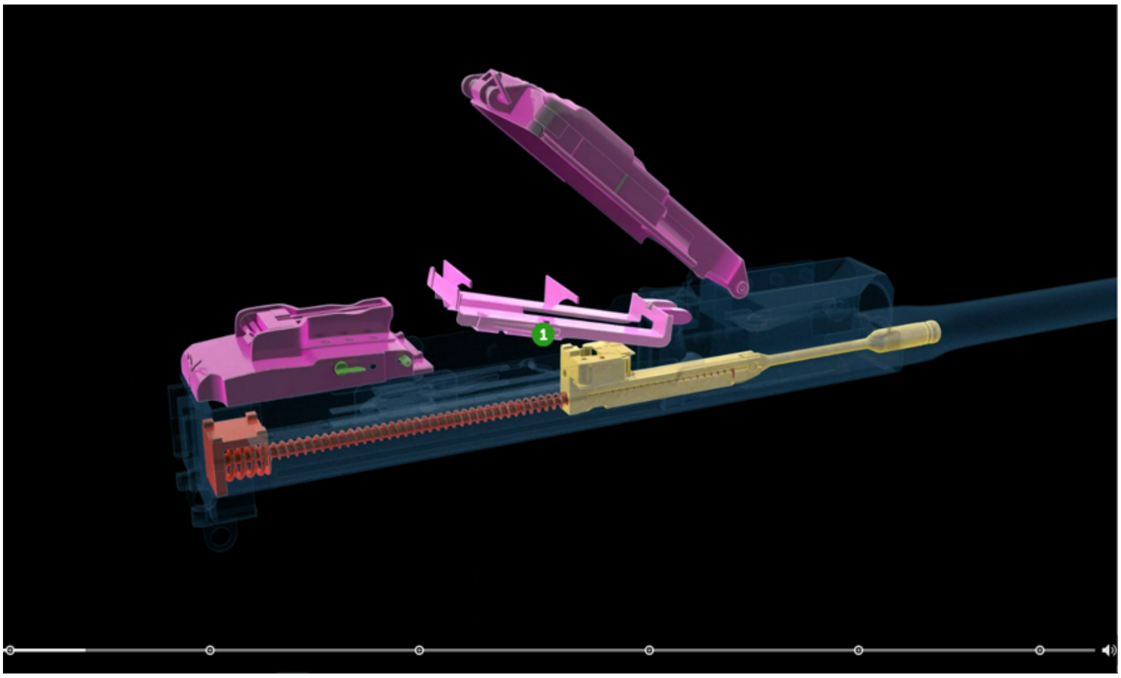

Figure 1: In the VR/AR learning environment there were 3D animations of the mechanical functionality of the weapon

Group 2 studied the same content, but with the help of more traditional material. Each participant had a copy of the light weapons manual and they were given a lesson based on PowerPoint presentation with material from the manual. The instructor lectured at the front of the classroom, showed text and pictures projected on a white screen, and guided the students to focus to relevant graphs, pictures and text parts in the weapons manual.

Figure 2: Users' view of the QR cube functionality, that enabled the viewing of the animated 3D model of the weapon.

The instructor for the both groups was the same person, a captain lieutenant with expertise in conscript training and in various weapon systems.

Figure 3: A timed and evaluated performance of the disassembly procedure with a real weapon.

After the one-hour lessons, participants of both of the groups did individually a timed and scored performance of disassembling the actual heavy machine gun. It was the first time that the participants were handling the real heavy machine gun.

At the end of the experiment each of the participants was shortly interviewed for feedback on the study material used in the experiment. In addition, subjective experiences regarding the usability of the VR environment and possibly experienced fatigue in the eyes were covered.

3.3. Questionnaires

Before the one-hour lessons participants of both of the groups were informed about the topic of the lesson and the pedagogical methods and technologies that would be used. They were then asked to fill in Questionnaire 1 for assessing their interest towards the topic of the lesson ("The lesson and the disassembly task were interesting.") [27, 35], self-efficacy ("I will perform well in the disassembly task.") and assessment of performance ("I performed well.") [36, 37], and perceptions of possible mistakes they would make ("Making mistakes will feel annoying.") [33].

After the lesson and the scored and timed disassembly performance the participants were asked to fill in Questionnaire 2, where items from Questionnaire 1 were repeated and additional items covered motivation to perform well ("I was motivated to do my best") and evaluations of the study material ("The study material supported well my learning.") [adapted from: 38, 39].

A 7-point Likert scale was used for the questionnaire items. Instead of the often used 5-point scale, the 7-point scale was used for more accurate data.

4. Results

4.1. Self-reports

Non-parametric tests (Mann-Whitney U test) for comparing two independent groups were used in the analyses, due to the non-normal distribution of the data.

There were no statistically significant differences between the two groups (Group 1: VR / AR; Group 2: Book) in the self-reports that were collected before the lessons. That is, no statistically significant differences were observed between the groups in interest towards the forthcoming class ($p = 0.09$), in estimated ability to learn needed skills during the forthcoming class ($p = 0.78$), in estimate of performance in the forthcoming disassembly task ($p = 0.99$), in how much mistakes they estimate to commit during the forthcoming class and disassembly task ($p = 0.64$), or how annoying these possible mistakes would be perceived as ($p = 0.24$).

In the self-reports collected after the lesson and the disassembly task there were statistically significant differences between the two groups. Participants from the Group 1 (VR / AR; $M = 5.94$; $SD = 0.68$) evaluated the class to have been more interesting than participants from the Group 2 (Book; $M = 4.44$; $SD = 0.89$); $U(30) = 24.50$; $Z = 4.04$; $p < 0.001$; $r = 0.71$.

Participants of the Group 1 ($M = 6.06$; $SD = 1.00$) also reported that during the class they were better able to learn the needed skills for disassembling the gun than participants of the Group 2 ($M = 3.75$; $SD = 1.44$); $U(30) = 27.50$; $Z = 3.92$; $p < 0.001$; $r = 0.69$.

In line with the previous result, participants of the Group 1 ($M = 6.69$; $SD = 0.60$) perceived that they performed better in the disassembly task after the class than the participants of the Group 2 ($M = 4.63$; $SD = 2.00$); $U(30) = 43.00$; $Z = 3.41$; $p = 0.001$; $r = 0.60$.

In addition, the participants of the Group 1 ($M = 1.50$; $SD = 0.52$) estimated the amount of mistakes that they made during the disassembly task to be smaller than those from the Group 2 ($M = 3.25$; $SD = 1.73$); $U(30) = 216.00$; $Z = 3.55$; $p = 0.001$; $r = 0.63$.

There were no statistically significant differences between the studied groups in how annoying the mistakes were perceived to be, $p = 0.06$.

There were no statistically significant differences between the groups in the perceived importance of the topic of the class ($p = 1.00$), how well they reportedly tried to perform during the disassembly task ($p = 0.78$) or how motivated they were during the class and the task ($p = 0.18$).

Participants of the Group 1 ($M = 6.44$; $SD = 0.51$) reported that the study material supported better their learning than participants of the Group 2 ($M = 3.50$; $SD = 1.21$); $U(30) = 4.50$; $Z = 4.77$; $p < 0.001$; $r = 0.84$.

In addition, in the Group 1 ($M = 5.50$; $SD = 0.82$) the participants reported that the material worked better than the participants of Group 2 ($M = 2.69$; $SD = 1.01$) did; $U(30) = 6.50$; $Z = 4.67$; $p < 0.001$; r = 0.83.

Lastly, the study material was also considered to be more logically structured for Group 1 (M = 6.13; SD = 0.62) than for Group 2 (M = 4.12; SD = 1.15); $U(30) = 18.00$; $Z = 4.26$; $p < 0.001$; $r = 0.75$.

4.2. Performance in the disassembly task

All the 16 participants of the Group 1 (VR / AR) were able to disassemble the heavy machine gun after their lesson, whereas for the Group 2 (Book) only 4 out of 16 were able to complete the task, this difference between the two groups was statistically significant; ($\chi 2$ (1) = 19.20; $p < 0.001$).

Of those who were able to complete the task, there was statistically significant difference between the groups in execution time, the participants of Group 1 (M = 73.63 sec; SD = 16.02) were faster in disassembling the heavy machine gun than those of the Group 2 (M = 174.50 sec; SD = 70.25); $U(18) = 55.00$; $Z = 2.18$; $p = 0.03$; $r = 0.49$.

The failure to disassemble the heavy machine gun was either due to incorrect order of removing the parts, which prevented removing of any further parts, or forgetting the correct order and thus freezing.

4.3. Interview results

In the Group 1, that used VR/AR technologies in the training, 12 out of the 16 mentioned the QR cube as the single best feature of the environment. This could be due to the order effect, the QR cube was used during the last part of the lesson, when the participants were already familiar with using the VR/AR environment. At that stage they were already familiar with the logics of using the VR/AR environment and they had formed a knowledge base of the studied subject. However, majority of those who mentioned the QR cube, also mentioned that interactivity was the thing that made the cube so preferred. The participants were able to use the cube to familiarize with the animated 3D AR model of the weapon mechanism at their own pace. Interactivity has been shown to be one mechanism that contributes to sense of presence, or sense of being there in a virtual environment [40]. Sense of presence may enhance focusing of the attention of the user to the content of the VR environment, instead of outside distractions, this may enhance learning [41, 42].

Only 3 out of 16 participants from the Group 1 commented the visual quality of the VR/AR environment. One commented the overall quality of the graphics, one about the design of the icons in the main menu, and one about the scale in the animated 3D models of the weapon. Still, these participants didn't consider that the visual quality would have hindered their learning. Physical fidelity, or representativeness, of a simulator or a digital learning environment is often considered as one of the most important qualities for effective learning or transfer of training to real-world performance, even when the psychological fidelity may be more important [43, 44]. It must be carefully considered how much time and resources should be put in developmental work of a VR/AR environment to hone the visual features, or if the effort should be put in achieving high psychological fidelity, or other type of fidelity instead.

Only 2 of the 16 participants in Group 1 mentioned that they felt by the end of the VR/AR augmented lesson slight fatigue in their eyes. The one-hour long use period was considered as doable by all the participants, but majority of them considered that a longer continuous use period should not be pursued. None of the participants mentioned any symptoms of nausea during the use period. The participants were not experienced VR or AR users, five of them mentioned that they had tried these technologies previously at least once, but none of the used them regularly.

5. Discussion

The primary research question of the study was to examine what effects the using of VR and AR technologies have on teaching effectiveness for manual disassembly task in military context, when compared to more traditional classroom teaching. Obtained results point to the effectiveness of VR/AR technologies in this task. The group that used VR/AR performed objectively better in the disassembly task, this is in line with previous studies that have shown the validity of VR/AR technologies in training of skills that are relevant for the military and security fields, for example [23]. They also held more positive stance towards their learning and they felt more strongly that the study material supported them in this learning task.

The second research question asked what effects the using of VR/AR technologies have on perceived interest towards the learning event when compared to more traditional classroom teaching. No statistically significant differences in the interest ratings before the lessons were observed, but the groups differed in the ratings after the lessons. The VR/AR group considered that the lesson was more interesting than the group that used more traditional methods, this is in line with [20]. It is possible that this increased interest was sparked by the overall interest evoked by the VR/AR technologies, a type of WOW effect.

The third research question considered self-efficacy and asked what effects the using of VR/AR technologies have on it when compared to more traditional teaching. The groups didn't differ in the self-efficacy ratings prior to the lessons. It is possible that the participants were in this sense selected, since as reserve officer students they have certain level of confidence even when confronting new types of challenges. However, the training had an effect. After the lesson the participants in VR/AR group rated their mastery of the needed skills higher than before the training; this was vice versa in the group that studied with more traditional methods. It is possible that this book-using group realized during the lesson how complicated the studied procedure of disassembling the heavy machine gun was and that they may not be able to complete it.

In the fourth research question it was asked if the using of VR/AR technologies lower the negative effect of error anxiety, when compared to more traditional teaching methods. In the error-related ratings before the lessons there was no statistically significant difference between the groups. In the VR/AR group the making of mistakes was rated to be less annoying after the lesson than in the group that used more traditional methods. Thus, this research question was not answered unequivocally and needs further studying.

The observed results encourage to continue the identifying of new pedagogical use cases for VR/AR technologies. It must be noted, that the obtained results are from a narrow application area and the presented research questions should be examined within other use cases and scenarios for more convincing justification for the using of VR/AR technologies in military training. It is possible that many ideas for use cases can be identified from the civilian world. For example, first aid skills are to an extent similar in both contexts and observed good practices in using VR/AR in training them are to some degree transferrable between the civilian and military applications. But there are also unique tasks in the military that require specific competences and skill sets. For identifying these, agile prototyping would be needed to be able to bring testable VR/AR prototypes to those who operate or train and educate others. This would enable collecting of feedback for iterative development of the VR/AR applications.

The solution presented in the current study showed potential as a tool in training. However, in training and education often various methods and technologies are used in combinations and the interrelations between these have to be planned carefully to design a cohesive blended learning system [45]. Bringing of VR/AR technologies to training doesn't mean that books and PowerPoint presentations would be obsolete. For example, in training the handling and disassembling of heavy machine gun (and other similar devices), books and other written material could be used for learning the theory base and prior to using the actual weapon the VR/XR material could be used. This would make use of the time that the conscripts may have to take to wait for their turn to use the actual weapon or device, or a more high-fidelity simulator. For theses kinds of use cases, short duration and easy to use VR/AR material would be needed. After the using of such VR/AR environment the conscripts would be more prepared to use the actual weapon and perform even more advanced procedures.

In future studies a third study group should be added to study more closely the effect of immersiveness, similarly with [18]. This third group would use the VR material on a computer screen and use mouse and keyboard for manipulating and rotating the virtual objects. It is possible that one of the benefits of using VR glasses is the capturing of attention to the study material from any outside distractions. But this would need to be studied more closely in the context of military training, where, especially within a conscription-based system, the background of the trainees is varied.

Another related topic for further inquiry is the amount of freedom that the trainees should be given for learning various topics. In the current experiment the pace for proceeding in the VR/AR environment was dictated by the lecturer. All the VR glasses of the students were connected to the same environment where the lecturer could control the pace by which the different functionalities were open to use for everyone. With this kind of a controlled setting some playful features of VR that would support experimental learning are lost, but on the other hand it is ensured that everyone completes the class in a given time. After the basics are learned and for more advanced topics the users could be provided with more freedom to explore the virtual content.

6. Appendices

The items of the pre- and post-questionnaire are presented in Appendix A.

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A. Online Resources

Questionnaire items before the lesson and the disassembly task:

1. The exercise seems to me: 1 = not at all interesting, 2, 3, 4, 5, 6, 7 = very interesting
2. I could learn the needed skills: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
3. I can perform the forthcoming disassembly task: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
4. I know beforehand that I will make mistakes during the lesson and the disassembly task: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
5. Making a mistake will be annoying: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree

Questionnaire items after the lesson and the disassembly task:

1. The lesson and the disassembly task were interesting: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
2. I could learn the needed skills: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
3. I could perform the disassembly task: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
4. I made a lot of mistakes: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
5. Making a mistake was annoying: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
6. The taught topics were important for me: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
7. I tried to perform in the disassembly task as well as possible: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree
8. Overall, I was motivated to do my best: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree

9. The study material supported my learning: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree

10. The study material was easily accessible: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree

11. The study material worked well: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree

12. The study material was logically structured: 1 = I don't agree at all, 2, 3, 4, 5, 6, 7 = I fully agree