Safety Science 167 (2023) 106278

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Study of motivation and engagement for chemical laboratory safety training with VR serious game

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ARTICLE INFO

Keywords:
Virtual reality
Safety training
Laboratory safety
Motivation
Engagement

ABSTRACT

Safety training is a necessity and inherent part of any safety management system in high-risk industries, such as chemical industry. Often, training programs use conventional methods, such as classroom or video lectures. However, with these methods, trainees are passive and can quickly lose their attention, thus making the safety training ineffective. Alternatively, a virtual reality (VR) serious game can be used as a hands-on training tool to motivate and engage trainees. Relevant situations are simulated in a virtual environment where trainees can learn safety concepts and awareness without causing real harm to themselves or others. The current study investigates person-centred variables: motivation and engagement. We measured how safety motivation and engagement changed with employees of a chemical company when playing the VR LaboSafe Game after a traditional video lecture. Results show that employees have a high autonomous motivation to follow safety training, particularly in terms of identified regulation. Playing the VR serious game significantly increased intrinsic motivation and engagement of the trainees. They believe that they are more active, can keep their attention better and enjoy the experience of relevant situations in a virtual environment. However, complicated usability and the unfamiliarity to VR can affect their autonomous motivation for safety training. Older employees (above 50) have more difficulties with using VR headsets than younger employees (under 30). Data suggest to combine conventional methods with VR as complementary tool and provide more frequent and smaller sessions, gradually introducing VR technology to beginners.

1. Introduction

The health and safety of people should unarguably be one of the core values of any organisation in high-risk industries, including companies in the chemical industry. Employees working in the chemical industry are constantly at risk of exposure to hazardous chemicals and extreme processing conditions (Garcia Fracaro et al., 2021; Srinivasan et al., 2019). Laboratory personnel have to work with a broad variety of hazardous substances and many different kinds of equipment and experimental setups. If these are not well managed, it could lead to a high risk of injury or even death (Schröder et al., 2016). Therefore, safety training is a necessity and is an inherent part of any safety management system.

Conventionally, safety training is taught with training methods such as classroom lectures, videos and printed safety manuals. These methods include a unidirectional flow of information where the trainee is required to pay attention and listen to the instructor (Bhide et al., 2015). It has the strength that a great amount of theory can be given in a short period and for a large audience (Blair and Seo, 2007). However, trainees are passive in their learning process and this could lead to boredom and reduced attention, which in turn leads to ineffective training (Fivizzani, 2005). Other common safety training methods are on-the-job and hands-on training, where the trainee learns the necessary safety measures by hands-on activities supervised by more experienced workers. This method encourages the trainees to be active in their learning process and cultivates their decision-making skills through experience (Bhide et al., 2015). However, training of highly dangerous situations is not allowed with this method because this puts them and others at a high risk.

Recently, there is a trend to use virtual reality (VR) technology as a tool for safety training in many different fields such as, mining (Zhang et al., 2019), construction (Li et al., 2018) and fire safety (Saghafian

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https://doi.org/10.1016/j.ssci.2023.106278
Received 7 December 2022; Received in revised form 3 June 2023; Accepted 25 July 2023

et al., 2020). Also in the chemical field, VR is being used for the training of chemical plant operators and chemical laboratory safety (Garcia Fracaro et al., 2022; Srinivasan et al., 2022). This simulation-based training method resembles hands-on training, as the trainees are actively performing safety practices in realistic work environments (Bhide et al., 2015). The trainees are situated in a virtual environment so that hands-on training becomes possible without real-life hazardous consequences. This means that they can make mistakes and learn from these mistakes without jeopardising their own safety, the safety of others and/or jeopardising the integrity of the equipment or process plant. Research on the use of VR technology for training and education reports inconsistencies in performance outcomes. Some studies report beneficial effects on performance outcomes (Howard et al., 2021), while other studies report no significant improvement (Grassini et al., 2020; Makransky et al., 2019). These results cannot be generalised to all VR training since these depend on many factors, such as the design of the VR application, complexity of the training content, the experimental design, etc. (Grassini et al., 2020). Research on VR training and education often focusses on the comparison of performance, while there is a lack of in-depth studies from the perspective of the trainees (i.e. their motivation, engagement and opinions to follow VR safety training).

In the *meta*-analysis by Burke et al. (2006), training methods are differentiated based on the participation of the trainee in the training process. Conventional safety training methods (e.g. classroom, video lecture) are categorised as ‘low-engaging methods’, while hands-on training and simulations are classified as ‘most engaging methods’. This study further revealed that the most engaging methods are more effective in reducing negative outcomes, such as accidents, than low-engaging methods. It shows the importance of the level of engagement and involvement in a safety course. However, the classification of engagement between training methods is originated by subjective perspectives from the study’s authors. Mariani et al. (2022) recognise that there is a need to further explore the engagement for safety training from the trainee’s perspective by evaluating the attributes of engagement. Furthermore, there is little evidence how employees are motivated to attend safety training and how the level of engagement of different training methods can play a role in this motivation. Especially, differences between individuals or population groups (e.g. age, gender, work experience) are important to investigate because motivation and engagement are highly personal.

The scope of the current study is to investigate more person-centred variables, namely motivation and engagement. On one hand, we address: “How can the motivation of employees be described when safety training is given with a more conventional method?”, “How engaged are they during the training process?”. On the other hand, we also address: “How does this motivation change when they play a VR safety training game?”, “Are they more engaged to safety training with the VR game than with a conventional method?”. To answer these questions, the present study makes a comparison of motivation and engagement between a safety video lecture (as an example of a conventional method) and a VR serious game that is given after the video lecture. The game is called VR LaboSafe Game and is designed to teach safety awareness and safety behaviour to chemical laboratory workers. The players have to identify safety risks, minimise these risks and perform experiments safely in a virtual laboratory environment. This VR serious game is custom made of which the design and development is described in the study of Chan et al. (2021). The current study will contribute to a better understanding of motivation and engagement of learners for chemical lab safety training.

2. Theoretical background: Safety motivation and engagement

2.1. Safety motivation

The general definition of safety motivation is defined as the willingness of an individual to put effort to enact safety behaviours in order to eliminate or reduce the risk of incidents at work (Griffin and Neal, 2000). In the study of Scott et al. (2014), this safety motivation is further distinguished in different levels and types of motivation according to the Self-Determination Theory of Deci & Ryan (2000): intrinsic safety motivation, identified safety regulation, introjected safety regulation, external safety regulation and amotivation. The definitions of these motivation types are presented in Table 1. Intrinsic safety motivation and identified safety regulation are further grouped into *autonomous safety motivation*, while introjected and external safety regulation are grouped into *controlled safety motivation*. With *autonomous safety motivation*, employees are self-motivated to work safely because they believe that these activities coincide with their own personal values and interests. On the contrary, *controlled safety motivation* describes that employees perform safety-related activities because they feel pressured or obliged by their peers (e.g. supervisors, co-workers or organisation). Although safety motivation originally refers to ‘working safely’ in the

Table 1
Definitions for the subscales of safety motivation (Scott et al., 2014) and engagement.

Safety motivation	**Autonomous motivation**	**Intrinsic safety motivation:** employees engage in safety behaviour completely volitionally because the employee finds pleasure, satisfaction and interest in it. **Identified safety regulation:** employees engage in safety behaviour because they personally believe safety is important for their work environment, not necessarily because they feel they are obliged nor because they have fun doing them.
	Controlled motivation	**Introjected safety regulation:** employees engage in safety behaviour because they feel an internal pressure to behave safely. This feeling can be in the form of guilt or shame. **External safety regulation:** employees feel external pressure or obligation from someone or something else. An external stimulus (i.e. reward for good behaviour or sanction for unsafe behaviour) can motivate them to enact safety behaviour.
	Amotivation	Employees have no motivation to enact in safety behaviour because they feel no reason to do so.
Engagement	**Attention**	The ability to invest mental effort or focused attention in the safety training. It includes that people are in a state of flow, which is a state when people are so engaged in a task that they devote their total attention in the activity and lose their sense of time (Csikszentmihalyi et al., 1990; Magyaródi et al., 2013). This attribute belongs to the cognitive engagement.
	Control and interactivity	The ability of feeling ‘in charge’ over the activity and the degree of interaction between people and systems. In context of safety training, this also refers to learners making their own instructional decisions resulting in an active involvement in their learning process (Lee et al., 2010). This attribute belongs to the behavioural engagement.
	Reengagement	The degree to which the participant has the intention and desire to do the activity again in the future. It is an important aspect in the process of engagement because, when people are willing to engage with the activity again, this means that they had a positive experience with it or that it offered something new that cannot be obtained somewhere else (Makransky and Lilleholt, 2018; O’Brien and Toms, 2008).

study of (Scott et al., 2014), the current study adapts this classification but the ‘motivation to attend safety training courses’ is investigated instead.

In general, it is preferred to promote the autonomous motivation of employees in order to establish a better safety culture, because this motivation type predicts *safety participation* (i.e. participating in voluntary activities that support the company’s safety culture) (Hedlund et al., 2016; Scott, 2016). Furthermore, safety training was found to be the most important management practice to mediate better safety motivation (Vinodkumar and Bhasi, 2010). Therefore, such training should be designed in a way to stimulate autonomous motivation of the employee.

2.2. *Engagement during safety training*

Engagement of an individual is a complex and broad concept with many different definitions. In literature, there is no clear consensus of the construct because the meaning of engagement can change depending on the object of engagement, the degree of engagement and whether we are talking about engagement during or outside the activity (Ashwin and McVitty, 2015; Bond et al., 2020; Casey et al., 2021). The aim of the current study is not to investigate the full construct of engagement. Therefore, specific attributes are selected that could be more suitable for the engagement during safety training. Similarly to the study of Mariani et al. (2022), these selected attributes are based on the User Engagement of O’Brien and Toms (2008) and are related to the three domains of engagement (i.e. cognitive, behavioural and affective engagement) (Ben-Eliyahu et al., 2018): attention, control and interactivity, and reengagement. The definitions of these engagement attributes are presented in Table 1. Often, engagement is confused with motivation and used interchangeably. However, motivation is rather the antecedent and driving force for engagement (Bond et al., 2020). Motivation can be considered as an attribute of affective engagement because it contains positive emotions such as, enjoyment and interest. In the remainder of the paper, when we use the term ‘engagement’, we refer to the three attributes mentioned above.

3. Method

3.1. *Participants*

The sample population consisted of 37 employees (14 men and 23 women) at a research centre of the chemical company Arkema in France, who were randomly selected and voluntarily agreed to participate. The site director distributed the recruitment invitations to all employees of the site. Some employees participated by their own personal choice, while others were highly recommended by their managers. Most of the employees were either laboratory technicians or managers who have experience in working in a chemical laboratory. The ages of the participants were recorded from 20 to 60 years old and were divided in age groups with an interval of 10 years (See Table 2). A total of 14 (38%) participants have responded that they have used VR headsets at least once and a total of 11 (30%) participants have responded that they have played video games before.

3.2. *Procedure*

Fig. 1 summarises the testing procedure of the study. At the start, participants followed a chemical laboratory safety training by means of a video lecture as conventional teaching method before playing the VR serious game. To ensure that it was more like a classroom lecture, typical functionalities of video media were restricted, for example, pausing and skipping the video. The content of the video lecture ensured that every participant obtained the same baseline of knowledge which was relevant for the VR LaboSafe Game. More information about the video lecture can be found in the *Appendix A. Supplementary material – Section A*. After this video, the participants filled in a pre-test questionnaire about their demographical information, VR and video game experience, attributes of engagement and self-determined motivation of safety training given by a conventional method. The anonymity of each individual was preserved by assigning the participants with a randomly generated ID-number.

Table 2
Number of participants with VR and/or game experience in each age group.

Age group in years	20–30	31–40	41–50	51–60
Total participants	12	6	12	7
Have used VR (once or more times)	5	3	4	2
Have played video games	4	1	4	2
Interview participants	4	3	4	3

Then, the participants played the VR LaboSafe Game that was installed on the Meta Quest 2 VR headset (See Table 1). More information on the VR hardware can be found in the *Appendix A. Supplementary material – Section B*. The total duration of the gameplay was approximately 50 min and was divided into separate game levels. The topics (e.g., identification of risks, use of personal protective equipment) embedded in the game were similar to the content of the video lecture (giving information on, e.g., product hazards, use of a fume hood). The knowledge gained in the video lecture could be applied to identify and solve risks in the VR LaboSafe Game. More details about VR LaboSafe Game can be found in the *Appendix A. Supplementary material – Section C* and in the paper of Chan et al. (2021). After each level of the game, a participant could choose to take a break from VR in order to prevent severe symptoms of simulator sickness. Because of COVID-19 sanitary measures, the participants wore a face mask and the VR headset was disinfected before each use. After playing the VR serious game, the participants filled in the post-test questionnaire with the same items as in the pre-test questionnaire but now related to safety training with VR serious games. Finally, the participants were then invited for a semi-structured interview to give more in-depth feedback about their engagement and motivation.

3.3. *Instrumentation*

In order to measure the engagement and motivation of the participants for chemical lab safety training, a combination of quantitative and qualitative methods was used. A set of pre-test and post-test questionnaires was used to characterise the motivation and engagement before and after the gameplay. All questionnaire items were scored on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). This Likert scale is a scaling method, so that each item of the questionnaire contains a quantified range of answers. The pre-test questionnaire items were oriented to ‘following safety training’, while the post-test questionnaire was focussed on ‘following safety training with VR serious games’. To conclude, a semi-structured interview was conducted on one-to-one basis with the participant after answering the post-test questionnaire. This interview was always done by the same interviewer. Questionnaires and interviews were in the mother tongue of the participants (i.e. French). For data processing and reporting, contents were translated to English.

3.3.1. *Questionnaires on motivation and engagement*

The questionnaires were inspired by previously published works. The complete list of items and subscales is given in *Appendix A. Supplementary material – Section D*.

Engagement during safety training was determined by assessing the three attributes: absorption in the task (i.e. attention); control and active learning (i.e. control and interactivity); and behavioural intention (i.e. reengagement). These definitions are related to known constructs from validated questionnaires. For consistency with literature, these definitions are kept as is. *Absorption in the task* was measured by a 4-item scale adapted from the Flow State Questionnaire (Magyaródi et al., 2013).

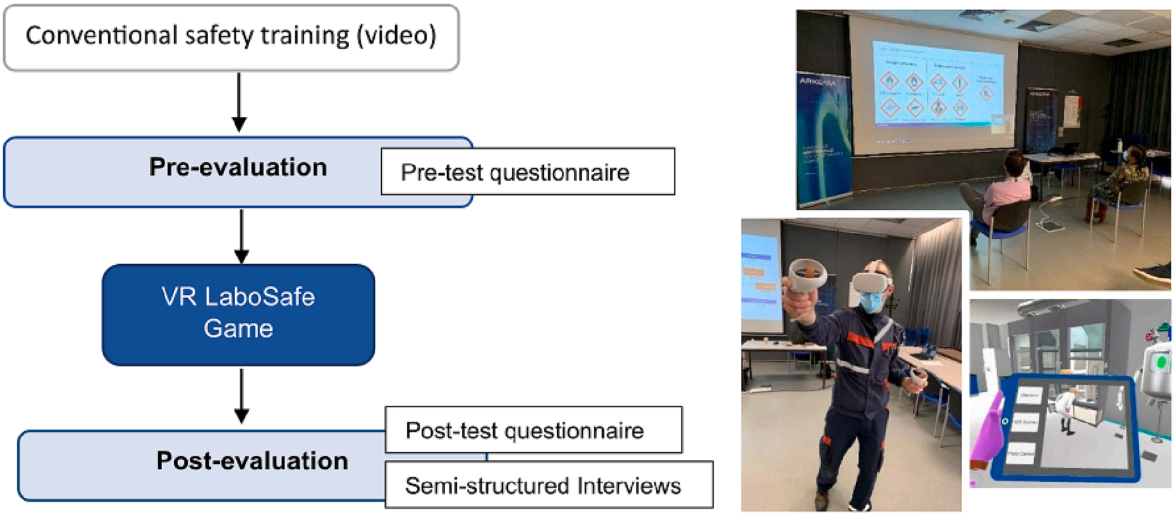

Fig. 1. Schematic representation of the testing procedure (left) and pictures of the participants (right) following the chemical laboratory safety training via video lecture (top) and VR LaboSafe Game (bottom).

Control and active learning was measured by a 4-item scale adapted from Lee et al. (2010). *Behavioural intention* was measured with a 4-item scale adapted from Makransky et al. (2018).

The motivation to follow safety training was measured using a 21-item scale adapted from Scott et al. (2016). The subject of each item in the original scale was adapted to correspond to the current subject of attending safety training with a conventional method and with a VR serious game method. Regarding the composite subscales, autonomous motivation scores were calculated by averaging the subscales of intrinsic motivation and identified regulation, while controlled motivation scores were calculated by averaging the subscales of introjected and external regulation as suggested by other researchers (Vansteenkiste et al., 2009). A principal component analyses confirmed in our case that two main principle components (eigenvalues for pre-test data: 2.67, 2.28, 1.39, 1.32; post-test data: 2.70, 2.49, 1.31, 1.14). explained 57% of the variance in the motivation items of the pre-test questionnaire and 63% of the variance in the post-test questionnaire. These components related to autonomous motivation and controlled motivation. Finally, the internal consistency based on Cronbach's alpha is satisfactory for both autonomous (pre-test: 0.90, post-test: 0.90) and controlled motivation (pre-test: 0.82, post-test: 0.93). This Cronbach's alpha is a measure of how items are closely related as a group. Conventionally, values above 0.70 depict an acceptable internal consistency (DeVellis, 2003).

3.3.2. Semi-structured interviews

After the participants played the VR LaboSafe Game, a semi-structured interview was conducted with 14 participants (7 men and 7 women). In this way, more nuanced data can be collected on the thoughts, behaviours and feelings of the participants about chemical lab safety training and the use of VR serious games. First, participants were asked whether they find the safety training more engaging with the video lecture or with VR LaboSafe Game. Then, they were asked if they believe they have a more autonomous or controlled motivation for safety training in a conventional way and for safety training with VR serious games. For both questions, they were asked to explain their opinion. At last, they were asked for suggestions to improve VR serious games for chemical lab safety training (e.g. content, implementation).

3.4. Data analysis

For the statistical analysis of the acquired data, we used the programming language R version 4.2.0 as statistical software. To analyse the results of the motivation and engagement questionnaires, responses per subscale were grouped and averaged. These mean values of the pre-test and post-test questionnaires were compared by using t-tests. For the comparison of motivational subscales, two-tailed paired samples t-tests were performed, whereas one-tailed paired samples t-tests were used for subscales of engagement attributes. The reason for this is because the study of motivation has a more exploratory nature, while the engagement for playing VR LaboSafe Game is hypothesised to be higher than with a video lecture. In addition, Pearson correlation was used to evaluate the relationship between motivation, engagement, age, gender, game and VR experience, and time spent in VR game levels.

Motivation is a complex psychological trait that is unique for each individual. Therefore, motivation was further investigated with a more person-centred approach by determining motivational profiles using a two-step cluster analysis method (van den Broeck et al., 2013). First, the responses of the motivation questionnaire were subjected to a hierarchical cluster analysis using squared Euclidian distances and Ward's method via the R package 'cluster' (Maechler et al., 2013). This enables us to find the optimal number of clusters and determine the cluster centres. In the second step, the motivational profiles are determined via a k-means clustering analysis while using the previously obtained cluster centres as initial seed points. This combination of hierarchical and iterative clustering methods is recommended in order to fine-tune the preliminary cluster solution (Moran et al., 2012).

In order to analyse and categorise data from the semi-structured interviews, the qualitative data analysis software NVivo version 1.6.1 was used. Interviews were audio recorded and converted to textual transcripts. Then, interesting segments were coded and categorised in themes.

4. Results

4.1. Safety training engagement

Table 3 summarises the descriptive statistics for the measured attributes of engagement. Correlations and internal consistencies of the scales are shown in Table 4. The Cronbach's alpha coefficient of the engagement attributes ranges from 0.72 to 0.90 with 4 items for each scale, indicating that the internal consistency of the questionnaire is acceptable (i.e. > 0.70) (DeVellis, 2003). The positive correlations between all attributes confirm that they are part of a larger latent variable: the learner engagement during safety training. The mean Likert scores per item are shown in Fig. 2.

One-tailed paired t-tests indicate that all investigated attributes of

Table 3
Descriptive statistics and p-values with Cohen's d effect size of the attributes of engagement.

	After video lecture (pre)		After VR LaboSafe Game (post)				
	Mean (SD)	Median	Mean (SD)	Median	*t* (36)	*p*	*d*
Engagement							
Absorption in the task	3.20 (0.76)	3.25	4.24 (0.72)	4.50	6.60	< 0.0001***	1.08
Control & active learning	3.26 (0.79)	3.25	3.58 (0.89)	3.75	1.97	0.028*	0.32
Behavioural intention	3.11 (0.86)	3.25	3.65 (0.93)	3.75	3.21	0.001**	0.53

Note: t (36) = t-statistics with 36 degrees of freedom, p = p-value of paired sample t-tests, d = Cohen's d effect size.
Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$.

Table 4
Correlations and internal consistencies among study variables of the pre-test questionnaire (i.e. after video lecture) and post-test questionnaire (i.e. after VR LaboSafe Game).

After video lecture (pre)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.			
1. Age	–												
2. Gender	**0.38**	–											
3. Absorption in the task	-0.05	-0.13	*(0.82)*										
4. Control & active learning	-0.23	0.06	**0.63**	*(0.82)*									
5. Behavioural intention	-0.13	0.01	**0.72**	**0.72**	*(0.87)*								
6. Intrinsic motivation	-0.30	0.02	**0.59**	**0.60**	**0.68**	*(0.90)*							
7. Identified regulation	-0.22	-0.01	**0.56**	**0.65**	**0.62**	**0.63**	*(0.85)*						
8. Introjected regulation	-0.20	0.08	0.28	0.31	**0.50**	**0.37**	0.20	*(0.84)*					
9. External regulation	0.18	0.29	-0.18	-0.15	-0.11	-0.09	-0.21	**0.35**	*(0.79)*				
10. Amotivation	0.17	0.03	**-0.54**	**-0.33**	**-0.52**	**-0.52**	**-0.73**	-0.21	0.18	*(0.87)*			
After VR game (post)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Age	–												
2. Gender	**0.38**	–											
3. Absorption in the task	-0.08	0.12	*(0.72)*										
4. Control & active learning	**-0.39**	-0.13	**0.62**	*(0.85)*									
5. Behavioural intention	-0.24	-0.05	**0.73**	**0.77**	*(0.90)*								
6. Intrinsic motivation	**-0.41**	0.04	**0.66**	**0.78**	**0.81**	*(0.87)*							
7. Identified regulation	-0.26	-0.06	**0.52**	**0.76**	**0.74**	**0.70**	*(0.85)*						
8. Introjected regulation	-0.11	-0.02	0.16	0.30	0.05	0.08	0.29	*(0.87)*					
9. External motivation	0.09	-0.03	-0.13	0.03	-0.25	-0.31	0.03	**0.68**	*(0.92)*				
10. Amotivation	**0.35**	0.05	**-0.42**	**-0.53**	**-0.54**	**-0.53**	**-0.54**	-0.03	0.21	*(0.95)*			
11. VR experience	-0.11	-0.03	-0.08	0.15	0.15	0.29	0.13	-0.08	-0.09	-0.07	–		
12. Game experience.	-0.01	**0.59**	0.29	0.08	0.15	**0.34**	0.11	-0.11	-0.13	-0.08	0.22	–	
13. VR tutorial time	**0.42**	-0.09	-0.10	-0.16	-0.05	-0.24	0.10	0.27	0.03	0.02	-0.23	**-0.34**	–
14. VR mission time	**0.45**	-0.15	0.12	0.07	0.13	0.01	0.22	-0.03	0.08	-0.13	-0.18	-0.16	**0.46**

Correlations shown in bold are significant at $p < 0.05$. Cronbach's alpha reliability coefficient for each scale is presented along the diagonal. Each measured scale consist of 4 items.

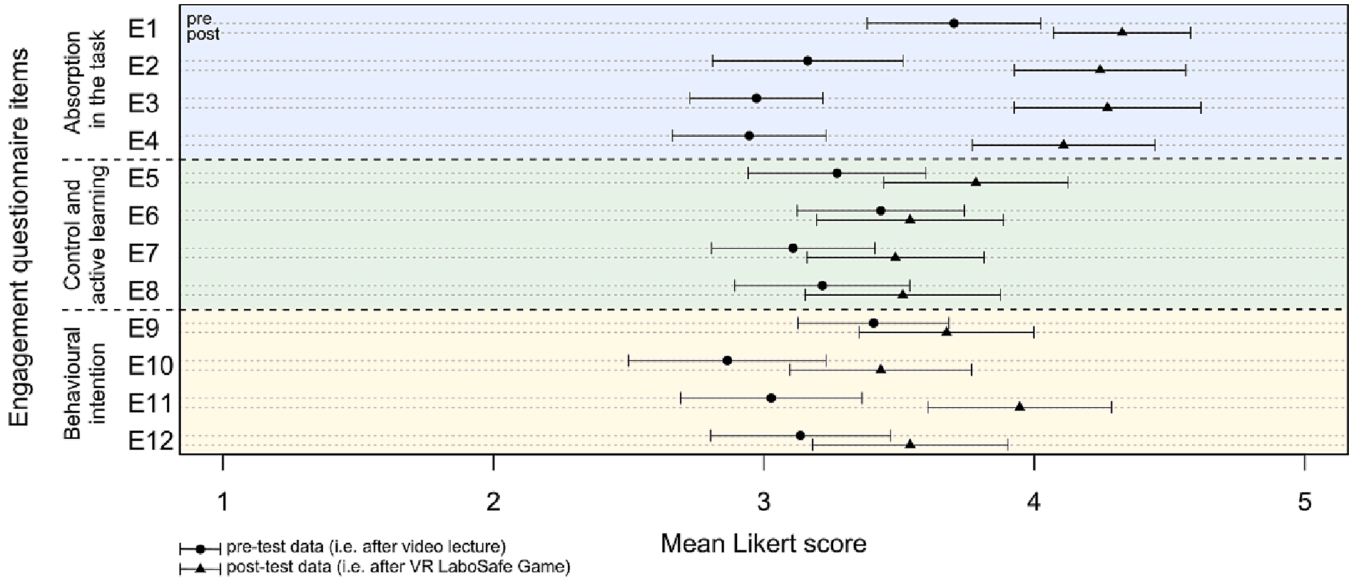

Fig. 2. Mean Likert scores per item from the engagement questionnaire (circles) after video lecture and (triangles) after VR LaboSafe Game. The error bars denote 95% confidence intervals. The description of the questions (E1 to E12) can be found in *Appendix A. Supplementary material Table 1S*.

engagement are significantly higher after playing the VR game. The “absorption in the task” shows a significant increase with a large effect size ($t(36) = 6.60, p < 0.0001$). Participants indicated that the VR game ‘engrossed their attention’ (E2) more and that the ‘time went faster than they have thought’ (E4), despite that the duration of the gameplay is much longer than the video lecture (i.e. 50 min. vs. 12 min.). The “control and active learning” shows a significant increase with a small effect size ($t(36) = 1.97$, $p = 0.028$). This means that participants answered that the VR game ‘allows them to be more responsive and active in their learning process’ (E5) and that it ‘promotes self-paced learning’ (E7) better than video lecture. The “behavioural intention” shows a significant increase with a medium effect size ($t(36) = 3.21, p = 0.001$). The results show that the participants would like to ‘participate in more safety trainings with VR serious games’ (E11) and ‘more frequently’ (E10) than safety training with a more conventional method, such as a video lecture.

4.2. *Safety training motivation*

4.2.1. *Comparison of motivation subscales*

Table 5 summarises the descriptive statistics for the motivation subscales (i.e. intrinsic motivation, identified regulation, introjected regulation, external regulation and amotivation) and composite subscales (i.e. autonomous motivation and controlled motivation). The Cronbach’s alpha coefficient of all motivation subscales ranges from 0.79 to 0.95 with 4 items for each scale, indicating that the internal consistency of the questionnaire is satisfactory (DeVellis, 2003). The mean Likert scores per item are shown in Fig. 3.

When comparing motivation subscales of the pre-test questionnaire (i.e. after video lecture) with the post-test questionnaire (i.e. after VR LaboSafe Game), significant differences can be observed. Intrinsic motivation has a significant increase with moderate effect size. However, also amotivation has increased significantly with a small effect size. Despite this increased value, it should be noted that the Likert scores of amotivation are still in the range of 1 to 2 (i.e. ‘strongly disagree’ to ‘disagree’). These increases are caused by the fact that, compared to conventional training, participants find the VR serious game more ‘fun’ (M2), while on the other hand, they do not think this VR game is more ‘a priority to them (M19) or their workplace (M20)’. When comparing identified, introjected and external regulation, these subscales show a significant decrease with moderate effect size after playing the VR serious game. These significant decreases originate from the fact that, compared to conventional safety training, participants do not think that the VR training game is more ‘important for them’ (M6), that they will not ‘feel more ashamed (M9) or guilty (M10) if they do not follow a safety training with a VR game’, and that they are not ‘supposed to follow safety training with VR serious games’ (M15). When comparing the composite motivation subscales between different training methods, autonomous motivation does not show a significant change, after playing VR LaboSafe game. This can be explained by the increase in intrinsic motivation but a decrease in identified regulation. On the other hand, a significant decrease with a large effect size was observed for controlled motivation, due to the decrease in introjected and external regulation.

Correlations and internal consistencies of these scales are shown in Table 4. The results show that positive correlations were found for intrinsic motivation with identified regulation and introjected with external regulation, which confirms that these subscales belong to autonomous and controlled motivation, respectively. As expected, amotivation is observed to be negatively related to autonomous motivation. Furthermore, autonomous motivation subscales (i.e. intrinsic motivation and identified regulation) are moderately to highly positively correlated with all attributes of engagement. Consequently, these attributes of engagement are negatively correlated with amotivation. This means that the higher the engagement during safety training, the higher the autonomous safety motivation and the lower the amotivation.

4.2.2. *Motivational profiles*

Clustering analysis of pre-test motivation data (i.e. after video lecture) is performed separately from post-test data (i.e. after VR LaboSafe Game) in order to independently determine the optimal number of clusters that are distinct from each other. Each cluster displays a unique pattern of scores on autonomous motivation, controlled motivation and amotivation. The distribution of the scores on motivational subscales per cluster can be found in Fig. 4. In literature, autonomous motivation is considered to deliver more beneficial outcomes than controlled motivation because it allows the satisfaction of the basic psychological needs of an individual (i.e. autonomy, competence and relatedness) (Scott et al., 2014; van den Broeck et al., 2013). Therefore, clusters are named alphabetically from A to D for pre-test motivation clusters and roman numerically from I to V for post-test motivation clusters in order to depict a ranking from highest to lowest autonomous motivation. When autonomous motivation scores are similar, then the cluster with a lower controlled motivation is more desirable because controlled motivation does not satisfy or even inhibits the basic psychological needs (Ryan and Deci, 2000; van den Broeck et al., 2013).

For the pre-test motivation data, the two-step clustering analysis resulted in a four-cluster solution. Inspection of the dendrogram (See Appendix A. Supplementary material –Figure2S) and the comparison with other cluster solutions indicate that the four-cluster solution is the most suitable. Profile A ($n = 8$) shows high scores in both autonomous and controlled motivation and can be identified as a ‘highly motivated’ profile. Profile B ($n = 19$) shows moderately high autonomous, but low controlled motivation values. The moderately high values of autonomous motivation are mainly attributed to the high identified regulation, not so much to intrinsic motivation. This profile is identified as ‘moderately autonomous’ motivation profile. Profile C ($n = 11$) shows neutral scores for autonomous and controlled motivation. This profile has a high identified regulation, but a low intrinsic motivation that is negatively oriented (below 3), thus resulting in a neutral autonomous motivation. So, profile C is identified as ‘neutral’ motivation profile. Profile D only has one participant who reported a very low level of

Table 5

Descriptive statistics and p-values with Cohen’s d effect size of motivation subscales.

	After video lecture(pre)		After VR LaboSafe Game(post)				
	Mean (SD)	Median	Mean (SD)	Median	*t* (36)	*p*	*d*
Motivation							
Autonomous	3.64 (0.71)	3.75	3.71 (0.74)	3.62	0.56	0.579	0.09
Intrinsic	3.11 (0.87)	3.00	3.75 (0.81)	4.00	4.04	0.0002**	0.66
Identified	4.17 (0.71)	4.25	3.66 (0.81)	3.50	−4.15	0.0002**	−0.68
Controlled	2.68 (0.75)	2.70	2.14 (0.87)	2.00	−4.87	< 0.0001***	−0.80
Introjected	2.75 (1.03)	2.50	2.16 (0.92)	2.00	−4.74	< 0.0001***	−0.78
External	2.63 (0.82)	2.60	2.12 (0.97)	2.00	−3.65	0.0008**	−0.60
Amotivation	1.57 (0.74)	1.25	1.85 (0.88)	2.00	2.25	0.031*	0.28

Note: t (36) = t-statistics with 36 degrees of freedom, p = p-value of paired sample t-tests, d = Cohen’s d effect size.
Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$.

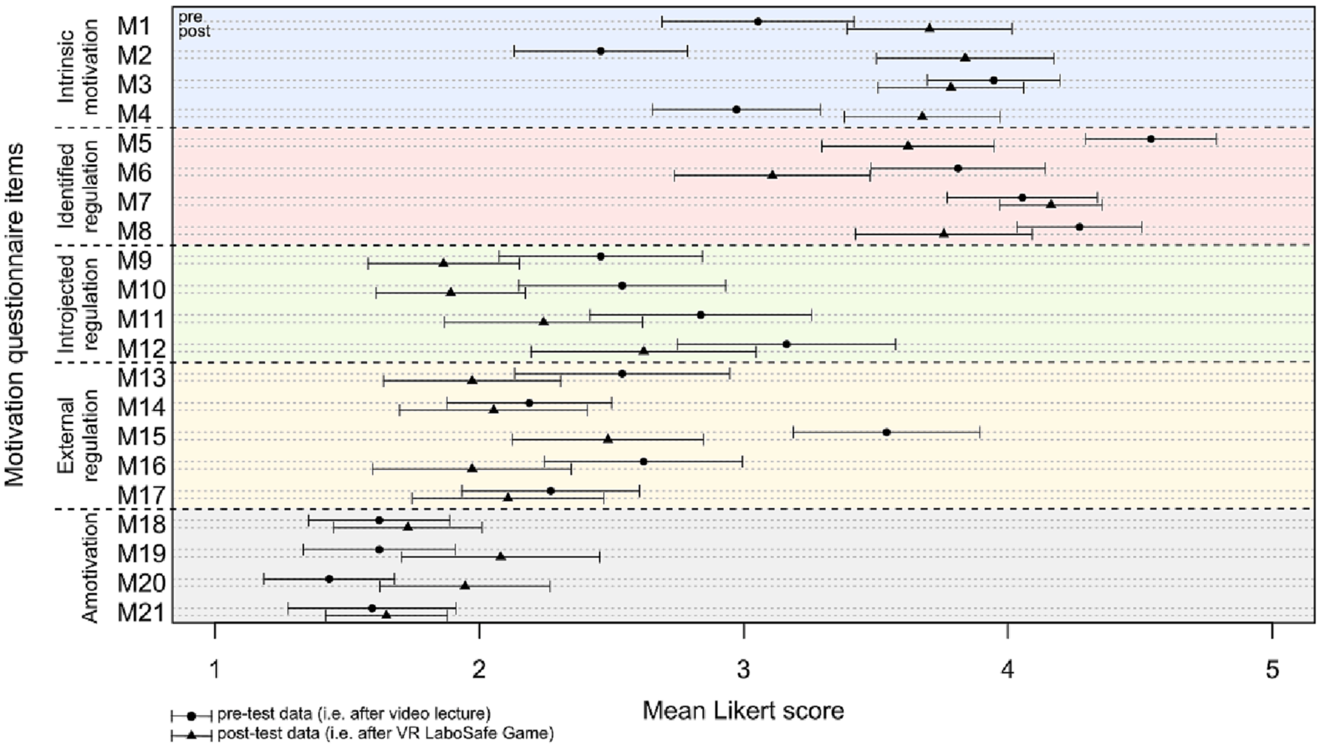

Fig. 3. Mean Likert scores per item from the motivation questionnaire (circles) after video lecture and (triangles) after VR LaboSafe Game. The error bars denote 95% confidence intervals. The description of the questions (M1 to M21) can be found in *Appendix A. Supplementary material Table 2S*.

autonomous motivation and neutral controlled motivation. It is noteworthy that this profile exhibits a high amotivation whereas the amotivation in the other profiles is much lower. Hence, this profile D can be identified as an 'amotivated' profile.

For the post-test motivation data, the same clustering analysis procedure was repeated and resulted in a five-cluster solution. In this case, the highest ranked profile I (n = 8) is distinct from the highest ranked profile from pre-test motivation (i.e. profile A). People with profile I have a high level of autonomous motivation and a low level of controlled motivation. This profile is similar to profile B (i.e. moderately high autonomous, low controlled) but with a higher quantity. Thus, this profile can be described as 'highly autonomous' motivation profile. Some profiles such as profile II (n = 3) and profile III (n = 13) are not much different from profile A and B from pre-test motivation, except a slight increase of intrinsic motivation and decrease in identified regulation in profile III. Therefore, these remain as 'highly motivated' profile and 'autonomous' motivation profile, respectively. Other profiles such as profile IV (n = 9) and profile V (n = 4) appear to have a different motivation distribution than the pre-test ones. Profile IV shows a much lower controlled motivation, while intrinsic motivation increased and identified regulation decreased, resulting in a more equalised autonomous motivation. This profile can be described as a 'low-controlled' motivation profile. Also, the lowest-ranked profile V shows resemblance to a 'neutral' motivation profile with a slightly negatively scored autonomous motivation, while no participants are identified with an 'amotivated' profile anymore.

Differences in demographics and engagement attributes between motivational profiles are displayed in Table 6. The changes in motivational profile of an individual are visualised in Fig. 5. After playing the VR serious game, participants from the age group 20–30 years old are identified with a higher ranked motivation profiles (i.e. I, II, III), while 51–60 years old participants are identified with lower ranked profiles (i.e. IV, V). It seems that some of the participants of the age group 51–60 years old have moved from high ranked profiles (i.e. A, B) before playing the VR serious game to low ranked profiles (i.e. IV, V) after playing the VR serious game. This is aligned with the results that the age of the participants is negatively related to intrinsic safety training motivation and positively related with amotivation after playing the VR serious game. Another noticeable difference between the motivational profiles in Table 6 is that higher-ranked profiles have higher scores on attributes of engagement than lower-ranked profiles. This coincides with the positive correlation between engagement attributes with autonomous motivation subscales as seen in Table 4.

4.3. *Semi-structured interviews*

Fig. 6 presents which training method the participants find the most engaging and whether their motivation is more autonomous or controlled to follow safety training with a conventional method or with VR serious games. The opinion of the participants about the teaching methods for chemical lab safety training is then categorised in different themes such as, the strengths and weaknesses of both learning methods and suggestions to improve VR safety training (See Table 7).

4.3.1. *Conventional safety training: Engagement and motivation*

The interviews with employees of the chemical company showed that, in general, employees are more autonomously motivated to follow safety training courses. Participants have described that safety training is "important for their own safety and safety of others" (P1 – the code refers to a quote from a participant) and that they "want to learn new things and enrich their knowledge about safety" (P8). Some employees are "super voluntary for safety activities" (P9). One interviewee said:

P6: "In the field of chemistry and for our activities, it's important to work safely; and that I find it interesting as well.".

Despite the fact that there is an obligation from the company to follow safety training, they are still self-motivated:

P4: "I am motivated by myself and enjoy doing it, but we still have an obligation to follow, as we work in the laboratory and it is mandatory to be aware of safety.".

However, even though these employees are autonomously

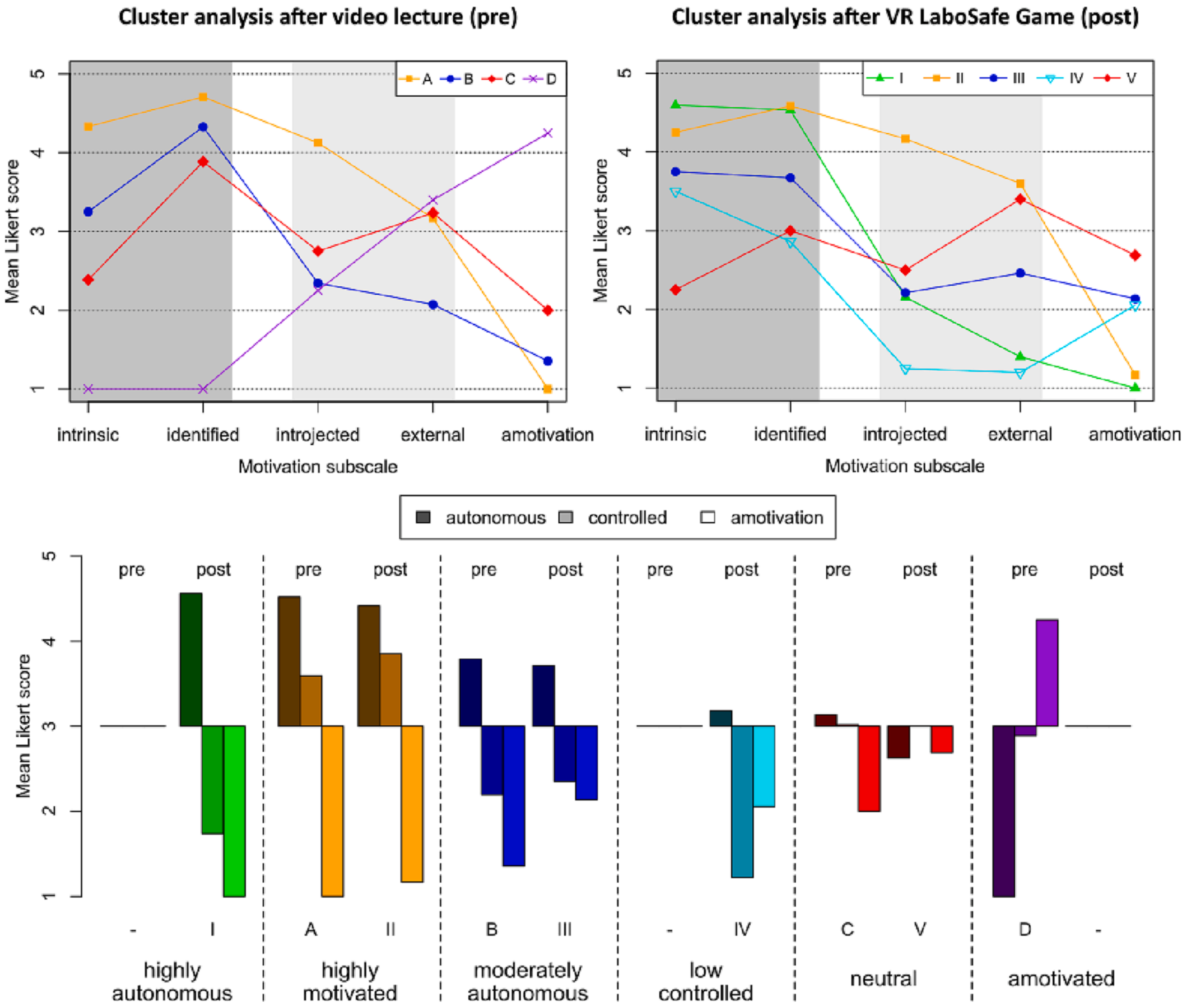

Fig. 4. Motivational profiles obtained by k-means clustering analysis of motivational subscales in pre-test (i.e. after video lecture) and post-test (i.e. after VR LaboSafe Game). The line curves do not represent continuous data but are intended to guide the eyes.

Table 6
Differences in demographics and engagement attributes per motivational profile.

	After video lecture (pre)				After VR LaboSafe Game (post)				
	A	B	C	D	I	II	III	IV	V
n	6	19	11	1	8	3	13	9	4
Gender									
Women	3	14	5	1	6	2	8	4	3
Men	3	5	6	0	2	1	5	5	1
Age									
20–30 years old	4	5	3	0	5	2	4	1	0
31–40 years old	0	6	0	0	1	0	1	3	1
41–50 years old	0	6	5	1	2	0	7	3	0
51–60 years old	2	2	3	0	0	1	1	2	3
VR experience									
No	5	9	8	1	4	2	7	7	3
Yes	1	10	3	0	4	1	6	2	1
Game experience									
No	4	14	7	1	5	2	10	5	4
Yes	2	5	4	0	3	1	3	4	0
Engagement attributes (mean Likert scores)									
Absorption in the task	4.08	3.25	2.75	1.75	4.75	4.97	4.00	4.19	3.56
Control and active learning	3.92	3.28	3.07	1.00	4.28	4.50	3.67	3.00	2.50
Behavioural intention	4.17	3.13	2.61	1.75	4.59	4.08	3.58	3.25	2.56

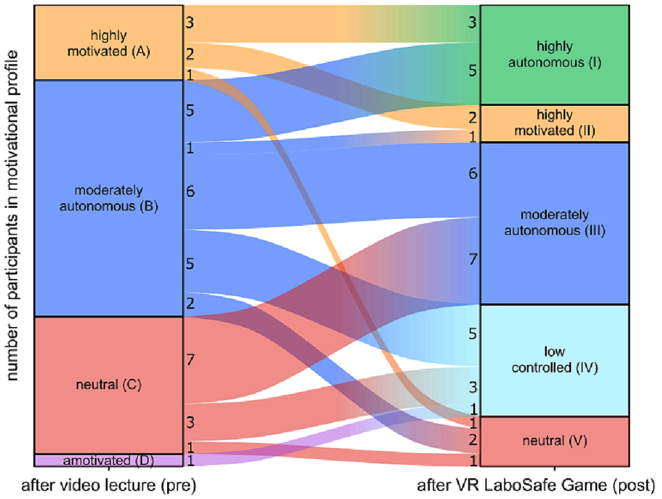

Fig. 5. Changes in motivational profiles of participants between the video lecture training (left) and the VR-based training (right).

motivated, they do not find safety training courses amusing. For example, one employee explained:

P5: “It’s not amusing, it’s not about pleasure. It is more about being motivated for my own safety and the safety of the people around me.”.

This displeasure can be more pronounced with other employees who have a more controlled motivation for safety training:

P14: “I don’t go too much for my own pleasure. I go there because we have to go there.”.

The modest dislike for current safety training arises from the fact that employees believe they receive “too much safety training” (P10) with “repetitive learning content” (P6). Particularly with conventional teaching methods, “content cannot be easily adapted to their work” (P5) and learners are “passive in front of a screen or a tutor” (P1). Consequently, it is “easy to not pay attention” (P7), hence a low engagement during safety training.

4.3.2. *Strengths of VR safety training*

When participants were asked how safety training with VR serious games compares to conventional methods, they mostly responded (71%) in favour of the use of VR serious games in terms of engagement. They mentioned several advantages that VR technology can provide which conventional methods lack.

Firstly, training with VR can provide opportunities for *situated learning* and *variability*. Employees described that this technology is “capable of realising almost real situations” (P6) with “more concrete examples” (P2). Compared to conventional methods, VR can “more easily add new things and create different situations each time” (P10), even “dangerous situations without placing the person in danger like in a real laboratory” (P3). Participants believe this training tool makes it possible for them “to visualise better” (P1) which makes it also “better for practising situations” (P4).

P13: “When you are in the video game, you realise that you are in a realistic situation. When in real-life, you cannot see everything and then you can miss problematic situations.”.

Secondly, VR serious games allow learners to have *control and be active* in their own learning process. Participants mentioned that training with VR serious games is “more dynamic” (P6) and has “more interactions” (P13) which leads to learners being “more active” (P1) and makes them “more an actor of their own training” (P14).

P3: “You are not sitting and listening, you have things to do.”.

This high level of interactivity and activity makes learners “more attentive in the video game, thus it permits to hold their attention better” (P9) which makes “the time pass more quickly” (P14).

P9: “You keep moving, you keep concentrating. You do not lose yourself in your own thoughts and you are always concentrating on the subject.”.

The *novelty of VR technology* also brings an increased interest than conventional methods. Before the safety training with VR, participants were “curious to see how it works” (P2) and they wanted to “discover another environment” (P14). While playing the VR serious game, participants were surprised by “how advanced this technology has grown” (P1). They felt a heightened *presence* due to the *high fidelity* of the tool. It is “much more immersive” (P1) because “the virtual space is unlimited” (P12) in which you can “walk everywhere” (P5) and because “certain situations can come close to reality” (P6).

P12: “The serious game really shows laboratory safety and that I find very striking. It is really a virtual reality, that’s for sure.”.

These strengths of VR safety training improve the autonomous motivation compared to conventional methods because employees believe training with VR serious games is “more amusing” (P5) and “more attractive” (P1). For these reasons, they find the VR safety training more engaging than conventional safety training.

4.3.3. *Weaknesses of VR safety training*

The participants have also mentioned limitations of using VR serious games for laboratory safety training. While *novelty* is one of the strengths of VR safety training, it is also its limitation for some users. For example, when asked if their interest would remain after the initial encounter, participants mentioned that “this phenomenon of discovery would fade”

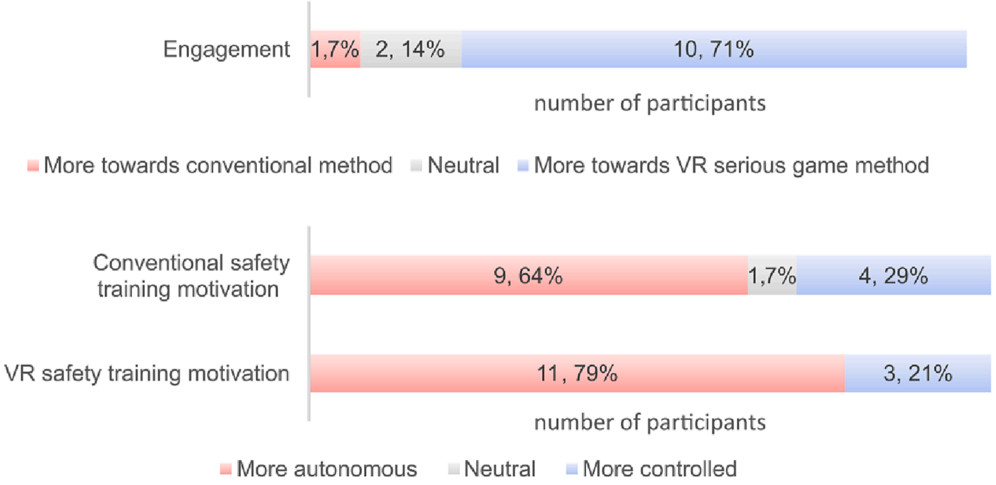

Fig. 6. Participants’ perception of the engagement and motivation of safety training with VR serious games compared to training with more conventional methods.

Table 7
Opinions of the participants (n = 14) derived from the semi-structured interviews.

Strengths of safety training with a conventional teaching method	**No. of people**	**Weaknesses of safety training with a conventional teaching method**	**No. of people**
Better knowledge acquisition	6 (43%)	Repetitive content, not easy to adapt	8 (57%)
People already have the habit	2 (14%)	Can lose attention quickly	6 (14%)
Real reality	1 (7%)	Passive learning	3 (21%)
Strengths of VR safety training	**No. of people**	**Weaknesses of VR safety training**	**No. of people**
Situated learning & variability	12 (86%)	Novelty & usability issues	9 (64%)
Control & active learning	10 (71%)	Ergonomic issues	7 (50%)
Absorption in the task	8 (57%)	Less suited for knowledge acquisition	5 (36%)
Novelty	6 (43%)	Discrepancy of reality	3 (21%)
Presence & fidelity	4 (29%)		
Suggestions for improvement			**No. of people**
More frequent, smaller sessions			7 (50%)
Complementary (i.e. combination with conventional methods)			7 (50%)
More specialised to the job			4 (29%)

(P14). Though, it can still remain interesting when new things are provided each time.

P10: “In the beginning I was happy to test the VR game, but after, it would become repetitive. That is why I hope VR can bring different things each time. It can create anything you want, so it is more easy to add new things and create different situations each time.”.

Moreover, some employees, who have never used VR or played games before, might struggle with the *usability* of this novel tool. For example, some participants mentioned that “the controllers are not easy to manipulate” (P13) and that they “need to put a lot of effort to learn to play the game” (P8). When trainees do not have the habit to use this new technology, it can become too complicated, making them “frustrated because they do not succeed in doing the things that they wanted to do” (P9). One participant mentioned that it also occurs with older people:

P2: “I have talked to other people around my age of 50 years old and all of them had the same problems with VR. It is because we don’t have the habit and it becomes complicated very quickly at some point.”.

This usability frustration together with wearing “a too heavy VR headset” (P8) can cause slight *ergonomic issues*. Due to the intense concentration and a lot of movement, participants experienced “tiredness” (P2), “a bit of nausea” (P4) and “reduced spatial awareness” (P3).

P1: “Sometimes I felt nauseous, but because the headset was quite heavy. I do not have the habit (of using VR headsets), I think.”.

Another limitation that the participants have noticed, is that using VR serious games is *less suited for knowledge acquisition* compared to conventional methods. Some responses are:

P14: “Difficulties of interacting with the game can obstruct taking in information. You can get distracted by other things, thus not learning the safety content.”.

P5: “I do not find all the information in the VR game that are taught in a classical lecture.”.

Moreover, some participants prefer training in real-life environments rather than a virtual reality. For example, one participant described:

P8: “The virtual reality is an artificial reality that is not the real reality. So, the construction of this reality of the game depends on the constructor and not from reality.”.

Ultimately, these weaknesses of VR safety training can result in a more controlled motivation and reduced autonomous motivation, as frustration makes the training unpleasant and becomes an obligation to follow.

4.3.4. Suggestions for improvement

In order to overcome the weaknesses of VR safety training, participants were asked to provide suggestions to improve the VR learning experience. Firstly, to overcome the most common issues of using VR (i.e. usability and ergonomic issues), the participants suggest “to give multiple smaller sessions and progressively introduce VR” (P6) and “provide more time to learn VR for those who need it” (P10). Most participants agree that they would get used to using the novel technology after the first sessions.

P6: “It’s a matter of habit. It is like using a new tool or a new machine; you have to take the time to understand it.”.

Secondly, employees still see the value of both conventional and VR teaching methods. They consider these methods as “complementary in a way that one cannot do without the other” (P10). A few suggestions to combine both teaching methods are:

P1: “Give a small part as a lecture in advance, to teach people what needs to be taught. Then afterwards, the video game can implement small exercises.”.

P9: “A presentation in class before the game and one after as debriefing. This is to make it more interactive between the learners for them to discuss and to make exchanges.”.

Other participants suggest to design VR applications with “modules that are more specialised and more oriented to their job” (P9).

P13: “The video game would be great for safety training of specific products, such as hydrogen fluoride or peroxides, because these products are a bit special.”.

5. Discussion

The aim of this study is to investigate the engagement and motivation of employees at a chemical company to follow lab safety training when it is given with a conventional method (i.e. video lecture) and when they play a VR serious game, in this case, the VR LaboSafe Game, after the conventional training. A combination of quantitative and qualitative research tools were used to achieve a better understanding.

5.1. Engagement and training motivation of conventional lab safety training

Data show that employees generally have a high autonomous motivation for conventional safety training such as a video lecture. Especially, a high level of identified regulation was observed because employees believe safety training is important for them in order to acquire skills and knowledge to improve their own safety and the safety of others. This is not surprising as the chemical company has a high focus on safety culture (Arkema, 2022). Even though safety training is mandatory, some employees believe their motivation is more autonomous rather than controlled. However, other employees feel more obliged when they do not like the safety training, so motivation subscales vary from person to person. For this reason, we grouped individuals with similar safety training motivation, resulting in four characteristic motivational profiles. Similar to the study of Howard et al. (2016) and their “motivational profiles at work”, we obtained profiles characterized as *highly motivated*, *autonomously motivated*, *neutral* and *amotivated*. These profiles are rated from high to low autonomous motivation, respectively. Intrinsic motivation is lower than identified regulation in each profile and amotivation increases with lower-ranked profiles. This can be explained by the fact that some employees do not find conventional safety training pleasing. They also believe that they are too passive and that such training is too repetitive and difficult to adapt, hence, they can lose their attention more easily. As autonomous motivation is correlated to the attributes of engagement, the low-engagement characteristic of conventional teaching methods can result in a lower quality of motivation. Although enjoyment is not the primary goal, it is still important to improve the motivation for safety training because employees who are intrinsically motivated can lead to a better safety participation (Hedlund et al., 2016; Scott, 2016). Without using a VR serious game, there are other ways to add engaging and motivating elements to conventional teaching: adding interactive questions; allowing collaborations between trainees; giving helpful feedback; etc. (Alaimo et al., 2010; Burke et al., 2006). With these techniques there is a possibility to significantly increase the engagement and motivation of the trainees for conventional training methods. However, a VR serious game as training tool can bring other benefits. For example, for a very large training group, the aforementioned techniques can become more challenging for the instructor to implement while providing every trainee with optimal support. While with a VR training tool, training could be given with better individual support taking into account the available devices and group distributions. Moreover with a VR training, trainees can follow more training sessions more frequently without requiring more time and effort from the instructors.

5.2. *Engagement and motivation of safety training with VR serious games*

5.2.1. *Positive effect of using VR serious games as safety training tool*

Engagement and motivation were assessed after the employees played the VR LaboSafe Game as training tool in order to compare the lecture-based training method with the VR serious game method. Firstly, the results show that the lab safety training with VR serious game has significantly higher scores on intrinsic motivation and on all measured attributes of engagement (i.e. absorption in the task; control and active learning; and behavioural intention). The interviews with the participants confirm that most of them are in favour of VR serious games than lecture-based methods in terms of engagement. In general, with VR-based training, employees believe that they are more active, attentive and have more control of their learning process. Furthermore, coinciding with the framework of Casey et al. (2021), trainees enjoy that VR has the possibility to realise situations that are more relevant for them and that they are able to be immersed in a semi-realistic environment. However, the novelty effect of the technology plays a large role in this increased engagement which could wear off after multiple uses (Makransky and Petersen, 2021). Nevertheless, employees will still be interested when VR keeps bringing new content every time. So, results of this study concur with the engagement classifications of previous reported literature where lecture-based methods were assumed to be low-engaging methods and VR-type methods as high-engaging methods (Burke et al., 2006; Casey et al., 2021).

When looking at motivation for VR safety training on an individual level, we determined five motivational profiles: *highly autonomous*, *highly motivated*, *autonomous*, *low-controlled* and *neutral*. Compared to motivational profiles for conventional safety training, the *highly motivational* and *low-controlled* motivational profiles are two profiles that were not described before while no people were identified with *amotivated* profile anymore. Moreover, with VR serious game as training method, more people (n = 11) are identified with high-ranked profiles (i.e. highly autonomous, highly motivated) than when a lecture-based training method (n = 6) is given. These changes can be related to the aforementioned strengths of using VR as training tool, since these employees find training with a VR serious game more engaging and more amusing while feeling less obliged.

5.2.2. *Limitations of using VR serious games as safety training tool*

When looking at individual groups of participants, it was observed that motivation to attend a VR safety training is primarily related with age, while no significant correlations are associated with gender nor VR/game experience. Younger employees (20–30 years old) have high-ranked motivational profiles, namely *highly autonomous*, *highly motivated*, *autonomous*. Older employees (51–60 years old) have a lower-ranked motivational profile, namely *low-controlled*, *neutral*. Furthermore, age is found to be negatively correlated with intrinsic motivation and positively correlated with amotivation. Based on the interview results and the fact that the age of employees is positively correlated with the time spent in VR, a possible explanation could be that the usability of VR technology is more complicated for older people. This interpretation seems to align with the definition of ‘digital native’ and ‘digital immigrants’. *Digital natives* are people, commonly from younger generations in developed countries, who are more proficient with the use of digital technologies. Whereas *digital immigrants*, commonly people from older generations, are not used to these technologies (Prensky, 2001). Digital natives have more experience with using the internet, using smart devices and playing video games, thus being more skilful than digital immigrants (Akçayr et al., 2016). This is also reflected in the negative correlation between game experience and time spent in VR tutorial levels. The novelty of VR technology can also bring mild ergonomic issues when users are not used to it. First-time users mentioned that long periods of constant concentration and movement can make them tired, slightly nauseous or lose spatial awareness. Despite these issues of using a novel tool, most employees are still willing to familiarise themselves with VR technologies. They suggested to provide more frequent and smaller session with VR while also introduce the technology gradually for first-time users. This means that the employees are more attracted to participate in multiple VR safety training sessions than with conventional methods, thus improving safety participation and safety culture. Regular practise of risk assessment and emergency situations allows employees to maintain their skill sets and leads to workplace improvements (Ruttenberg and Rice, 2019).

An important observation for chemical companies is that employees do not believe that VR safety training can replace conventional safety training. While a VR serious game is good to practise real-life dangerous situations, it is less suited to learn factual knowledge about safety (Makransky et al., 2019). This attitude about VR safety training could explain the significant lower scores for identified regulation and higher scores for amotivation compared to conventional methods. Employees are used to attend safety training with conventional methods, but are unfamiliar with using VR games as training tool. They are certain that conventional safety training has a high priority for them. However, based on the questionnaire and interview results, it could be that they do not know if VR serious games will be as important for them, since some people have minor issues with the technology. Nevertheless, they suggest VR serious games should be used as a complementary tool to lecture-based training. Conventional safety training can be given before the VR serious game to teach theoretical content and can also be given after the VR experience as a debriefing session (Crookall, 2010).

6. Conclusions

The current study shows that lab technicians and managers in a chemical company have a high autonomous motivation to follow safety training, particularly in terms of identified regulation. They find it important to acquire the necessary skills to maintain a safe work environment for themselves and their peers. However, some employees find conventional training methods (such as classroom and video lecture) not entertaining, because they are rather passive, find it too repetitive and can quickly lose their attention. It is important to make safety training more attractive and engaging in order to stimulate safety participation. In this study, we found that providing a safety training with a VR serious game, such as the VR LaboSafe Game, significantly increases intrinsic motivation and engagement of the trainees. They mention that they are more active, can keep their attention better and enjoy the realisation of relevant situations in a virtual environment. This leads to a significantly lower controlled motivation and makes people more oriented to higher-ranked motivation profiles.

However, this study also presents limitations of using VR as safety training tool. The digital novelty of VR technology makes it hard for people to get used to such training method. Complicated usability and uncomfortable ergonomics can lead to lower-ranked motivational profiles. Especially older employees (above 50 years old) in this study have more issues with this technology than younger employees (below 30 years old). Moreover, some learning content are better taught in a classroom than with VR. So, people are still unfamiliar with VR serious games being used in safety training which explains that some people believe that safety training with VR serious games is not more important for them than with conventional methods. In order to overcome these shortcomings, it is suggested to combine conventional methods with VR as complementary tool and provide more frequent and smaller sessions, gradually introducing VR technology to beginners.

At the end, employees are more intrinsically motivated and are more willing to reengage with VR safety training than with conventional training methods alone. So, when employees like to follow more safety training sessions and more frequently, their attitude towards safety training will improve which could eventually bring better safety outcomes.

6.1. *Future research*

While motivational profiles are commonly analysed in education, they are rarely used in context of safety training. More research is needed to comprehend the motivational driving forces for safety education in various companies with different safety culture and in international settings. Also, future work should focus on long term effects of using VR serious games on safety performance variables, such as safety motivation and safety participation.

6.2. *Limitations*

Results of the motivational profile analysis could be affected due to the relatively small sample population. However, a larger sample size could not be achieved due to the extensive testing duration and due to the limited availability of volunteering employees at the chemical company. Another limitation of this study is that the elevated engagement and motivation could be subdued by the volunteer bias. Though, obliging employees to participate could also affect the results.

CRediT authorship contribution statement

Philippe Chan: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Tom Van Gerven:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Jean-Luc Dubois:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Kristel Bernaerts:** Writing – review & editing, Supervision, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement 812716. This publication reflects only the author's view exempting the community from any liability. Project website: https://charming-etn.eu/.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2023.106278.

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