Durall, Eva; Leinonen, Teemu

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Feeler: supporting awareness and reflection about learning through EEG data

Eva Durall[1], Teemu Leinonen[1]

[1]Learning Environments research group. School of Arts, Design and Architecture. Aalto University. Helsinki, Finland
{eva.durall, teemu.leinonen}@aalto.fi

Abstract. In education, sensor technologies are regarded with interest and new systems making use of physiological data are developed with the aim of augmenting cognition and personalize learning. This paper maps most common biomarkers associated to learning and discusses mainstream approaches adopted in education. It is claimed that students' data should be used to support self-awareness and reflection and Feeler, a design-in-progress tool that fosters reflection about learning experiences through EEG data is presented. Feeler design is carried out with research-based design methodology. The research borrows from experiential learning theory and design approaches based on inquiry and experience. Feeler design makes use of time, personal experience, the display of hidden information and incompleteness as key elements for reflection. Feeler research aims to discuss the possibilities and challenges of biomarkers in learning and education. The next stages of Feeler research include testing the prototype and iterate the design.

Keywords. biomarkers, EEG, reflection, awareness, learning

1 Introduction

In behavioural sciences, in learning science and study of education, an increasing number of scholars are working on the identification of biomarkers related to learning. Due to the close connection between cognitive functions and learning [5], most promising methods for studying users' mental context during learning come from neuroscience.

This paper discusses the use of biomarkers in learning, focusing on brain electrical activity through electroencephalographs (EEG). Concretely, it explores how this data can support students' awareness and reflection about how their mental states affect their study performance. The focus of the paper, however, is on Feeler prototype, a tangible computing device designed as part of the research. The prototype engages users in brain waves self-monitoring through an EEG device.

The following sections include a review of the most common real-time biomarkers used through non-invasive technology for monitoring learning, as well as a description of Feeler prototype. The research methodology and design strategies adopted are also described, as well as some early conclusions of the ongoing research about how to support awareness and reflection about learning through physiological data.

2 Biomarkers for monitoring learning

Much of the current literature on biomarkers connected to learning pays particular attention to the identification of mental states dealing with cognitive load, attention, meditation, mental fatigue, alertness, emotions, and stress. Table 1 presents a list of most frequently used real-time biomarkers using non-invasive technology for monitoring different aspects connected to learning. The list is not exhaustive, but it gives an overview of the main aspects tracked in education.

Table 1. Mapping of most frequently used real-time biomarkers using non-invasive technology

	EEG	**Skin Conductance**	**Heart Rate**	**Pupil Dilation / Blink Rate**	**Body Posture / Gaze**	**Expression Recognition**
Cognitive Load	x	x	x	x	x	
Attention	x			x	x	
Meditation	x		x			
Mental Fatigue	x	x		x	x	x
Alertness	x		x	x	x	x
Emotions	x	x	x	x	x	x
Stress	x	x	x			x

Cognitive load is a term used in cognitive psychology to describe the amount of effort that a particular task requires to the person executing it. It's a multidimensional construct that takes into consideration how mental workload dealing with learning, thinking and reasoning demands from working memory. According to cognitive load theory, the ability to learn is limited when working memory is overloaded [5].

Most popular biomarkers used for monitoring cognitive load, attention and mental fatigue are pupil dilation and EEG. Experiments focusing on pupil dilation while performing cognitive tasks have concluded that the increase in pupil size correlates to the increase of mental workload [6]. As noted by [17], blink rate decreases when subjects deal with cognitively demanding tasks.

As alternative to eye monitoring systems, EEG has proved a reasonably good technique for tracking changes in cognitive activity associated with cognitive load [12, 17]. Due to EEG data reliability, EEG has been widely adopted as a technique for monitoring all mental states connected to learning. Despite accurate interpretations of EEG can be complex, changes between different mental states can be easily spotted As a short summary, delta waves can be linked to deep sleep, theta to deep relaxation and meditation and alpha to states in which the person is physically and mentally relaxed. Beta would be predominant when the person is awake and gamma when she is performing cognitively demanding tasks. EEG has been used not only to monitor but also to enhance learning. For instance, in neurofeedback EEG has been also applied to activate specific aspects of people's cognitive performance [16].

During last decades, several scholars have recognized the importance of emotions in learning [7]. As a consequence, an increasing body of research is exploring how to monitor learners' emotions in order to give feedback to educators, personalize students' learning experiences and create awareness with the aim of enhancing self-regulation skills. Most popular biomarkers used in the field of emotion are skin conductance [10] and expression recognition [1].

Skin conductance has also been used for detecting stress. In education, stress can enhance or block learning and memory [11]. Therefore, biomarkers that indicate stress based on changes in skin conductance and heart rate have been used to improve user experience by designing systems that identify and react to user's stress levels [9].

In formal education, research on biomarkers associated to learning has been used to personalize learning and inform the design of augmented cognition systems. Augmented cognition is an interdisciplinary research field that seeks to measure users' cognitive status with the aim of creating applications that regulate the information flow according to the users' cognitive capacity. Despite augmented cognition environments can be a powerful tool for leveraging cognitive load and improving efficiency when dealing with complex information, its' use in formal education contexts poses some challenges. For instance, in many occasions biomarkers are not directly related to learning, but to the conditions that are considered necessary for learning to occur. In addition, it's important to note the difficulty to define some general standards that could be applied to identify individual mental states. Considering the opportunities that the monitoring of physiological data offers for supporting learners' self-understanding, rather than personalizing learning environments that make use of biomarkers should be oriented to create awareness and reflection. Feeler design research makes use of EEG data to foster learners' thinking about their mental activity when studying.

3 Feeler: a reflective tool based on EEG self-monitoring

Feeler is a prototype created in the framework of a research looking for solutions to help people develop awareness on how different habits and mental states have an impact on their learning. The aim of Feeler research is to encourage reflection about physiological data related to learning, such as brain wave activity, in order to improve learning experiences.

Feeler is built around a script that structures a study activity in three stages. The tangible computing tools are guiding students to realize the scrip. The stages are

1. Meditation: user receives guidance to perform deep breathing and relaxation exercise before studying.
2. Study: users' online search behavior is monitored and some metadata is saved. The metadata is visualized once the study session has ended.
3. Self-assessment: Once time for study is over, user is encouraged to answer some reflective questions about their activity.

Fig. 1. Feeler interactive tangible objects and screen capture of the data visualization.

Feeler scenario of use draws on research demonstrating the positive effects of meditative practices on cognitive performance [3]. EEG about mental states is monitored during the whole session. This data is sent to a desktop app that visualizes the information once the user has ended the study session. The information recorded includes: meditation and attention levels, as well as brain waves (delta, theta, alpha, beta, gamma) and blink rate.

During the activity, within the headset that monitors EEG activity, students are given a set of physical, computational blocks that guide their actions during the different stages (figure 1). By interacting with each block, students receive instructions about the task through visual and haptic feedback. Although brain waves data is monitored throughout all the study activity, this information is not displayed in the devices.

4 Research and Design Methodology

Feeler design is carried out with research-based design methodology [14], which identifies 4 phases in the design process: Contextual Inquiry, Participatory Design, Product Design and Design of Prototype as Hypothesis. The design activity is characterized for being highly iterative and should not be understood as a linear process [14].

So far, 6 semi-structured interviews, 2 focus groups (5 attendants in each one) and 3 co-design workshops (number of participants ranged from 5 to 4 people) have conducted as part of the contextual inquiry and participatory design research (N=22). In all cases, participants were high education students with ages comprised between 25 and 45 years old. Their countries of origin were America, Europe and Asia.

The interviews and the focus groups were part of the Contextual Inquiry research. In these cases, the aim was to define the design space and identify main possibilities and design challenges. Interviewees were asked to define through pictures and in their own words the following concepts: health, mindfulness and well-being. In the workshops, participants were invited to explore how well-being could be connected to learning through self-monitoring. With this aim, a design game about reflection on self-monitored data was created. Main conclusions extracted from the workshops dealt with the amount of data that should be visualized, as well as the difficulty to find learning indicators. Regarding the data visualization, participants showed interest in having access to the raw data, although they also highlighted the need of some initial analysis that helped them make sense out of it. In relation to learning, students considered necessary to distinguish between learning and academic activity since, from their point of view, learning is not limited to their studies and takes place in very different situations and contexts.

The 3 co-design workshops organized as part of the Participatory Design stage made use of the feedback obtained during the Contextual Inquiry and helped to extend understanding on how to monitor learning and visualize information. These workshops were conducted with students of Kyushu University Design School. Students expressed interest in ambient visualizations and their wish to access different information levels in the visualization design. Main design constraints dealt with students' short time for reviewing the data, as well as strong privacy concerns.

The empirical data gathered during the Contextual and Participatory Design stages informed Feeler Product Design. Literature from educational and design research was reviewed in order to support awareness and reflection on self-monitored data.

Feeler design builds on experiential learning cycle [13] in which reflection is understood as a cyclic process characterized by concrete/abstract and action/reflection dialectics. From this perspective, learning is tightly connected to experience and it involves all areas of human functioning (thinking, feeling, perceiving and behaving). In Feeler, we expect that the concrete experience of monitoring EEG activity would support reflective observation, which would enable some abstract conceptualization. These hypotheses could be tested through active experimentation that would lead to the production of concrete experiences. Feeler is designed as a tool for self-knowledge, so behavior change is not considered as a priority.

Despite workshop participants did not express clear interest in monitoring their brain wave activity, Feeler design focuses on the visualization of EEG data. This decision was motivated by [6]'s technology levels of reflection, concretely the one labeled as *Dialogic reflection*. According to [6], the presentation of "hidden information", such as the obtained through self-monitoring can support awareness and reflection by fostering users' curiosity. Due to the close connection between EEG and learning, the display of this type of data can help people increase understanding on their mental activity by making connections and seeing things from multiple perspectives.

The design approaches for supporting reflection that are taken into consideration during Feeler research are slow technology, inquisitive design and technology as experience. Slow technology [8] is a design philosophy in which time is considered as a prerequisite for reflection. As students' feedback showed, the time they are willing to allocate to reflect on their own activity, no matter what benefits it may bring in the future, is quite short. In Feeler, the introduction of a script slows down the academic activity with the aim of encouraging students to take the time to think about their study performance in relation to their EEG data.

Inquisitive design and technology as experience emphasize the role of experience when designing for reflection. Inquisitive design [4] introduces experience and conflict as key elements to support deep thinking through exploration and experimentation. The visualization of personal data in Feeler prototype is expected to create a strong link with participants since they have a first hand experience that, hopefully, will motivate them to explore the data more deeply. The decision to let the users interpret the data recorded during the session (gamma, beta, alpha, theta and delta activity, as well as meditation, attention and blink rate) creates some uncertainty and act as the basis of an inquiry process in which students identify and explore how different mental states affect their study performance.

With the term technology as experience, [15] calls for the need to develop richer models for HCI that truly take into consideration experience and how people make sense of it. Openness and incompleteness are presented as part of the strategies that designers can use to support dialogic relations between different stakeholders. The last module of Feeler tangible prototype presents the user three questions: 1) How did you feel during the session? 2) What do you expect from EEG data and 3) What would you change for next session? These interrogations are intended to support reflection and help them contrast their subjective experience with the physiological data monitored by the system.

The analysis of the information gathered through the workshops has been used to develop the first Feeler prototype, which is part of the Product Design stage. This design will be tested with MA students of Aalto Medialab and more iterations are expected in the short term.

5 Conclusions

In this paper Feeler prototype is presented as a learning tool that supports awareness and reflection about study activity through EEG data. Feeler design is based on the assumption that learning technology based on monitoring physiological data should aim to empower students by helping them understand the different aspects that have an impact on their learning performance. Therefore, Feeler research explores several strategies for supporting reflection in the prototype design such as the creation of time, asking reflective questions and leave some aspects incomplete in order to encourage users to inquire its meaning.

The methodology adopted, research based design, is strongly influenced by participatory design and human-centered design. Despite that the Feeler research is still ongoing, we consider relevant sharing the research approach and early conclusions in order to open the discussion on the role of physiological data for supporting awareness and reflection in learning.

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