HOW CAN LEARNING EXPERIENCES BE EXPLORED IN SIMULATION-BASED LEARNING SITUATIONS?

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ABSTRACT

The aim of our research is to investigate what methods can be used to explore learning experiences. In this case example, we describe how we extracted quantitative and qualitative data reflecting learning experiences from simulation-based learning (SBL) situations. Data collection was conducted in the fields of aviation and forestry. After the SBL situation, the students participated in a stimulated recall interview. The transcribed interview data were analysed using data-driven methods. To capture the dynamics in the (neuro)physiological signals associated with varying states of learning experiences, we recorded activity of the autonomic and central nervous systems. When analysing (neuro)physiological data, we focused on extracting reliable signatures reflecting both the state and the reactivity of the autonomic and central nervous systems. Later on, different data types will be integrated and analysed together. The aim of this article is to elaborate the extent to which different data types can be integrated in analysis to produce meaningful information about learning experiences. Our results based on the students' interviews highlight the meaningfulness of the instructor's guidance in SBL situations. We also show that it is possible to extract reliable features from (neuro)physiological signals measured during natural learning situations. These (neuro)physiological features also seem to vary depending on the phase of the simulation. Therefore, we conclude that by including (neuro)physiological

measurements in research designs, it is possible to achieve a more comprehensive understanding of learning experiences. This type of multidisciplinary research is likely to provide novel insights in developing learning environments and guidance.

INTRODUCTION

There is increasing interest in exploring learners' emotions and their role in learning and teaching processes (Damasio, 2000; Rienties & Rivers, 2014; Rowe & Fitness, 2018; Zeivots, 2016). In addition to emotions, the increased understanding of the links between experiences and the related (neuro)physiological states and reactions during learning enables new insights in developing educational practice and research methods. As learning experiences form via complex processes, the integration of different methods and theoretical frameworks could provide a more detailed understanding of the characteristics involved in learning experiences.

In previous studies, varying combinations of (neuro)physiological measures, such as electrodermal activity (EDA) or skin conductance responses (SCR), heart rate (HR) and heart rate variability (HRV), eye-tracking and electroencephalogram (EEG), and experiential measures, such as self-reports, video recordings and questionnaires, have been employed to investigate adult learning experiences. For instance, affective or emotional learner experiences have been investigated in combination with EDA and SCR measurements (Eteläpelto et al., 2018; Hardy et al., 2013). Larmuseau et al. (2019) used a combination of EDA, skin temperature and self-reports to assess cognitive load during learning tasks. In addition to physiological measures, neurophysiological measures, such as EEG, have been combined with eye-tracking and video recordings to understand learning experiences (Giannakos et al., 2019). Multimethod approaches have also been applied in technology-enhanced learning environments with the aim of improving learning experiences and outcomes (Aguayo et al., 2018; Cowley et al., 2013; Girzadas et al., 2009; Wang & Cesar, 2015). The very different methodologies used in these studies highlight the need to integrate standardized research methods and theoretical frameworks when investigating holistic learning experiences.

While the basis for rudimentary (e.g. perceptual) learning is in repetition, the learning of more complex entities often requires the disruption of routines. According to Malinen (2000), meaningful learning experiences, 'fractures', distort familiar and safe lifelines and mindsets and are consequently starting points for a critical and analytic phase with beneficial self-reflection of one's own way of thinking or doing. The experiences ultimately build on the basis of the actions and reactions of our nervous system, which incorporates mechanisms both for learning through repetition and change in perspective via an elaborated change in the mindset. For the ongoing evolving of learning experience, it is likely that our brain and body systems also offer a specific 'tone' contributing to the state of mind that can be more or less beneficial for safe and successful learning experiences.

Simulation-based learning (SBL) as a learning method can be theoretically approached from the perspective of experiential learning (see e.g. Kolb & Kolb, 2017). SBL situations are suggested to be powerful learning experiences due to their authentic nature and connection to emotions and reflections that they stimulate, which are also debriefed as part of a SBL situation (e.g. Bearman et al., 2019; Fromm et al., 2021; Lateef, 2010). Moreover, SBL enables the varying of different elements, such as the difficulty level of learning tasks or the involvement of an instructor.

We explored SBL situations by applying autonomic and central nervous system recording techniques in combination with traditional educational research methods, such as stimulated recall interviews. The SBL context offers an excellent opportunity to scientifically approach experiential learning, as it can be a) controlled according to a specific simulation protocol and enable higher (neuro)physiological quality recordings and b) generates authentic learning experiences. As no detectable features in the (neuro)physiological signals directly correlate with learning experiences, we focus on extracting well-studied characteristics from the (neuro)physiological data that are linked to particular states, such as arousal, stress and attention (Berntson et al., 1997; Klimesch, 2012; Quintana et al., 2012).

In this case example, we describe how we extracted experiential and (neuro)physiological data from SBL situations. Furthermore, we present some preliminary findings regarding self-reported learning experiences and the variation of (neuro)physiological activity during the different phases of an SBL situation.

RESEARCH QUESTIONS

The central research questions of our project are as follows:

- How can learning experiences be measured in natural settings? What methods and technologies can be used to explore self-reported learning experiences, (neuro)physiological activity and reactions associated with these experiences?
- What is an SBL situation like as a self-reported learning experience?
- How can (neuro)physiological recordings be used in investigating self-reported meaningful moments of SBL?

METHODOLOGY

Participants

Data collection was conducted in natural learning settings in the fields of aviation and forestry. The participants were six aviation pilot students, two aviation training instructors, six forestry students and two forestry training instructors, and they formed 12 student–instructor dyads. The students' ages were between 16 and 25. All participants were male. Written informed consent was obtained from all participants before the study began, and the study was conducted in accordance with the Declaration of Helsinki. The study protocol was approved by the local ethics committee of the University of Jyväskylä.

Procedure

Data collection for a dyad lasted approximately 3.5 hours, including preparations for the (neuro)physiological measurements, the SBL situation and a stimulated recall interview. Each SBL situation was video-recorded to gather detailed information on the timeline and events during the different phases of the simulation.

All SBL situations consisted of three phases—an introduction, the performance of tasks and a debriefing. An instructor guided each student throughout the SBL situation. At the introduction phase, the instructor explained the topic and structure of forthcoming simulation tasks and gave the student general instructions. In addition, the student had the opportunity to ask questions. During the simulation tasks, the difficulty level increased progressively, and after every task the student's performance was briefly reviewed. After all tasks were completed, an in-depth debriefing was carried out where both the instructor and the student commented on and evaluated the student's performance of the tasks. After the SBL situation, the students participated in a stimulated recall interview; this included watching their own performance on the video recording. During the interview, the students also filled out a form where they reported episodes they considered relevant in terms of their learning and described these moments to the interviewer. To gather information about the instructors' pedagogical thinking and conceptions about the SBL, the instructors were also individually interviewed.

As there was an extensive amount of equipment used (e.g. simulators as training tools, various physiological measurement devices), we wanted to know whether the equipment may have caused any disturbance in terms of the learning situation. Therefore, we gathered information about the learners' possible attention to the research setting. Consequently, at the beginning and at the end of the interview, the participants were asked about their general experiences, which gave them an opportunity to reflect on their experiences, the research setting and the measurement equipment. The participants were also free to give the researchers feedback at the end of the interview.

To capture the dynamics in the (neuro)physiological signals that are associated with varying states of learning experiences, both autonomic (electrocardiogram [ECG]; frequency and phases of respiration) and central nervous system (EEG) activity were monitored throughout the SBL situation. Each dyad was measured simultaneously. Physiological and neurophysiological signals were recorded using the Bittium NeurOne system (Bittium Biosignals Ltd, Finland). EEG signals of all the instructors and aviation pilot students were recorded using a standard 64-channel EEG cap (EASYCAP, BrainProducts GmbH, Germany). As a virtual reality headset was used in the forestry SBL situation, a customized 13-channel EEG cap (neoprene headcap with NG geltrode electrodes and press stud cables, Neuroelectrics, Spain) was used for the forest machine operator students. Together with the EEG, cardiac and respiratory signals were simultaneously recorded using two ECG electrodes placed beneath each collar bone and a flexible piezo-based respiratory belt (Spes Medica, Italy) placed around the participant’s lower chest. During the SBL situations, annotations, such as a timestamp at the beginning of each task, were added to the (neuro)physiological data for later temporal synchronization of different data modalities.

Analysis

Each data type was pre-processed and analysed separately. Later on, different types of data will be combined in the forthcoming analysis steps. The integration and synchronization of different data modalities will improve our understanding of learning experiences on several levels, ranging from self-reported experiences to (neuro)physiology.

Video recordings of SBL situations

Video recordings were used to gather information on the timeline of the SBL situation to enable the integration of (neuro)physiological and experiential data. While watching the video recordings, a timeline with relevant annotations related to specific events during the SBL situation was created. The content of the video recordings will be analysed to gather information on the interaction and communication between the student and the instructor during the SBL situation.

Analysis of the interview data

The stimulated recall interview data of each student was examined using data-driven methods. The students’ interviews were first transcribed, and all expressed utterances were placed into a table format as a linear continuum of the events. It was important to maintain the temporal order of the events in the SBL situation. The interview questions also followed the SBL structure (i.e. the phases of simulation

from preparation to debriefing), thus further supporting the temporal representation of the SBL events.

The utterances were given content descriptions and a code that described them in terms of the content. To increase the reliability and validity, two or three researchers then independently generated codes for the contents. To reach agreement, each code was jointly discussed. Consequently, thematic entities that emerged during the coding process were generated to describe the main elements of the SBL experiences. For the forestry data, the researchers focused more on a few thematic elements selected in advance, whereas for the aviation data all utterances were utilized to form a more comprehensive description of the SBL situation as a learning experience.

Analysis of the EEG and ECG data

In the analysis of (neuro)physiological data, we focused on extracting reliable, artifact-free signatures reflecting both the state and the reactivity of the autonomic and central nervous systems throughout the SBL situation.

First, the signal quality of the EEG data was visually inspected and electrodes with poor signal quality were excluded from further analysis. Second, artifacts such as eye blinks, saccades and heart beats were removed using independent component analysis. After re-referencing and filtering, the data was converted from time-domain to frequency-domain using Fast Fourier Transform. Finally, measures of rhythmic brain activity, particularly alpha-band oscillations, were extracted from the pre-processed EEG data. ECG data was pre-processed and analysed using Kubios HRV Premium software (Biosignal Analysis and Medical Imaging Group, University of Eastern Finland, Kuopio, Finland), which provides standardized and validated methods for extracting both HR and HRV measures from the ECG signal (Tarvainen et al., 2014). Both time-domain (e.g. mean HR, root mean square of the successive R–R differences) and frequency-domain measures (e.g. frequency components of HRV) will be investigated.

After pre-processing, the data will be analysed using two different approaches—state-based analysis and analysis of continuous signals. In the state-based analysis, the SBL situation is divided into behaviourally and pedagogically distinct phases (e.g. rest, simulation tasks, debriefing) based on the analysis of video recordings. This allows us to investigate the (neuro)physiological characteristics in each behavioural and/or pedagogical state both at the individual subject level and also as a group average. In the data-driven analysis of continuous data, we focus on investigating the time-varying nature of (neuro)physiological signals. This approach enables the investigation of intra- and inter-subject synchrony of the ongoing neural and bodily signals (e.g. HRV−EEG synchrony within an individual, HRV−HRV synchrony between the student and the instructor) during the SBL situation.

RESULTS

It should be noted that the analysis is currently in progress. Therefore, only preliminary findings regarding the stimulated interviews and EEG and ECG data are presented here.

Self-reported learning experiences

Our preliminary results based on the students' interviews highlight the meaningfulness of the instructors' feedback and guidance in SBL situations. This finding is in line with theoretical knowledge of experiential learning in which an open and confidential dialogue between a student and an instructor is one critical aspect supporting learning (see e.g. Schön, 1983). In both aviation and forestry, the role of the instructor was made manifest, for example, through advice, feedback, joint discussion and reflection, which highlights the value and importance of reciprocal interaction in SBL. Instructors might also play a significant role in what aspects of SBL students pay attention to, whether the discussion during learning is focused on technology and its effect on the learning experience or whether the focus is on learning experiences per se. Notably, in the descriptions presented by the students while relating their learning experiences, the instructors appeared to have a significant role in the learning process. However, these are only descriptions of the instructors' actions from the students' perspective and not direct interpretations of the instructors' behaviour, which could be interpreted from the video recordings in the future.

Likewise, simulator features were seen to affect the learners' experiences. The role of technology was indeed emphasized, as tasks were performed with simulators, which is likely to have an effect on students' experiences. For instance, many of the students' meaningful episodes were observations relating to mistakes and successes in performance during tasks, and they were mainly focused on technological issues.

In addition to these thematic elements mentioned above, the influence of simulation technology and experimental setting could also be considered when investigating learning experiences with this kind of multimethod approach because they seem to affect the way the learners experience and verbally describe their experiences during the SBL situation. As expected, many of the students somehow took into account the presence of the measurement equipment (mainly the EEG), and some also mentioned being aware of the researchers being physically present in the room. In relation to their learning experiences, the students stated that at first they were pretty much aware of the ongoing measurements, but when the SBL situation progressed and

tasks became more intensive and challenging, the measurements and the presence of the researchers were more or less forgotten. Overall, research equipment was not considered to play a significant role, as students indicated being fairly focused on the SBL tasks.

EEG and ECG data

Although individually varying amounts of artifacts were observed in the (neuro)physiological signals, the EEG and ECG recordings were successfully performed for all individuals. Our preliminary analysis of the EEG and ECG data shows it is possible to extract reliable and robust features of EEG and HRV signals measured in natural SBL situations. Regarding EEG, the most robust measure seems to be alpha-band oscillatory activity. Moreover, the variability of alpha activity can be associated with varying arousal levels. Indeed, our preliminary analysis of EEG data indicates clear separation between task vs. no-task states. Because ECG forms the basis for the computation of various HR-based measures, they can be used to particularly assess the parasympathetic activity of the autonomic nervous system during the SBL situation. As an example, the variability of the mean HR (beats per minute) during the different phases of the SBL situation is presented in Figure 1. Based on the visual inspection of the HR data, this measure of autonomic nervous system activity seems to vary depending on the phase of the simulation (e.g. rest – task – feedback) both for the instructors and the students; however, more statistical testing is needed to confirm these preliminary findings.

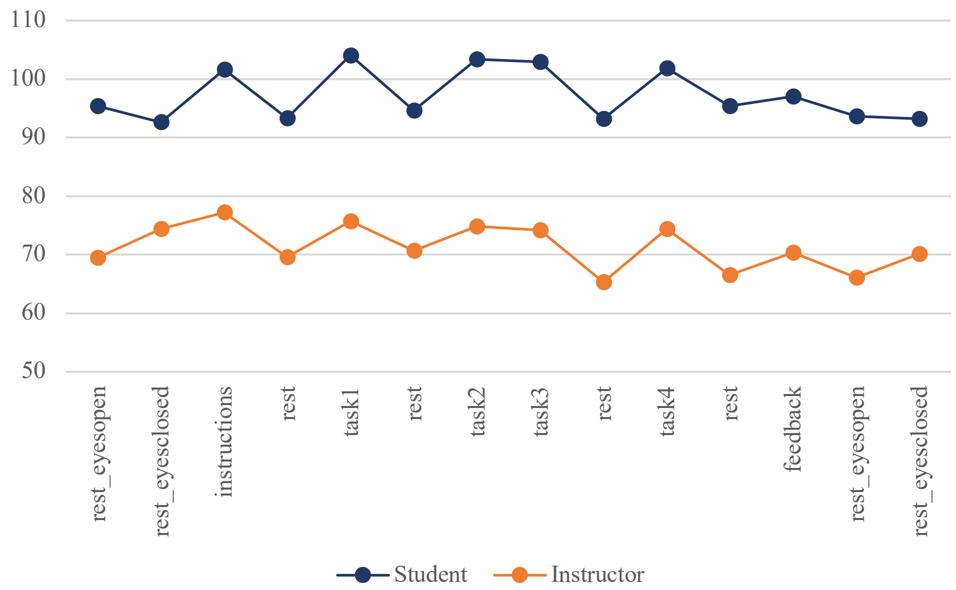

Figure 1. An example of the variability of the mean heart rate (beats per minute) of a student–instructor dyad during the different phases of the SBL situation

DISCUSSION

The aim of our research is to investigate what methods can be used to explore self-reported learning experiences and (neuro)physiological characteristics that are associated with these experiences. Simultaneously, we also respond to the lack of empirical evidence in investigating learning experiences in SBL situations (Silvennoinen et al., 2020). With our multidisciplinary and multimethod approach, we are opening up new possibilities to understand learning experiences by acknowledging that they cannot be understood by exploring each aspect in isolation. Therefore, the integration of various types of data to capture simultaneous changes in both (neuro)physiology and reported experiences is essential to deepen our understanding (Silvennoinen et al., 2020).

As the (neuro)physiological recordings were successfully performed and we were able to extract reliable and robust features of EEG and ECG signals measured in natural learning situations, it seems fair to say that (neuro)physiological measurements can be included in research designs aiming to understand the complex nature of learning experiences more comprehensively. However, conducting research that combines educational and (neuro)physiological methods is not straightforward. First, the signal quality measured in natural learning settings is typically poorer due to the missing shielding against electromagnetic interference. Furthermore, natural movements related to the simulation tasks and student–instructor interaction (e.g. steering the simulator, talking) may further weaken the quality of the measured (neuro)physiological data. Therefore, advanced knowledge and use of state-of-the-art analysis methods is required to obtain reliable results. Second, due to the complex nature of natural learning situations, the analysis and interpretation of the data is far more challenging compared to experimental designs used in a controlled laboratory environment. Although exploring learning in natural settings involves challenges, modern technology such as lighter and mobile measurement technologies and methods such as SBL enable developing research designs to investigate learning experiences based on their most authentic nature.

Our preliminary results also highlight the influence of the instructor and simulation technology on the individual learning experiences, learning outcomes and interaction. For instance, when seeking to explore a learner's experiences, the impact of the instructor on the course of discussion may be relatively high, which in turn should be taken into account. Moreover, natural learning situations involve instructor–student interaction, but the research setting necessitates that part of the multidisciplinary research team be physically present in the situation. This inevitably changes the dynamics of the interaction, which is important to try to ignore as much as possible. As the impact of instructors on students' learning experiences seems to be relatively high, there is a need to explore the existence and meaning of interaction as a synchrony between instructor and student with different measurement modalities in more detail (e.g. HRV-EEG, EEG-EEG). It is worth noting that combining different types of data is also challenged by different traditions in terms of methodologies and analysis processes. Therefore, experts from each discipline are required to be involved in the analysis processes and interpretation of the findings.

In the future, we need to improve our understanding of how various elements, such as authenticity and features of the simulators and experimental settings, affect learning experiences. When the authenticity of the learning situation is considered, the differences between real situations and simulations need to be taken into account. The authenticity could also be improved by using VR technology, which may provide an enhanced feeling of authenticity through immersion (see Vesisenaho et al., 2019). Furthermore, the degree to which the experimental setting and measurement devices used (e.g. EEG cap, HRV electrodes) affect the authenticity and operability during the SBL situation should be assessed. For some individuals, the experimental setting might feel disturbing, whereas others may almost forget the research instruments and be fully focused on the SBL situation. Therefore, careful planning and implementation of the experimental setting and the use of mobile measurement technologies could further improve the authenticity of the research conducted in SBL situations. This type of multimethod and multidisciplinary

research that takes into account various elements affecting learning experiences is likely to provide novel insights into how learning environments and guidance can be developed to support learning processes in the most effective way.

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