Department of Media

Reflection and Self-Regulation Using Monitoring Tools in Learning

Critical Design Exploration on Self-Monitoring During Independent Study

Eva Durall Gazulla

Aalto University

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Abstract

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Abstract

This doctoral dissertation used a research-based design approach to explore the opportunities and challenges of using monitoring tools in learning. Although the practice of monitoring is considered key in the acquisition of important learning skills, such as self-regulation, monitoring tools are still an emerging technology in teaching and learning.

While researchers and practitioners have started exploring how to use monitoring tools for teaching and learning, little attention has been dedicated to critical issues regarding the adoption of techno-monitoring practices in learning contexts, like the nature of data and the inferences that are made based on them, the role of students in learning, and the conception of learning and technology. This dissertation aims to address this research gap and provide an understanding of the issues related to the design of monitoring tools and the adoption of techno-monitoring practices in learning through a critical exploration of self-monitoring during independent study. To this end, the articles included in this dissertation elaborate on the values and socio-economic discourses that are embedded in the design of monitoring tools, on the issues related to the design process, and on the implications that monitoring tools have for learning.

The research contributions of this dissertation include the introduction of a functional prototype (Feeler) that uses self-monitoring of brain activity in independent study situations, as well as the identification of several implications to take into consideration in the adoption and design of monitoring tools. The design of the prototype was informed by the participatory design and human-centered design traditions and allows students experience a hypothetical solution regarding the use of self-monitoring tools during independent study. This research builds on the analyses of students' reactions to the prototype, as well as on the findings from the research actions performed throughout the study to identify several implications for the design of monitoring tools.

These implications are organised around a set of key themes, which consist in self-knowledge, agency-oriented technology, reflection and self-regulation, and are expected to guide the design of monitoring tools, as well as the adoption of techno-monitoring practices. This research points at data-privacy and design for autonomy in learning as sensitizing concepts in TEL design and research. The design principles presented in this dissertation are exemplified by the Feeler prototype in order to help practitioners and researchers understand how the empirical findings can be translated into actionable ideas when designing monitoring tools.

Finally, this research should be regarded as an effort to introduce a humanistic perspective to the design of monitoring tools and the adoption of techno-monitoring practices in learning and a call for taking into consideration ethical aspects when analyzing the opportunities and challenges that monitoring tools pose to teaching and learning.

Keywords Monitoring Technology, Self-Monitoring, Reflection, Self-Regulation, Critical Design

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Acknowledgements

A doctoral research can be described as a journey. Usually, it starts with a challenge or question that takes you out of your comfort zone. At some point of the journey, you get overwhelmed, you fail and you try to keep going while learning from your mistakes. But above all, you get lots of help, much more than you would imagine and what you would dare to ask for. In this text I want to express my gratitude to the people who have been part of this journey.

First and foremost, I want to thank my two advisors, Teemu Leinonen and Begoña Gros. Throughout these years, they have shared with me their time and knowledge, offering guidance, criticism and support when needed. I have learned a lot from Teemu and Begoña at professional, but also at personal level. Teemu's approach to design and learning has been a great source of inspiration. The skills and confidence I have gained while working with him go beyond what I can thank in this doctoral dissertation. I truly appreciate the discussions we had, as they helped me look at things from different perspectives and gave me food for thought. Before staring the doctoral studies, I had the pleasure to work with Begoña. From the very beginning she trusted me (at some points more than myself) and offered me challenges that helped me learn and grow as researcher. Her open mind and rigor have been a great help for bridging the gaps between different areas. Thank you both, Begoña and Teemu, for your patience, trust and insightful feedback.

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My deepest gratitude goes to the members of the Learning Environments research group (Legroup). I would not had been able to walk this journey without: Tarmo Toikkanen, Juka Purma, Kiarii Ngua, Juha Kronqvist, Merja Bauters, Hans Poldoja, Anna Keune, Marjo Virnes, Jana Pejoska, Jaana Brinck, Iida Hietala and many others who have been part of Legroup. From them I have got advice, support and great conversations, but also laughs, complicity, and friendship, plus some sweets and fruits. I have learned a lot from each and every one of them. Thanks!

This doctoral dissertation has been developed in the context of two research projects: LEAD: Learning Design – Design for Learning (2012-2014, funded by Tekes - the Finnish Funding Agency for Innovation) and Humex – Quantifying Human Experience (2018-2020, funded by Business Finland). Having a funded position has enabled me to work full-time on the research, without struggling to find another job to sustain me financially. I am aware of this privilege. Everyone should have access to the same, if not more, opportunities I have had. By taking part in LEAD and Humex I have also been able to meet and collaborate with curious and passionate minds. Thanks to Jarmo Viteli, Matti Nelimarkka, Kai Kuikkaniemi, Teemu Mikkonen, Antti Syvänen, Suse Miessner and the many others who took part in LEAD. The researchers and partners involved in Humex have also provided me inspiration and energy. In particular, the cozy office of the Cognitive Brain Research Unit of University of Helsinki has been a safe space where work and joy go hand-in-hand. A warm thank you to Katri Saarikivi, Valtteri Wikström, Silja Martikainen and Mari Falcon.

As part of the LEAD project, I had the opportunity to do a research stay at Kyushu University faculty of Design (Fukuoka, Japan), at the inclusive design lab lead by professor Yasuyuki Hirai. I want to express my gratitude to Kari-Hans Kommonen for making this possible, to Hirai sensei for his kindness and great work, as well as to the members of Kyushu University for their generous support during this period. The inclusive design lab was my academic home in Japan. I am very thankful to the people I met there, who kindly showed me that collaboration and friendship do not necessarily require using the same language. My special thanks to Kyoko Maruo, Shinichiro Ito, Akihiro Kawaguchi, Yoshihiko Gogou, Yuma Mitsui, Qinggel Shi and many others who helped me during my stay at the faculty of design.

This research would not have been possible without developing research prototypes. Thus, the people involved in the technical development of the prototypes deserve my deepest gratitude, as quite often they had to bear with unexpected challenges and time pressures. A big thanks to Niklas Pöllönen, Régis Frias and Joaquín Aldunate.

Throughout the research, many people have generously shared their time and insights in interviews, focus groups, questionnaires, workshops and user tests. For the sake of anonymity, I will not mention their names. I truly appreciate the feedback and reflections they shared with me. Thank you all!

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Once more, thank you all, it has been a pleasure to share this journey with you.

Tapiola, 30 September 2018
Eva

Contents

List of Abbreviations and Symbols

EEG	Electroencephalographic
HCI	Human Computer Interaction
IT	Information Technology
LA	Learning Analytics
LED	Light-Emitting Diode
QS	Quantified Self
SDL	Self-Directed Learning
SRL	Self-Regulated Learning
TEL	Technology Enhanced Learning

List of Publications

This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their Roman numerals

I. Durall, E., & Leinonen, T. (2015). Why do we want data for learning? Learning analytics and the laws of media. In B. Gros, Kinshuk, M. Maina (Eds.), *The Future of Ubiquitous Learning. Learning Designs for Emerging Pedagogies* (pp. 59-72). Berlin Heidelberg: Springer. doi: 10.1007/978-3-662-47724-3_4

II. Durall, E., Leinonen, T., & González, J.F. (2014). Feeler Reflection Game: a Case Study on a Design Game for Participatory Design. In J. Salamanca, P. Desmet, A. Burbano, G. Ludden, J. Maya (Eds.), *Proceedings of the Colors of Care: The 9th International Conference on Design & Emotion* (pp. 349-356). Bogotá, Colombia: Ediciones Uniandes.

III. Durall, E., Leinonen, T., Gros, B., & Rodriguez-Kaarto, T. (2017). Reflection in Learning through a Self-monitoring Device: Design Research on EEG Self-Monitoring during a Study Session. *Designs for Learning, 9*(1), 10–20. doi: http://doi.org/10.5334/dfl.75

IV. Durall, E., Leinonen, T. (2017). Data Won't Change Your Behavior. A Critical Design Exploration of Quantified Self Technologies. In J. Jaramillo Arango, A. Burbano, F. C. Londoño, G. Mauricio Mejía (Eds.), *Proceedings of the 23rd International Symposium on Electronic Arts* (pp. 136-142). Manizales, Colombia: Universidad de Caldas.

V. Durall, E., Virnes, M., Leinonen, T., Gros, B. (n.d.). Self-Monitoring Technology for Self-Regulated Learning: An Exploratory Study Using Prototype Evaluation. *Educational Technology Research and Development* (submitted).

Author's Contribution

Publication I: Why do we want data for learning? Learning analytics and the laws of media

For this article, I was responsible for framing the research and writing the manuscript. My co-author, Teemu Leinonen, provided comments and feedback before and during the writing process.

Publication II: Feeler Reflection Game: a Case Study on a Design Game for Participatory Design

In this article, I took the leading role for the game design, workshop facilitation, data analysis, and writing of the paper. My co-authors, Teemu Leinonen and Juan F. González, collaborated in the workshop planning (providing assessment of and contributing to the design of the game materials), the data collection, and the writing of the article.

Publication III: Reflection in Learning through a Self-monitoring Device: Design Research on EEG Self-Monitoring during a Study Session

This article was co-authored with Teemu Leinonen, Begoña Gros, and Tania Rodriguez-Kaarto. I was responsible for the prototype design, whose technical development was performed by Niklas Pöllönen; the research design; the data collection and analysis; and the framing and writing of the article. Teemu Leinonen and Begoña Gros assessed the research design, provided feedback on the design of the research instruments, and contributed to the writing of the article by commenting on and editing the content. Tania Rodriguez-Kaarto was involved in the thematic analysis of the interviews by contributing to the development of the coding scheme and its deployment to analyze the audio recording of the interviews. She also participated in the interpretation of the data and the writing of some parts of the article.

Publication IV: Data Won't Change Your Behavior. A Critical Design Exploration of Quantified Self Technologies

For this article, I analyzed the research data and decided the approach and structure of the manuscript. I was also responsible for the writing of the article. Teemu Leinonen, the co-author of the article, provided guidance and contributed to the writing of the text.

Publication V: Self-Monitoring Technology for Self-Regulated Learning: An Exploratory Study Using Prototype Evaluation

For this article, I led the design work of Feeler v.2.0 and coordinated the technical development of Feeler v.2.0, which was realized by Niklas Pöllönen, Régis Frias, and Joaquín Aldunate. Juan F. González collaborated on the visual identity design of Feeler v.2.0. I also assumed tasks related to the organization and facilitation of the sessions, data collection and analysis, and the structuring and writing of the manuscript. My co-authors, Teemu Leinonen and Begoña Gros, supervised and commented on the exploratory study design, and provided feedback on the content of the article. Marjo Virnes participated in the qualitative data analysis and in the writing of the paper.

1. Introduction

1.1 Background and Research Environment

Throughout history, people have developed diverse technologies in order to solve different types of problems (Cole, 1996). From this perspective, technologies are tools that help people achieve specific goals, whether those goals relate to intellectual or physical activities. According to Säljö (1999), the mastering of different types of tools is characteristic of human learning. Tools not only support learning but also transform how people learn and interpret what they learn (Säljö, 2010). Therefore, learning technologies are tools for enhancing teaching and learning (Leinonen, Toikkanen, & Silfvast, 2008).

In education, technology forecasts consider tools and practices that rely on data collection and analysis a growing trend. Various methods to monitor physiological states based on collecting data from both online and physical learning environments by saving log files and by using physical sensors embedded in wearable devices have been studied to explore opportunities for supporting the adaptation and personalization of learning (Arroyo, Cooper, Burleson, Wolf, Mulder, & Christopherson, 2009; Burleson, Picard, Perlin, & Lippincott, 2004; Shen, Wang, & Shen, 2009). It is expected that the analysis of automatically collected data will inform deeper understanding of students' cognitive and affective states, as well as their behavior, and lead to better decision making regarding how to adapt teaching and learning. For instance, the 2017 Technology Outlooks published by the New Media Consortium (Becker, Cummins, Davis, Freeman, Hall, & Ananthanarayanan, 2017; Becker, Huang, Liu, Gao, Cummins, Hall, & Shedd, 2017; Becker, Cummins, Freeman, & Rose, 2017; Freeman, Becker, Cummins, Davis, & Hall, 2017) predict that measuring learning will become a growing trend in K-12 and higher education in two to three years. Regarding technology adoption, adaptive learning technologies may become popular in higher education from one to two or three years. Learning Analytics tools (LA) are also expected to gain momentum in K-12 and higher education in two to three years. According to the 2017 New Media Consortium technology reports, techno-monitoring practices such as the Quantified Self (QS), and wearable technologies are expected to affect K-12 and higher education in two to three years and five years' time.

The practice of monitoring involves observation and control over a specific phenomenon. Monitoring tools enable the automatic measurement, collection, and analysis of data to provide feedback about a specific process. In the context of this research, monitoring tools allow learners to capture data and make visible aspects connected to their actions and physiological reactions while engaging in independent study. The diversity of practices that use technology to capture data about personal states and behaviors makes it challenging to identify a term that encompasses all of these practices. Because the technological practices of lifelogging, self-surveillance, self-tracking, personal informatics, the QS, living by numbers, self-monitoring, personal analytics, and LA are similar in that they involve automatic observation and data gathering of human activity using digital technologies to gain insight into thought and behavior processes (see, for instance, Ferguson, 2012; Gurrin, Smeaton, & Doherty, 2014; Lupton, 2012; Rooksby, Rost, Morrison, & Chalmers, 2014; Ruckenstein, 2014; Swan, 2013), I refer to these practices as techno-monitoring practices. Rather than elaborating on the specificities of each of these technological practices, the term *techno-monitoring practices* addresses the attention on what they share: an interest on data collection as means to gain insight into thought and behavior processes.

Monitoring can be exercised by third parties or by individuals who voluntarily decide to track some aspect of their activity. The main difference lies in the control that the people whose activity is being monitored have over the type of data being tracked, as well as over the decisions that are informed by the analysis of these data. For instance, in formal education, teacher and student activity have been the objects of analytics. In this context, the common places for collecting data are the virtual environments used to manage teaching and learning. Academic institutions consider relevant to collect data about student and teacher activity since this practice allows for discovering, interpreting, and communicating patterns that can support decision making and help develop personalized programs informed by evidence (Harmelen & Workman, 2012). As Harmelen and Workman indicate, the adoption of analytics in formal education can help identify students at risk, provide recommendations, tailor educational programs, identify and assist teachers to improve their pedagogical practices, and recruit students. Although LA tools may positively affect teaching and learning, their application is still controversial. According to Verbert et al. (2014), there is still little evidence regarding what data related to learning are the most relevant to track and visualize because teachers and learners may have different views and needs (Baillie & Fitzgerald, 2000). In addition, although scholars are increasingly criticizing the use of analytics in education, a top-down approach, in which students have little say regarding data tracking practices, tends to predominate (Kruse & Pongsajapan 2012). In this regard, some scholars have advocated for student-centered analytics (Clow 2012; Duval 2011; Kruse & Pongsajapan 2012) that focus on serving the needs of students rather than those of the institution.

Major concerns regarding the use of data in education involve data privacy and ownership (Slade & Prinsloo, 2013), data analysis (Slade & Prinsloo, 2013), data usage that may support a reductive and biased understanding of what constitutes learning (Eynon 2015), student passivity and institutional dependency, unequal power relations, and managerialism practices and surveillance (Buckingham & Ferguson, 2012; Knox 2010; Kruse & Pongsajapan, 2012; Selwyn, 2015). Critics of educational data problematize the nature of educational data as socially constructed. In the educational community, the debate about the use of LA tools has ignited a discussion of ethical issues, which, in some cases, has led to the creation of guidelines and policies regarding LA.

When examining self-monitoring performed by individuals, a myriad of techno-practices, such as lifelogging, personal informatics, the QS, and personal analytics, have gained popularity during the last decade (see, for instance, Rapp and Cena [2014]). With the aid of sensor-based technologies, individuals have started to track their behaviors and physiological states to gain self-understanding and modify their practices. Some of these endeavors have focused on areas related to learning and work, in which tools for improving well-being, productivity, and time management have become popular. Quite frequently, the design of these tools includes gamification elements in order to increase motivation and user retention (Whitson, 2013). Recently, scholars have suggested that personal data have become a tradable good that people give in exchange for the free use of a specific service (see, for instance, Acquisti [2010]). The lack of transparency regarding the type of data collected, as well as its potential uses, has raised concerns regarding people's privacy and the limits of the commodification of personal data, especially because it is not clear to what extent people are aware of the data traces that their activity with computing systems is generating (Mortier, Haddadi, Henderson, McAuley, & Crowcroft, 2014; van Dijck, 2014).

In education, although the adoption of techno-practices like the QS remains marginal, scholars consider probable that monitoring technology integrates into informal and formal education (Eynon, 2015). In the field of Technology Enhanced Learning (TEL), researchers investigate the possibilities that monitoring tools offer for supporting awareness, reflection (Rivera-Pelayo, Zacharias, Müller, & Braun, 2012), and behavior change (Li, Dey, & Forlizzi, 2010). As a result, several tools and prototypes have been developed during the last decades (see Schneider et al., 2015 for a review of sensor-based technology in TEL). According to Schneider et al. (2015), although the number of initiatives using data from personal informatics and the QS in learning is increasing, it is still not clear how nor to what extent sensor-based technology contributes to learning.

The adoption of monitoring techniques in education raises the question of what parts of the learning experience can be measured and quantified (Eynon, 2015) and how learners may benefit from this monitoring. This research addresses this question and uses a design perspective to explore the opportunities and challenges that monitoring tools and techno-monitoring practices pose to learning. To this end, I designed a tool (called Feeler) that uses electroencephalographic[1] (EEG) self-monitoring to identify learners' cognitive states and prompts learners to record their subjective evaluation of their cognitive state during an independent study situation.

The term *cognitive state* refers to a person's cognitive processes or state of mind. It is assumed that one's cognitive state affects one's cognitive abilities.

[1] Electroencephalography (EEG) is a monitoring method to record electrical activity of the brain. EEG is recorded with electrodes that are attached to the subject's head. See more about EEG in: Hari, R., & Puce, A. (2017). MEG-EEG Primer. Oxford University Press.

Thus, one must identify one's own cognitive state to successfully process new information, as one's cognitive state is strongly connected to one's cognitive load. During the last decades, scholars have identified physiological data related to cognitive states, such as attentiveness, meditation, and mental fatigue, using non-invasive techniques (for a summary of the physiological data associated with learning processes, as well as the most common techniques to monitor these data, see Durall and Leinonen [2015]). For the purpose of this study, the Feeler prototype focuses on the monitoring of the cognitive states associated with meditation and attention.

In the context of this research, independent study refers to study that is conducted separate from teachers and by individual learners who decide what, when, where, and how to study. Individuals conducting independent study activities are responsible for maintaining their motivation and evaluating their progress (Moore, 1977). Although independent study is self-directed, it differs from other autonomous learning endeavors, such as autodidacticism, in which the emphasis is on the pleasure of learning without external guidance. The independent study situations that the Feeler prototype aims to support are connected to formal education and are comprised of settings in which students search and read materials to write an essay, solve an assignment, prepare an exam, or work on a large project, such as a final thesis. In this context, learners' independent study may happen as part of a course or study group and may be guided by teachers or study advisors.

The Feeler prototype is part of the research outcomes and encourages critical reflection on the impact that monitoring tools and techno-practices may have for learning. This is a timely and relevant discussion because behind the use and development of monitoring tools lie critical questions regarding the philosophical principles on which learning and education are based.

In the following sections, I introduce the objectives and the approach of the research. I also present the articles compiled in this dissertation. Finally, I provide an overview of the structure of the dissertation.

1.2 Objectives

This research investigates the diverse aspects connected to the adoption of monitoring tools and techno-monitoring practices in learning contexts using a design perspective. This means that, in order to critically explore the opportunities and challenges that monitoring tools and techno-monitoring practices pose to learning, it was necessary to build a self-monitoring tool that was precisely designed for a learning situation.

This research seeks to highlight the implications of monitoring tools and techno-monitoring practices by analyzing how monitoring tools and techno-monitoring practices can affect learning and teaching and by outlining design opportunities and challenges regarding the adoption of monitoring tools in learning contexts. Moreover, this research aims to contribute to TEL research by exploring how monitoring tools can support learners to reflect on and self-regulate their learning and by discussing the most suitable approaches to the design of monitoring tools for learning.

When exploring the potential of monitoring tools for learning, I start by discussing how monitoring tools and techno-monitoring practices affect people and discuss the implications of these monitoring tools and practices for teaching and learning. I also consider the epistemological aspects connected to technology design and discuss them in the context of learning and education. This research is guided by the following research question: What opportunities for and challenges to learning do monitoring tools and techno-monitoring practices introduce?

In this research, I considered design methods and approaches to narrow the design opportunities without ignoring the complexity and challenges that tools dealing with automatic data collection and analysis pose to individuals and society. I paid special attention to the role of the people who would receive the design in the context of learning and education and the power relations that were at the core of the design processes. When reflecting on most suitable design methods for the design of monitoring tools for learning, I aimed to answer the following research question: What approaches to the design of monitoring tools contribute to the balance of power relations when adopting techno-monitoring practices in learning?

The adoption of a design approach means that research questions unfold as the study advances. During the course of the investigation, I examined the connection between monitoring tools and reflection and self-regulation skills. Considering that the research was oriented to the design of artifacts that explore the possibilities of monitoring tools in learning, the following research question was formulated: How can monitoring tools support learners to reflect on and self-regulate their learning? The key issues connected to this research question relate to learning approaches and to skills considered important for fostering independent and autonomous learning.

The articles included in this dissertation relate to different research areas in different degrees (see Table 1). The research regarding each of the areas of interest is guided by a research question.

Table 1. The grouping of articles based on research interests and questions.

	Article 1	Article 2	Article 3	Article 4	Article 5
RQ1. What opportunities for and challenges to learning do monitoring tools and techno-monitoring practices introduce?	x			x	
RQ2. What approaches to the design of monitoring tools contribute to the balance of power relations when adopting techno-monitoring practices in learning?		x	x	x	x
RQ3. How can monitoring tools support learners to reflect on and self-regulate their learning?			x	x	x

1.3 Research Approach

This research was design oriented, which means that theory and empirical research informed the design of a monitoring tool for learning purposes. The designed artifact is an important research outcome because it synthesizes, materializes, and presents the results obtained during the research design process.

The interrelations between different knowledge domains characterize contemporary design practices (Dykes, Rodgers, & Smyth, 2009). Among the aspects that explain the increasing interrelation between different knowledge domains are the fading of borders between disciplines, the diversity of the backgrounds of the people working in design, and the shift in emphasis from material aspects to experience and interaction (Sanders, 2006). Based on the models of collaboration across disciplines (Jantsch, 1972; Stein, 2007), Dykes et al. (2009) distinguish between disciplinary, multidisciplinary, cross-disciplinary, interdisciplinary, and transdisciplinary design. This research can be considered transdisciplinary because it draws on different knowledge domains, such as TEL, new media studies, and Human Computer Interaction (HCI) in order to gain an understanding of techno-monitoring practices and explore opportunities related to the adoption of monitoring tools and techno-monitoring practices in learning (see Figure 1).

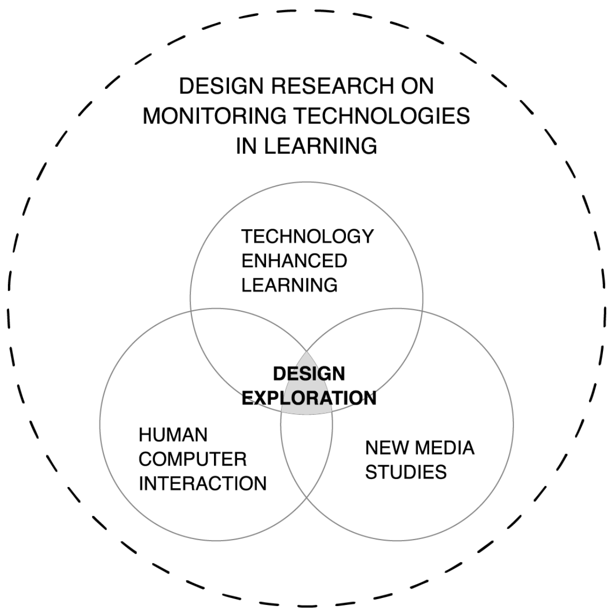

Figure 1. The disciplinary perspectives combined in the design research on monitoring technologies in learning.

In interaction design research, Fallman (2008) proposes a model that distinguishes three areas: design practice, design studies, and design exploration. Although the use of methods may be similar in the different areas, each of the areas addresses different questions and therefore offers a different lens to approach interaction design research. Building on Fallman (2008), the following questions guided the interaction design research that took place through the design process of Feeler

- How can physiological data be integrated and visualized in independent learning situations? (design practice)
- What type of interactions take place using monitoring tools? (design studies)
- What could be the preferred situation regarding the adoption of monitoring tools and techno-monitoring practices in learning contexts? (design exploration)

Design practice refers to activities that are similar to the ones conducted by interaction designers working in the industry. In these activities, the researcher is actively involved in the design practice, and the research question guides the design activity. Design studies focus on building fundamental knowledge to contribute to discussions on, for instance, design theory, design education, and design tools and methods. In design exploration, the design researcher self-initiates the projects to test ideas and question, provoke, or criticize existing assumptions. Usually, this is materialized through the development of an artifact. The what if question that underlies design explorations motivates efforts to experiment and challenge traditional paradigms.

According to Fallman (2008), the areas of design practice, design studies, and design exploration are interconnected, and designers can move between them, as each area allows designers to adopt a different perspective on design. Fallman identifies three types of movement between the areas: trajectories, loops, and dimensions. Trajectories refer to planned or unintentional moves that take place inside one or more activity areas. Loops refer to trajectories that happen continuously between different areas. Dimensions expose conceptual extremes and identify tensions between the activity areas; these tensions arise due to the challenge designers face to balance the ideal (design explorations) with the real (design practice) and the true (design studies) (Nelson & Stolterman, 2003).

This research consists of a critical design exploration. It seeks to comment on a technology trend in learning and education that involves the collection of personal data using monitoring tools. The design of the Feeler prototype is inspired by the critical design tradition and aims to generate discussion on what would be the ideal regarding the adoption of monitoring tools and techno-monitoring practices in learning contexts. Because the design research required developing a tool that could be used in real contexts, tensions between design practice and design exploration occurred throughout the project. As a research designer, I was part of a team that gathered people with expertise on product and graphic design, as well as on the development of interactive prototypes. The project was not driven by a client brief, but this did not prevent challenges in finding solutions that reconciled time, budget, and other resource constraints with the research hypothesis. As a result of these challenges, there was a continuous loop between design exploration and practice. In addition, within the project framework there was a reflection process on the methods, the design approach, and the specific design elements that contributed to support learners' reflection on and self-regulation of learning using monitoring tools. In this way, the exploration of a design area, such as the adoption of monitoring tools and techno-monitoring practices in learning, offered opportunities to contribute to design studies.

1.4 Research Articles

This dissertation is a compilation of five articles, four of which have been published in peer-reviewed academic forums: one journal (Article III), one book chapter (Article I), and two conferences (Articles II and IV). Article V has been submitted and is currently under revision.

Article I performs a theoretical analysis of LA tools to determine the implications that these tools have for teaching and learning. In the article, McLuhan's tetrad of media effects (1998) was adopted to conduct a semiotic analysis that revolved around four key questions about LA tools: what do they enhance, make obsolete, retrieve, and revert to when taken to their limit? The analysis concluded that LA tools supported the prediction and personalization of learning by accessing hidden information about teaching and learning. As a result, certain teachers' skills, personal interactions between teachers and students, and qualitative interpretations of learning were displaced. The analysis revealed that LA tools retrieved a behaviorist approach to learning, as well as a new type of divide based on data literacy. At their limit, the effects of LA tools were reversed, and it was observed that these tools could potentially support learners' awareness, reflection, and self-regulation skills.

Article II explores the potential of design games to support an empathic understanding between design researchers and participants and help them to jointly identify design challenges. To this end, a design game was created and used with graduate students during the contextual inquiry of the Feeler prototype design process. The analysis of the workshop in which the design game was used showed that the game successfully helped participants put themselves into the situation of use and offered a first-hand view of the design concept. The use of design techniques, such as storytelling, personas, and scenarios, in the game were considered key for achieving empathic communication, as well as for creating a playful and safe space that fostered creative thinking. The article concluded that the use of a design game at the early stages of the design research helped reduce the complexity of aspects connected to well-being, learning, reflection, and behavior change. Simultaneously, the design game acted as a boundary object that triggered productive dialogue between the participants and the research designer.

Article III presents results from the design study of the use of monitoring technology in independent study activities. The results consist of a) a functional prototype (Feeler v.1.0) that guides students through a specific learning script while monitoring their EEG activity during a set of tasks and b) conclusions from the proof-of-concept study conducted with six graduate students who used the prototype during one session. The thematic analysis of the interviews indicated that the Feeler learning script and the EEG visualization supported students' reflection by triggering curiosity, puzzlement, and personal inquiry. Other aspects that contributed to reflective thinking consisted of having a personal experience, challenging existing assumptions, and contextualizing data. These results validated the design concept and helped gain an understanding about the specific ways the tool supported students' awareness of and reflection on their cognitive states when engaging in independent academic tasks.

Article IV critically analyzes the potential of monitored data to change behavior using a critical design approach. The article reviews existing discourses on monitoring technologies, such as lifelogging, personal informatics, and the QS tools, and opens questions around the influence of these technologies on self-images. The article questions to what extent QS tools enhance people's abilities and whether it is desirable to develop such a technological dependency. The article builds on the data collected during the Feeler v.2.0 exploratory study with six graduate students in order to gain understanding on students' views regarding the use of QS tools in learning. Findings of this study deal with people's trust on QS technologies and the capacity of these tools to support behavior change. In some cases, participants' trust of the data monitored by the QS tools made them modify their self-perceptions and self-assessments. For instance, the revision of participants' self-assessments on attention and relaxation levels showed that throughout the sessions, participants tried to match their self-assessments to the results they thought the EEG system would display. Another finding of this study was participants' assumption that QS tools support productivity and self-improvement and therefore, the use of these tools would help them become more efficient. However, the careful examination of participants' reasoning for reconsidering some of their behaviors showed that data in itself was not enough to motivate a change. Participants only seriously committed to modify their habits when they connected the data to their personal experiences. Throughout the sessions, participants engaged in a reflection process that led them to reconsider some of their initial assumptions and develop a critical attitude toward how self-monitored data can help them improve their lives.

Article V explores how self-monitoring tools can support the self-regulation of learning. A second version of the Feeler prototype was designed, built (Feeler v.2.0), and used during an exploratory study in which six graduate students used Feeler v.2.0 three times during a period of three weeks. Each session was followed by a semi-structured interview, and all the participants took part in a focus group. The thematic analysis of the audio recording of the interviews and the focus group showed that the Feeler prototype supported the metacognitive, motivational, and behavioral dimensions of Self-Regulated Learning (SRL). The analysis of participants' comments demonstrated that the prototype helped the participants to develop self-awareness, self-monitoring, and self-assessment skills, which contributed to self-knowledge. The prototype introduced participants to new strategies to control their attention and relaxation, which had a positive impact on their self-confidence and motivation to try new practices. By tracking and visualizing participants' actions and cognitive states during the session, Feeler supported self-reflection, which contributed to the self-regulation of behavior. The article concluded that the Feeler prototype may have contributed to the acquisition of SRL skills connected to metacognition, motivation, and behavior regulation. The research limitations and suggestions for future studies were also indicated.

1.5 Dissertation Structure

To a certain extent, the articles can be understood as a narration of the evolution of research design, which is not linear. For instance, the definition of the design space was influenced by the theoretical analysis and the empirical research, and vice versa. Figure 2 visualizes how the articles are interconnected.

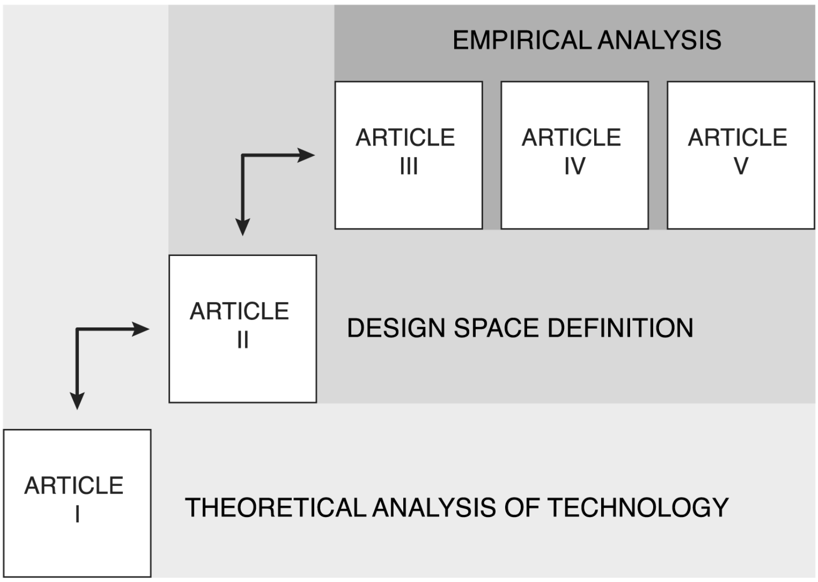

Figure 2. The relations between the articles.

On the basis of the articles and the research issues described, I present a transversal narrative that links the insights gained during the research design process. In this section of the dissertation, I have introduced the research background and problem, the research objectives, and the research questions. I have also included a summary of the research articles. In section 2, I review key research areas, and section 3 describes the research methods. In section 4 and section 5, I present the research outputs. I elaborate on the research outputs in section 6, in which I expose the implications for the design of monitoring tools in learning contexts. In section 7, I answer the research questions and discuss issues connected to the opportunities and challenges associated with the use of monitoring tools, as well as the design of those tools, in learning. I conclude section 7 by outlining the research limitations and making suggestions for future research.

2. Theoretical Framework

In this section, I elaborate on several transversal and interlinked topics related to this research, which are connected to monitoring technology, interaction design approaches, and SRL. Rather than presenting an exhaustive literature review concerning all of these topics, I narrow the scope of topics and views on monitoring technology and techno-monitoring practices to the ones that have been critical to inform the design of the Feeler prototype. The purpose of this section is to provide a theoretical background that helps understand the foundation of the decisions taken during the design research. Therefore, I start by connecting current claims regarding monitoring tools to grand discourses on the epistemology of technology. I consider this necessary in order to identify the main epistemological perspectives about these tools and to highlight their implications. Building from this initial mapping, I elaborate on interaction design approaches to monitoring tools that are based on supporting reflective thinking. Finally, I conclude the section by reviewing perspectives on independent and autonomous learning in which reflective thinking plays an important role. To this end, I focus on the models of SRL, which have been critical to the design of the Feeler prototype.

2.1 Epistemological Approaches to Technology and Monitoring Tools

Technology as an extension of human senses has been a recurrent idea throughout the history of thought on technology (Brey, 2000; McLuhan, 1964; Rothenberg, 1995). From this perspective, technology connects with existing senses to augment human capabilities. For instance, for McLuhan and Fiore (1967), the book was an extension of the eye; for Rothenberg, calculators and numerical systems extended abstract thought (1995). Authors like McLuhan and Rothenberg consider that technological artifacts may act as body or cognitive extensions.

Tools that collect and process data about human states and behaviors may also be regarded as extensions of human senses. For example, a common approach to monitoring tools used in techno-monitoring practices is to consider that they augment human memory (Bell, Gemmell, & Gates, 2009; Mann, 2004; Rothenberg, 1995). Furthermore, the automatic analysis of data captured through monitoring tools is expected to bring new insights based on the analysis of individual data (Fawcett, 2015) and big data (Swan, 2013).

Although people have constantly extended their human capabilities through artifacts, some authors discuss the consequences of replacing human senses with technological artifacts (see, for example, Borgmann, 1984; Illich, 1973; McLuhan, 1964; Marcuse, 1964). In his work, McLuhan warns that as a result of replacing human senses with media technologies, certain human capabilities may be diminished (1964). McLuhan (1964) goes further by claiming that technology has great psychological and social consequences because it changes how people think and perceive the world. Other authors claim that the transfer of certain abilities from humans to machines will make people passive and dependent (Borgmann, 1984; Carr, 2011; Illich, 1973).

Discussions on the effects of technology on humanity tend to include optimistic versus pessimistic views of how technology will impact individuals and societies. For instance, in the case of monitoring tools, some researchers believe that these tools will improve our understanding of human cognition and behavior (Cena, Likavec, & Rapp, 2015), foster self-knowledge (Wolf, 2009), and support people to document their activities and achieve their goals (Rooksby, Rost, Morrison, & Chalmers, 2014). As a result, through the use of monitoring tools, people are expected to improve their well-being and achieve a better quality of life. However, critics of monitoring tools argue that these tools act as surveillance devices (Lupton, 2014b) that support dataveillance practices (Poster, 1996), such as statistical discrimination (Gandy, 2012). In these contexts, surveillance of individual activity may easily become normal and invisible as people become accustomed to having their personal data examined by third parties. No matter how bright or negative the future looks, determinist perspectives on technology give little space for human agency because the future is shaped by technology.

The relation between technology and culture has been at the center of the debate among scholars of science and technology studies. Although hard determinist positions that attribute technology great power to drive society have been displaced, "softer accounts" that recognize technology as a cause and effect of societal changes have remained (see, for instance, Carr [2011], Kelly [2017] and Thompson [2013]). For instance, in the case of monitoring tools, techno-practices, such as the QS, may be regarded as the continuation of a data-driven culture into the personal arena because the feedback provided by these devices modifies people's self-images and encourages them to undertake action to meet their goals (see, for instance, Swan [2012] and Wolf [2009]). Following this line of thinking, some authors have emphasized automated data collection as the ultimate way to study the objective self (Gemmell, Bell, Lueder, Drucker, & Wong, 2002; Hesse, 2008; Jain & Jalali, 2014).

Some approaches to technological determinism have been criticized for promoting an essentialist view of the nature of technology, in which technology's characteristics and features are considered value-neutral. Instrumental approaches to technology share the idea that technology in itself is ethically neutral and therefore that the consequences of technology depend on the use people grant them (Pitt, 2000). The non-neutrality of technology is widely discussed (Feenberg, 2017; Habermas, 1970; Heidegger, 1977; Winner, 1980), even by determinist authors, such as Jacques Ellul (1990), who claim that societies become conditioned by their technological systems. In the same line of thought, the American philosopher Neil Postman stated that "To a man with a computer, everything looks like data" (1993, p.14), meaning that tools imply a certain worldview, as they are built to perform specific tasks.

As far as technological development is a goal-oriented process, the design of technological artifacts includes specific functions to accomplish these predefined goals. Therefore, although technological artifacts may be used in unexpected ways, their design makes it easier and more effective to achieve certain goals. The academic literature on monitoring tools shows a strong presence of behaviorist and persuasive approaches in the design of these tools (Rapp & Tirassa, 2017; Lupton, 2014a), especially in areas such as health, well-being, and sports (MacLeod, Tang, & Carpendale, 2013; Pina, Ramirez & Griswold, 2012; Purpura, Schwanda, Williams, Stubler, & Sengers, 2011). As Ruckenstein and Pantzar (2017) note, the data captured by monitoring tools is expected to support feedback loops that lead to action, thus helping to achieve more sustainable and healthy behaviors. Other approaches to the design of monitoring tools emphasize self-knowledge and reflection (Li, Dey, & Forlizzi, 2011; Rapp & Tirassa, 2017). Depending on whether technology intends to support behavior change or self-reflection, its design tends to include specific sets of functionalities. For instance, monitoring tools oriented to behavior change usually include suggestions and rewards to provide feedback and sustain motivation (Oinas-Kukkonen, & Harjumaa, 2018).

Cultural studies of science and technology have refuted the idea that social change is caused by technology. From this perspective, social factors are the ones that shape technological change (MacKenzie & Wajcman, 1985; Smith & Marx, 1994). This approach to technology stresses the need to take into consideration the social and economic systems in which technologies are embedded. The motivation for shifting the research agendas from technological effects to how society affects technology development is to avoid viewing technology as an independent factor.

Regarding monitoring and self-tracking tools, Lupton (2014a) expressed that "Self-tracking as a phenomenon has no meaning in itself. It is endowed with meaning by wider discourses on technology, selfhood, the body and social relations that circulate within the cultural context in which the practice is carried out." (Lupton, 2014a, p.2). According to Lupton, in order to understand monitoring, it is necessary to examine the socio-cultural context in which these tools are deployed. Ruckenstein and Pantzar (2015) indicated *knowing capitalism*, a trend coined by Nigel Thrift (2005), which considers knowledge the motor of value-creation processes, as the socio-economic context in which monitoring takes place. From this perspective, the data captured by digital devices offer opportunities to produce knowledge in different ways (Anderson, 2008). The hunger for data connects and supports managerial discourses that stress the need for constant adaptation based on the feedback provided by the data. These ideas move from the societal, business, and organization levels to individuals, who are expected to incorporate self-management discourses to become productive assets that can adapt to uncertain conditions (Moore & Robinson, 2016). From this view, failure to adapt to a demanding and fast-changing system is attributed to individual shortcomings.

Scholars studying the social construction of technology have paid special attention to the politics of science and technology, as technological artifacts are considered to reproduce specific forms of power and authority (Winner, 1980; Mumford, 1964). From this view, technological development responds to the interests and values of certain social groups rather than the common interest. From a socio-constructivist perspective, the definition of the problems that technology should address are highly political. According to Pinch and Bijker, “In deciding which problems are relevant, a crucial role is played by the social groups concerned with the artefact, and by the meanings which those groups give to the artefact: a problem is only defined as such, when there is a social group for which it constitutes a 'problem'” (1984, p.414). Thus, the needs and problems addressed by technology relate to the interests of socially and economically powerful groups.

In the context of monitoring tools and the datafication processes associated with them, Sharon and Zandbergen (2016) notice a politics of measurement in which numbers and the constructs they support are not neutral and contribute to normalizing and defining ideals regarding well-being or productivity. At the same time, the reduction of phenomena to numbers dismisses the value of other ways of knowing based on subjective and embodied experiences. As Lupton (2013) observes, techno-monitoring practices like the QS may be regarded as a particular mode of governing the self that aligns with Foucault’s reflections on technologies of the self (1988) but is adapted to the interests of neoliberalism.

The identification of the motivations for why people use self-monitoring tools offers revealing insights regarding the values that guide such practices. In a study conducted by Gimpel, Nißen, and Görlitz (2013), the researchers identify the following motivations among people using self-monitoring tools: self-entertainment, self-association to a community, self-design and self-optimization, and self-discipline and self-healing. Among those, self-optimization, particularly of health and performance, is the one that has been the most widely advertised by QS advocators, and it has become the foundational principle of the biohacker community. It is also relevant to note that such engagements with monitoring tools are highly individualistic and tend to reinforce the idea of self-discovery and self-exploration (Ruckenstein & Pantzar, 2017).

The notion of agency—of humans and technological artifacts—has been widely discussed in ethical reflections on technology. While technology-driven approaches may attribute technology high levels of agency, authors advocating for the role of social factors claim that agency resides in humans. From a humanist perspective, the existence of a technology does not mean that it will be necessarily used and adopted (Chandler, 2002), as humans and societies are able to make such decisions. From this perspective, the socio-historical context in which a technology is produced plays an important role in the future of a given technology. As MacKenzie and Wajcman highlighted, “The characteristics of a society play a major part in deciding which technologies are adopted” (1985, p.6).

In science and technology studies, scholars have advocated for a vision of agency that is distributed (Latour, 1996; Lawson, 2010; Akrich, 1992). This means that to understand change and innovation in science and technology it is necessary to understand the social, economic, political, and cultural values connected to any technological innovation. This view rejects the idea that technical change is neutral and recognizes the need to go beyond arguments based on efficiency when deciding on the adoption of a certain technology (Lawson, 2010).

In relation to monitoring, some of these tools are already widely adopted and, as Lupton (2014a) states, institutions are also promoting their use. In light of this situation, some scholars question people's capacity to decide whether they will embrace self-monitoring as, in some cases, the use of monitoring tools is mandatory to keep a job (Moore & Robinson, 2016). Similarly, in educational institutions, monitoring tools such as LA are increasingly integrated in online learning environments. In this context, scholars have raised questions regarding the opportunities that teachers and students have to reject or influence the tracking of their individual activity (Campbell & Oblinger, 2007; Slade & Prinsloo, 2013).

Simultaneously, some voices from the HCI community have started to question technology designs that reduce the human experience to data and that respond to performance, individualism, efficiency, measurement, and rational analysis criteria (Elsden, Kirk, Selby, & Speed, 2015; Khovanskaya, Baumer, Cosley, Voida, & Gay, 2013; Ohlin & Olsson, 2015; Rooksby et al., 2014). Works that challenge conventional views of monitoring tools based on personal optimization and self-improvement are influenced by design approaches, such as critical design (Dunne & Raby, 2001), reflective design (Sengers, Boehner, David, & Kaye, 2005), and value-sensitive design (Friedman, 1996). These approaches to the design of interactive technologies seek to unveil the hidden assumptions and biases that underlie technology design while fostering reflection and debate. The research questions presented in section 1 address research gaps that hinder public debate on the adoption of monitoring tools and monitoring techno-practices in learning contexts. For instance, the lack of empirical research identifying the opportunities and challenges that monitoring tools and monitoring techno-practices pose for learning prevents from developing a full understanding of these tools that would enable stakeholders engage in public debates on the adoption of monitoring tools in learning contexts. To this aim, the research question 1 focuses on the opportunities and challenges that monitoring tools and monitoring techno-practices introduce to learning.

Several scholars have argued for the democratization of technology development by fostering public debate regarding technology design (Feenberg, 1992; Jasanoff, 2003; Sclove, 1995). These views acknowledge the impact that technology has on people's lives and therefore consider important that individuals without technical expertise have the opportunity to participate in and influence the technology design processes (Feenberg, 1992; Ehn, 2008). Far from denying technology development and the adoption of technological artifacts, these approaches should be regarded as efforts to ensure people's agency in technological systems. This research is framed in this tradition and seeks to contribute to the debate on the design and deployment of monitoring tools in learning contexts.

2.2 Supporting Reflection through Technology

In earlier attempts to design technologies that support reflection, designers have approached reflection in two main ways. The difference is their way of determining when the reflection is expected to happen, which can be understood in Schön's (1983) terms of reflection-in-action and reflection-on-action.

Tools that support reflection-in-action seek to influence people's behaviors while they are happening. To this aim, tools that monitor people's activity and support reflection during the action focus on providing real-time feedback. This is a common approach in activity trackers (see, for instance, Consolvo, Everitt, Smith, & Landay, 2006), energy consumption (such as the designs proposed by Kappel and Grechenig [2009] and Holmes [2007]) or in ambient displays of group activity (see Lamberty, Adams, Biatek, Froiland, & Lapham [2011] and Weiser and Brown's *Dangling String* [1996]). For instance, in TEL reflection-in-action has been also integrated in computer-supported design (see Fischer, & Morch, 1988; McCall, Fischer, & Morch, 1990), in inquiry-based learning environments (see Pedaste, & Sarapuu, 2014) and in collaborative learning (Lavoué, Molinari, Prié, & Khezami, 2015).

Reflection-on-action builds on a different approach to reflection, in which past experiences are considered critical triggers of reflective thought. Some examples of monitoring tools that support reflection-on-action focus on workplace experiences (see, for instance, Müller, Divitini, Mora, Rivera-Pelayo, & Stork [2015]), sleep (see Kay, Choe, Shepherd, Greenstein, Watson, Consolvo, & Kientz's *Lullaby* [2012]), personal memories and experiences (as in Branham, Harrison, & Hirsch, 2012; Isaacs, Konrad, Walendowski, Lennig, Hollis, & Whittaker, 2013) or mood and affect (as in the *MoodMapp App* developed by Fessl, Rivera-Pelayo, Pammer, & Braun [2012], and in the *Affective Diary* designed by Ståhl, Höök, Svensson, Taylor, & Combetto [2009]). In TEL, examples of tools aiming to trigger reflection-on-action using tools that track user activity can be found in collaborative learning (see Phielix, Prins, & Kirschner, 2010), teacher development (see Sung, Chang, Yu, & Chang, 2009) and in project-based learning (see Leinonen, Keune, Veermans, & Toikkanen, 2014).

During the last decade, interaction design scholars and designers have dedicated increasing attention to the ways in which technology can support reflection on experience (Baumer, Khovanskaya, Matthews, Reynolds, Schwanda, Sosik, & Gay, 2014; Bodker, 2006; Sas & Dix, 2009). Among those scholars and designers, McCarthy and Wright (2004) described technology as a form of experience. From McCarthy and Wright's perspective, people's lived experiences of technology involve anticipation as well as reflection on and revision of experiences. McCarthy and Wright's argument is highly influenced by Dewey's work on reflection, in which reflection is presented as "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends" (1933, p.6). According to Dewey, reflection is a specific type of thinking that is strongly linked to experience. This view of reflection is also shared by other authors who have studied the role of reflection in education and learning (Boud, Keogh, & Walker, 1985; Kolb, 1984; Schön, 1983).

Despite the increasing research on reflection, there has been little agreement regarding what constitutes reflection and what its limits are. The theoretical backgrounds that have influenced technological designs that aim to support reflection build on different traditions, including education, cognitive psychology, and critical theory (Baumer et al., 2014). In research on learning, reflection has been regarded as a high-order thinking skill (Strampel & Oliver, 2007) that is essential to support new ways of thinking and sense-making (Boud et al., 1985; Kolb, 1984), solve problems (Hmelo-Silver, 2004), take decisions (Pee, Woodman, Fry & Davenport, 2000), and enable change and transformation processes (Mezirow, 1991). A well-accepted definition of reflection is the one provided by Boud et al., in which reflection is described as a "generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations. It may take place in isolation or in association with others. It can be done well or badly, successfully or unsuccessfully" (1985, p.19). This view recognizes the many ways in which reflection can be performed while acknowledging how past experiences are essential to trigger reflection and develop new insights.

Drawing from the work of seminal authors (Dewey, 1933; Kolb, 1984; Mezirow, 1991; Peltier, Hay & Drago, 2005; Kember, Leung, Jones, Loke, McKay, Sinclair, Tse, Webb, Wong, Wong, & Yeung, 2000), it is possible to distinguish a hierarchy of reflective thought that consists of three main stages: awareness, critical analysis, and change. Awareness refers to when a person becomes conscious of a past experience. This means that the person can describe the situation and recall the reasons that led him/her to make certain decisions. This stage is followed by the critical analysis stage, during which the focus is on making hypothesis, creating relations, and developing different explanations, in which the same situation is analyzed from different perspectives. As a result of the critical analysis, there is a transformation of thought. This change is the consequence of asking fundamental questions about one's beliefs and may lead to action.

These levels of reflection connect to those described by Fleck and Fitzpatrick (2010) when they reviewed the different ways in which learning technology can support reflection: (1) Revisiting; (2) Revisiting with explanation; (3) Dialogic reflection; (4) Transformative reflection; and (5) Critical reflection. Based on Fleck and Fitzpatrick's classification, levels 1 and 2 aim to foster awareness by recording events. In TEL, video (see Lamberty and Kolodner [2005] and Leijen, Lam, Wildschut, Simons, and Admiraal [2009]) and video analytics (see Giannakos, Chorianopoulos, & Chrisochoides, 2014) have been used to support students and teachers to gain awareness of students' actions and develop an enhanced understanding of them. Scholars have also considered LA as valuable tools for developing a deeper understanding of students' actions through visualizations (see, for instance, *GLASS*, developed by Leony, Pardo, de la Fuente

Valentín, de Castro, and Kloos [2012]) or the *Visual Interaction Mapping System* developed by Jyothi, McAvinia, & Keating [2012]).

Dialogic reflection consists of exploring relationships. According to Fleck and Fitzpatrick (2010), in this level of reflection (3) technology enhances perception by supporting learners to see things from multiple perspectives through accessing hidden information. Some examples of tools that augment learners' senses in order to trigger reflection are Johnston, Amitani, and Edmonds's *Virtual Music Environment* (2005); and LA tools like Santos, Govaerts, Verbert, and Duval's *goal-oriented visualizations* (2012); and Govaerts, Verbert, Duval, and Pardo's *Student Activity Meter* (2012). Müller, Rivera-Pelayo, Kunzmann, and Schmidt's study on stress management at the workplace (2011) is another example in which data collected through physiological sensors were used to support reflection and learning. Furthermore, dialogic reflection can be also triggered by sharing monitored data and using that data to inform group discussions (see, for instance, Fleck and Fitzpatrick's analysis of how *SenseCam* supports social reflection [2009]).

The last levels of reflection indicated by Fleck and Fitzpatrick (2010) refer to transformative and critical reflection. As the authors highlight, transformative and critical reflection lead people to make a fundamental change as a consequence of revisiting the data captured by technology. Because this is a process of personal transformation, it may be influenced by many aspects that are not necessarily related to technology. Thus, it is not possible to provide examples of monitoring tools that necessarily lead to such changes. As Fleck and Fitzpatrick (2010) note, the same techniques may lead to different levels of reflection depending on the learner and the context of use. Therefore, the association of monitoring tools to specific levels of reflection should be made with caution.

Although assessing the extent to which engaging in reflective thinking may be challenging, several authors have stressed the importance of creating conditions that encourage reflection to happen (Moon, 1999). In the field of technology design, monitoring tools can be designed to structure and support reflection. In TEL, several authors have claimed the potential of LA tools to support reflection (Durall & Gros, 2014; Govaerts, Verbert, Duval, & Pardo, 2012; Greller & Drachsler, 2012). Some of the strategies suggested to trigger reflection consist in, for instance, allowing learners chose the aspects they want to track in online learning environments (see Ji, Michel, Lavoué & George, 2014), adopting Open Learner Models in order to make data-based inferences transparent (see Bull and Kay, 2008; Mazzola and Mazza, 2011) and visualize information through visual dashboards (see Charleer, Odriozola, Luis, Klerkx, & Duval, 2014).

According to Baumer (2015), conflict, inquiry, and transformation are the three key dimensions of reflective informatics that help to trigger, foster, and facilitate reflective thinking. As Baumer (2015) notes, an important influence on the theoretical background of technology design centered on reflection is pragmatism. In particular, the work of Dewey (1933) has inspired several technology design approaches, such as inquisitive design (Dalsgaard, 2008) and technology as experience (McCarthy & Wright, 2004). These technology design approaches based on reflection focus on people's lived experiences and sense-making using an embodied perspective.

Another important issue in the literature on reflective thought is the recognition that reflection processes need time (Moon, 1999). In this regard, cognitive psychology scholars investigating dual-process models of cognition distinguish reflection as a specific mode of thought, characterized by slowness, deliberation, and conscious intentionality (Kahneman, 2011; Norman, 1993). These findings have influenced further work in the design of tools for reflection. For instance, in HCI Hallnäs and Redström (2001) coined the term *slow technology* to designate technology design approaches that "create" time in order to support reflection and mental rest, unlike approaches based on efficiency and productivity.

Other approaches to technology design centered on reflection are reflective design (Sengers et al. 2005), critical design, and speculative design (Dunne & Raby, 2001; Dunne & Raby, 2013). These approaches build on critical theory as an epistemological paradigm and therefore view reflection as a means to unveil the hidden agendas and value systems that drive technology design. The technology design works framed in the reflective design tradition seek to trigger critical reflection. Scholars who study change processes, such as Mezirow (1998), claim that critical reflection involves uncovering tacit assumptions and questioning naturalized cultural norms. In technology design, Sengers et al. state that critical reflection "identifies unconscious assumptions in HCI that may result in negative impacts on our quality of life" (2005, p.49). In both cases, the authors highlight the importance of developing an awareness of ideas and beliefs that are taken for granted and question the implications that such ideas and beliefs have for the design of technological artifacts.

Reflective design responds to a concern regarding the values embedded in technology designs (Sengers et al., 2005). From Sengers et al.'s (2005) view, there is a need to foster critical reflection on computing objects as well as on the practices they support. This approach to technology design is influenced by reflection-in-action (Schön, 1983), participatory design (Ehn, 1993; Greenbaum & Kyng, 1991), ludic design (Gaver & Martin, 2000), value-sensitive design (Friedman, 1996), critical technical practice (Agre, 1997), and critical design (Dunne & Raby, 2001). In Sengers et al.'s (2005) description of reflective design, the authors outline a set of strategies to trigger reflection, such as supporting flexible interpretations, encouraging user participation, providing and inspiring rich feedback to and from users, understanding technology as a probe, and inverting the metaphors and cross boundaries used in the design.

Critical design aims to trigger reflection by posing difficult questions about the role of design in society. Introduced by Dunne and Raby in the mid-90s, critical design was presented as a challenge to affirmative design, which primarily served a consumerist culture. Instead, Dunne and Raby aimed to design "products for the mind" (2001, p.64) that provoked people by challenging their assumptions and triggering debates (Dunne, 2008). As Bardzell and Bardzell explain, "Critical design is a form of research aimed at leveraging designs to make consumers more critical about their everyday lives, and in particular how their lives are mediated by assumptions, values, ideologies, and behavioral norms inscribed in designs" (2013, p.3297). In critical design projects, the focus is on developing a critical sensibility in consumers. Thus, the main outcome of critical design is knowledge, rather than the objects of the design. Some of the strategies used in critical design to support reflection are provocation, defamiliarization, and estrangement. Examples of critical design in HCI can be found in the work of Feinberg, Carter, and Bullard (2014), as well as in Pierce and Paulos (2014).

Speculative design builds on the same tradition as critical design, but the focus is on fostering reflection through questions regarding technology and culture (Dunne & Raby, 2013). Speculative design projects look into the future by proposing plausible scenarios regarding science and technology, often from a dystopian perspective. As Malpass (2013) notes, key strategies for supporting reflection are ambiguity and open interpretations (Gaver, Beaver, & Benford, 2003). Speculative designs explore the boundaries between technological development and societal implications while encouraging a democratic discussion of the values and agendas that drive scientific and technological development (Malpass, 2013). In monitoring technology, prototypes such as the objects designed for *Vital Signs*[2], which were developed as part of the *Material Beliefs* project (Beaver, Pennington, & Kerridge, 2009), speculate on the biometric monitoring of children's lives by anxious parents. As discussed in Lawson, Kirman, Linehan, Feltwell, and Hopkins (2015), prototypes speculating on the implementation of quantified technology to monitor pets expand the discussion beyond human monitoring to explore how these tools may enhance human-animal communication. In a way, speculative design can be regarded as a design research endeavor to foster public participation in a discussion regarding science and technology, similar to Feenberg's claim for a democratic transformation of technology (1992, 2002).

While critical design and speculative design have been recognised as powerful strategies to support reflection and public debate, they have not been deployed in other areas outside art and design such as TEL. One possible reason is because in TEL, design research has focused on development of new tools, without giving much opportunities for the questioning and critical examination of the existing ones. In this regard, TEL design researchers have focused their efforts on problem-solving rather than in critically redefining current relations with technology. This research is built on the assumption that in TEL, critical and speculative design can be a valuable approach, particularly for exploring the opportunities and challenges associated to emerging technologies.

To sum up, reflection is a powerful concept that has been approached from several areas, ranging from psychology and education to design and interactive technology. As I have presented, reflection can happen in many ways, and there are different levels of reflection. In this study, I build on existing research on reflective thought in order to explore how monitoring tools can support reflective processes in learning contexts. Moreover, I show how self-monitoring and the ability to reflect play an important role in the self-regulation of learning. In

[2] Documentation of the "Vital Signs" is accessible at http://www.materialbeliefs.co.uk/~materi15/prototypes/vitalsigns.php.

the following section, I revise the main aspects of self-regulated learning in order to understand how monitoring tools may contribute to SRL.

2.3 Self-Monitoring in Self-Regulated Learning Processes

Supporting students to become independent, autonomous learners is one of the challenges faced by institutions of higher education (Gow & Kember, 1990). In this context, students are expected to be actively engaged and take responsibility for their own learning. However, this is not always the case because managing learning requires a set of skills that, too often, are left to serendipity (Knight, 1996).

Scholars investigating learners' ability to learn and manage their learning progress on their own have referred to this set of skills and practices as Self-Directed Learning (SDL) and Self-Regulated Learning (SRL). According to Loyens, Magda, and Rickens (2008), SDL and SRL are very similar, as both approaches to learning imply learners' active engagement and goal-driven behavior.

SDL has been defined as "a process in which individuals take the initiative, with or without the help from others, in diagnosing their learning needs, formulating goals, identifying human and material resources, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (Knowles, 1975, p.18). Correspondingly, a well-accepted definition of SRL is "the degree to which students are metacognitively, motivationally, and behaviorally active participants in their own learning processes" (Zimmerman, 1989, p.329). SRL is strongly connected to Knowles's definition of SDL (1975), as most models of SRL include activities that consist of defining goals, analyzing tasks, planning and implementing diverse learning strategies, and self-assessing the efficacy of actions. Overall, the overlap between SDL and SRL is so significant that the terms have been used synonymously in previous research (Evensen, Salisbury-Glennon & Glenn, 2001).

The main differences between SDL and SRL relate to their backgrounds: SDL is rooted in adult learning and informal learning, while SRL traditionally takes place in formal and non-formal learning contexts. According to Loyens et al. (2008), SDL should be understood as a broader term that may encompass SRL, as SDL refers to aspects concerning the learning environment design and the learner's attributes. In contrast, SRL tends to focus on the learner's characteristics and on the specific steps of the learning process, such as defining the learning objectives and strategies.

Considering that this research explores the use of self-monitoring tools in independent study, SRL is an important theoretical construct for this research. The main models of SRL stress the importance of self-monitoring and reflection, to the extent that they are considered specific stages of the process of self-regulation. The Feeler prototype designed as part of this research aims to support the stages of SRL related to self-monitoring, self-control, and self-reflection.

SRL has been considered an umbrella term that involves metacognitive processes, motivational aspects, affective factors, and strategic action (Loyens et al., 2008; Pintrich, 2004). The main models of SRL distinguish three phases: preparation, performance, and evaluation (Puustinen & Pulkkinen, 2001). The phases are closely interconnected, and each phase influences the following one. In this regard, researchers highlight the existence of a self-regulation cycle because the feedback collected during the evaluation affects the preparation of subsequent learning endeavors (Panadero, 2017).

To date, most empirical studies of SRL have been conducted based on Boekaerts's models of SRL (Boekaerts, 1992; Boekaerts & Corno, 2005), Borkowski's process-oriented model of metacognition (Borkowski, Chan, & Muthukrishna, 2000), Pintrich's general framework for SRL (Pintrich, 2000), Winne's four-stage model of SRL (Winne & Hadwin, 1998), and Zimmerman's social cognitive model of self-regulation (Zimmerman, 1989, 2000, 2013). In recent years, other models of SRL have appeared, such as the socially shared regulated learning model (Hadwin, Järvelä, & Miller, 2011) and the metacognitive and affective model of SRL (Efklides, 2011).

Initial research on SRL strove to understand students' use of metacognitive processes, such as the election of task strategies and self-monitoring (Boekaerts & Corno, 2005). Later, metacognition was included as part of self-regulation (Winne & Hadwin, 1998; Zimmerman, 1990). Planning, goal setting, organization, self-monitoring, and self-evaluation are metacognitive processes that self-regulated learners implement at several phases of the self-regulation cycle (Corno, 1989; Zimmerman, 1990).

Metacognition is connected to motivation. Studies by Kuhl (2000) and Wolters (2003) demonstrate how students can learn to control their motivation. Strategy selection is also connected to motivation. For instance, according to Borkowski et al. (2000), learning to choose the appropriate strategies is strongly related to the development of self-efficacy perceptions and attributional beliefs, which are important motivational constructs.

Self-efficacy refers to a person's beliefs about his or her abilities to successfully perform a task. Research shows that people's self-efficacy beliefs affect their motivation and performance. The more confidence people have in their own capabilities, the more challenging goals they will seek and the more effort and persistence they will be willing to dedicate to achieve those goals. (Bandura, 1991)

People may fail to self-regulate their learning due to a mismatch between one's sense of efficacy regarding a specific task and one's actual performance. The adjustment between self-perception and actual performance is known as self-efficacy calibration (Zimmerman & Moylan, 2009). Studies show that people who can self-calibrate their efficiency realistically can learn more effectively (Schunk & Pajares, 2004). In a way, self-calibration can be considered part of self-knowledge. Therefore, monitoring tools oriented at self-knowledge may contribute to learners' self-knowledge by providing them feedback that helps them self-calibrate their efficacy perceptions.

Attributional beliefs relate to the explanations that people build about the causes and consequences of their behaviors. When analyzing outcomes, people can attribute their failure or success to their own abilities or to external factors, such as strategy use. Explanations that indicate personal competence as the cause for a given result affect self-efficacy (Zimmerman & Schunk, 2004). This effect may be positive or negative; therefore, it is important to carefully consider the way in which feedback is provided. Regarding monitoring tools, some authors have already warned about the negative effects of continuous data flows, which can generate anxiety and frustration among people whose activity is monitored (Lupton, 2016).

Effective learners are aware of the relation between their patterns of thought and the strategies they use. SRL strategies refer to actions that learners undertake to support their learning and improve their performance. The effective use of self-regulation strategies enhances perceptions of self-control and efficacy, which, in turn, motivates further efforts to self-regulate behavior during learning. (Zimmerman, 1986)

In higher education, the ability to self-regulate has been related to well-being (Ryan & Deci, 2000). For instance, Heikkilä, Lonka, Nieminen, and Niemivirta (2012) determined that first year university students who did not regulate their learning activity reported higher levels of stress and exhaustion and a greater lack of interest in comparison to those who deployed self-regulation skills. For this reason, several TEL tools have been developed in order to support learners to engage in SRL. Such tools include personal learning environments, which provide personalized and flexible solutions that allow learners to regulate their activity. TEL solutions that focus on SRL also include projects such as *iClass* (Aviram, Ronen, Somekh, Winer, & Sarid, 2008), the *Responsive Open Learning Environment* (Nussbaumer, Dahn, Kroop, Mikroyannidis, & Albert, 2015), and *Just4me* (García, Gros, & Noguera, 2013). Many of the TEL tools that focus on SRL adopt a holistic and open approach in order to offer learners rich environments that include a diverse range of possibilities to self-regulate their learning. Despite these environments benefit from automatic data collection technologies, students' input is central as they are expected to self-monitor their activity and report about it in the system.

To date, the main focus of tools aiming to support SRL has been on monitoring and regulating external behavior (see for instance Schmitz, Scheffel, Friedrich, Jahn, Niemann, & Wolpers, 2009). Few studies have focused on learners' inner behavior (see for instance the work of Li, Zhao, Liu, Peng, Qi, Mao, Fang, & Hu [2012] and Pijeira-Díaz, Drachsler, Järvelä, & Kirschner, [2016]). However, in these cases physiological data has been collected for research purposes and they have not been used to provide learners' feedback about their inner behaviors. To the best of my knowledge, so far learners' physiological data have not been used to support SRL.

In HCI, researchers have explored the potential of physiological data for self-regulation through prototypes (see for instance the work of Salehzadeh Niksirat, Silpasuwanchai, Mohamed Hussien, Cheng and Ren [2017], Sas and Chopra [2015] and Sas, Umair and Hamza Latif [2018]). Although HCI design researchers' work brings inspiring examples for the design of TEL tools, it does not tackle the specific challenges that learners face when self-regulating aspects connected to their learning processes. Thus, there is a need to investigate the links between self-regulated learning and measurable physiological data since these are not clear yet.

The main models of SRL refer to monitoring, and self-monitoring in particular, as a critical factor in the development of self-regulation skills (Pintrich, 2000; Winne, 1996; Zimmerman & Moylan, 2009). Therefore, helping learners to develop self-monitoring abilities may contribute to the self-regulation of their learning processes. This research builds on the assumption that tools that help learners self-monitor their activity during independent study can facilitate the acquisition of self-regulation skills.

2.4 Summary

In this section, I reviewed the key issues regarding the epistemological understandings of technology and monitoring tools and the interaction design perspectives that support reflective thinking, as well as the approaches to independent and autonomous learning based on SRL and the role that tools for self-monitoring play in such learning.

First, I discussed the theoretical traditions that present technology as extensions of human senses and provide examples of current discourses that present monitoring technology as an augmentation of human capabilities. Such views on technology tend to focus on the positive and negative effects of technology on individuals and societies that occur due to the addition of new capabilities through technological development. Although researchers challenge technological determinism for providing a reductionist understanding of the relation between technology and culture, there are softer accounts of technological determinism in current discussions of monitoring tools.

In analyzing the role of technology in society, researchers and scholars have extensively debated the notion of agency. While humanist perspectives stress that technology is socially shaped, technological determinist views emphasize the consequences of technology development and highlight how such development creates new realities. In science and technology studies, authors advocate for distributed views of agency that recognize technological artifacts and humans as agents with the ability to influence the systems in which they operate.

In light of such discussions, in recent years there has been an increase in approaches to the design of monitoring tools that challenge notions of efficiency and productivity while favoring critical views. Authors in science and technology studies acknowledge the effect that tools have on people's lives and seek to create opportunities to engage non-experts in democratic discussions regarding technological development. In order to support such democratic debates I argue that there is a need for further studies that help to understand the opportunities and challenges that monitoring tools and monitoring techno-practices pose for learning.

Second, I analyzed approaches to the design of monitoring tools that foster reflection. Moreover, I reviewed definitions of reflective thinking from different traditions that have been influential to this research: learning and education, pragmatism, and critical theory. I also presented an overview of the hierarchies of reflection and provided examples of TEL tools that monitor learners' activity in some way.

Although it is not possible to ensure that a given tool will make reflection happen, conditions to support reflection can be designed. Aspects such as conflict, emotions, personal experiences, and inquiry have been highlighted in the literature on reflection and have influenced interaction design approaches that are based on reflection.

In design, approaches such as reflective design, critical design, and speculative design have sparked a discussion of the non-neutrality of technology by fostering citizen engagement and dialogue regarding the hidden values that drive technology design. Some of the strategies used in order to trigger reflection are the inversion of metaphors, provocation, defamiliarization, and estrangement, as well as confronting the audience with plausible dystopian views of future technology development. Considering the lack of TEL tools developed using a critical perspective, I advocate for the adoption of critical and speculative design approaches for the design of learning tools, particularly for exploring the opportunities and challenges connected to the adoption of emerging technologies in learning contexts.

Third, I focused on the learning theories that were found to be the most relevant in independent and autonomous learning: SDL and SRL. Although SDL and SRL have many aspects in common, they also have some minor differences due to the different traditions from which they stem. Because of the characteristics of this research, SRL models and theories were regarded as more suitable than SDL to guide this research.

Self-monitoring and reflection are important components of SRL models. Therefore, this section revised the main aspects of SRL and dedicated special attention to the metacognitive, motivational, and behavioral dimensions of SRL. To exemplify how SRL theories influence TEL designs, I benchmarked several tools that adopt a holistic approach to help learners self-regulate their academic activity and I point out the lack of studies that build on physiological data to provide students feedback that helps them self-regulate their learning process. Finally, considering the significant role of self-monitoring in the main SRL models, I infer that monitoring tools can be used to help learners develop SRL skills and I argue for the need of further research that explores how physiological data can support the self-regulation of learning.

3. Research Methods

In this section, I describe the methods applied in this research. I adopted a research-based design as a mode of inquiry and used a variety of instruments to collect data to inform the design process. Moreover, this section introduces the methods and research instruments used during the different research phases and describes the evaluation methods deployed to analyze the tests conducted with the functional Feeler prototypes.

3.1 Research-Based Design

Research-based design is a methodological approach for the design of tools and artifacts for learning (Leinonen et al., 2008; Leinonen, 2010). It builds on the design tradition, and, similar to research-oriented design (Fallman, 2003, 2007) and research through design (Zimmerman, Forlizzi & Evenson, 2007), research-based design emphasizes the artifacts that result from the design process. From this perspective, the artifacts are future-oriented, explore preferred situations, and open new design spaces (in this case, in the context of learning). The tools and artifacts are informed by research, but they also embody knowledge in ways that are similar to those in critical and speculative design. Because the design outputs are expected to be used by the educational community, the aspects related to their implementation, look, and feel are also considered relevant.

Leinonen (2010) proposed research-based design to apply design research and design thinking to the design of learning tools. The focus on learning is a distinctive trait that distinguishes research-based design from other constructive design research approaches. To date, design researchers have used research-based design to guide the design of learning software that focuses on collaborative learning (see *Future Learning Environment* in Rubens, Emans, Leinonen, Skarmeta, and Simons [2005] and Raike, Keune, Lindholm, and Muttilainen [2013]), informal and mobile learning (see *MobilED* in Ford and Leinonen [2009], *DSpace-based digital libraries* in Rosa, Shmorgun, Sousa, Rogalevitš, and Lamas [2012], *AchSo!* in Bauters, Purma, and Leinonen [2014] and *SoAR* in Pejoska, Bauters, Purma, and Leinonen [2016]) and SDL (see the *Digital Portfolio-Based Personal Learning Ecosystem* created by Laanpere, Pata, Normak, and Põldoja [2014]). Research-based design has been also adopted to design open learning ecosystems (see Põldoja [2016]) and to support school innovation as well as the development of learning designs that integrate technology in meaningful ways (see Lewin and McNicol [2014]). Recently, research-based design has been adopted to analyze the potential of emerging tools for learning (see Li's study on the use of e-readers in academic contexts [2017]).

Influenced by the human-centered tradition and the participatory design approach, research-based design is based on the idea that the people who will receive the final design should have the opportunity to influence it because the final tools will have an impact on those people's work and learning processes (Ehn & Kyng, 1987; Leinonen & Durall, 2014). In order to support these aspects, Leinonen advocates for a continued iteration in which defining, redefining, and designing occur in a continuous dialogue with the people who will be affected by the design solutions. Leinonen et al. (2008) distinguish four phases in research-based design: *contextual inquiry*, *participatory design*, *product design*, and the *development of a software prototype as a hypothesis*. The phases should not be understood linearly but should indicate the emphasis of the design activity at the different stages of the design process (see Figure 3).

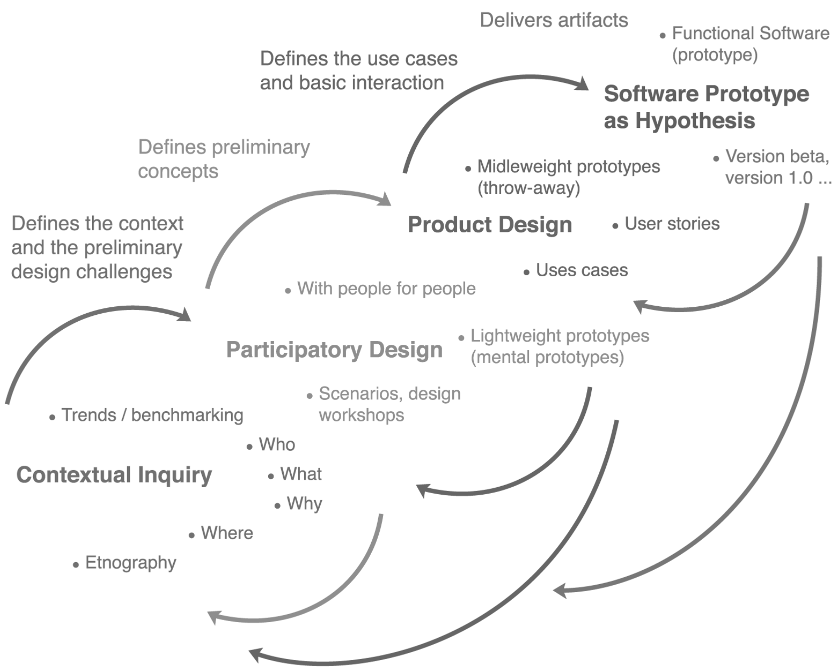

Figure 3. Research-based design (Leinonen, 2010).

Following the user-centered design tradition, the research-based design process starts by investigating the context of the design and the people to whom the design is expected to serve. Thus, the first phase of the design process consists of a contextual inquiry in which the focus is on understanding the context in order to identify people's needs and to frame the design problem. During *contextual inquiry*, design researchers benchmark and analyze trends in the field.

Frequently, design researchers adopt rapid ethnography (Millen, 2000) to gain insights into the socio-cultural context of the design.

Once design researchers define the design space and understand the context, they move to the *participatory design* phase, which relies on the strong involvement of the people who will be affected by the design solution. Although research-based design could be considered a participatory design process, during this phase designers dedicate special attention to actively involve stakeholders. To this end, design researchers organize participatory design workshops and create opportunities to engage people in the design process by creating scenarios and sketches and building lightweight prototypes.

When moving to the *product design* phase, design researchers build on the data collected during the *participatory design* phase. During *the product design* phase, design researchers "give a more concrete form to the ideas presented in the earlier stages of the process" (Leinonen, 2010, p.63). In order to consolidate the data and build models that help identify patterns and trends, the designers' work moves to the studio. During this phase, design researchers also work closely with developers and programmers to identify solutions to technical challenges. The nature of the work developed during this phase requires that designers create some distance from stakeholders in order to use specific methods and professional jargon. Once models (such as personas and scenarios) and throw-away prototypes are built, design researchers can organize additional participatory design sessions to obtain feedback from stakeholders.

The last phase of the research-based design process consists of the production of a *software prototype as a hypothesis*. The work conducted during this phase focuses on the production of functional prototypes, which are tested to gain insights regarding the effect they have on the environments in which they would be used and the communities that would use them. According to Leinonen, "The prototypes are hypotheses, potential solutions to the design challenges defined earlier in the process" (2010, p.64). The prototypes are not neutral; rather, they introduce a certain perspective regarding teaching and learning. Therefore, the solutions that the prototypes propose must be validated. This is why prototypes are considered hypotheses.

3.2 The Feeler Design Process

The motivation for using a research-based design in this research stems from the combination of different traditions, including design, learning, and technology development, which all fall under the umbrella of the humanist perspective. Research-based design applies the participatory design tradition to learning technology design and places learners' needs at the center of the design process. This approach recognizes the influence of the design to support certain behaviors above others. Research-based design makes design influence explicit by claiming that the final products embody values and perspectives regarding learning and teaching. Because of these particular traits, research-based design was considered a suitable approach to guide the design of the Feeler prototype.

In the research-based design of Feeler, the *contextual inquiry* consisted of conducting semi-structured interviews with students and experts in related areas, such as health, psychology, learning, and neuroscience. Additionally, contextual inquiry data was obtained by conducting field observations, a literature review, the benchmarking of existing tools and solutions, and focus groups and questionnaires regarding students' experiences and habits related to learning (see Table 2).

When collecting data from participants, such as in interviews and focus groups, special attention was paid to the creation of a comfortable environment where participants felt able to communicate freely (see Articles II, III, and V). To this end, specific materials were created. For instance, in the exploratory interviews conducted with the students, the participants were asked to visualize and define in their own terms concepts, such as well-being, mindfulness, and health, and share this information with them before the meeting. The information provided by participants was used to create inspiration cards (Figure 4), which were discussed at the beginning of the interviews. The analysis of the interviews brought light into aspects such as the connection between meditation and emotional well-being. In particular, some of the interviewees highlighted the positive impact of meditation after experiencing situations of anxiety and burning out. Interviewees also recognised the value of time-management techniques for balancing work and study with their personal life.

For the focus groups, a design game was created to communicate the participants key aspects and decisions regarding self-monitoring for behavior change (see Article II). Like the inspiration cards, the design game helped to break the ice and create a first-hand experience that participants could refer to when expressing their views on complex issues, such as well-being or self-monitoring. The diverse techniques used to explore the design context helped identify aspects connected to the students' well-being, such as the positive perceptions of self-awareness, meditation, and self-monitoring, as well as the main challenges students faced when performing independent study work, such as the difficulty to concentrate due to frequent access to social media. In particular, participants expressed the wish to be able to regulate their attention since in many occasions they felt they were not able to control it. The data collected through the literature review and during the subject-expert interviews helped identify the challenges to the integration of physiological data as feedback about learning processes (see Articles II and IV).

Figure 4. The inspiration cards used during the interviews conducted as part of the Feeler contextual inquiry.

During the participatory design phase of Feeler, participatory design workshops and feedback sessions were organized (see Table 2, as well as Article II and III). During these sessions, students and educational stakeholders were invited to comment on the challenges and opportunities regarding the use of self-monitoring technologies in learning, as well as to discuss different scenarios in which these technologies could be used. In order to foster participation, a collaborative design game was created. In it, participants were invited to visualize different types of self-monitored data that they considered relevant for learning (Figure 5).

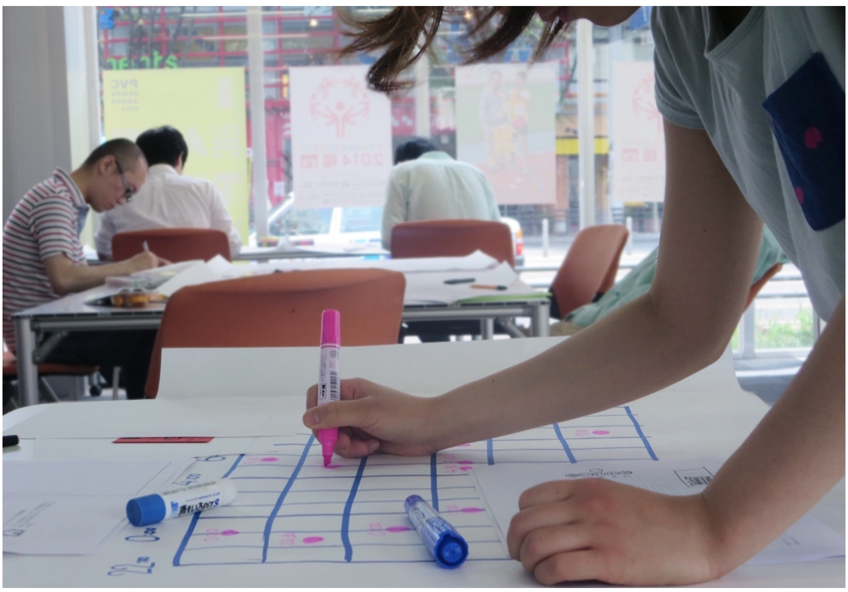

Figure 5. The co-design workshop organized with graduate students of Kyushu University (Japan).

The feedback obtained during the participatory design sessions shed light on participants' views on and interest in specific types of self-monitoring and conditions for reflection on the collected data; the feedback also highlighted the participants' concerns regarding data privacy and ownership. This feedback informed the creation of data models during the product design of Feeler, which consisted of the use of personas and scenarios (see Table 2). The work performed during this phase helped to define the requirements that guided the design of middle-way prototypes made with paper and plywood. Although these prototypes were still incomplete and lacked functionality, they helped advance the design by communicating the concept and representing the experience of use in a performative way.

The *product design* phase led to the production of *a software as a hypothesis*, which resulted in the development of two functional prototypes. The requirements that guided the development of the functional prototypes related to measuring learner's levels of attention and relaxation, include learners' personal impressions as part of the data collected, allow learners build their own meanings while providing them opportunities to contextualize the data tracked about their activity, encourage reflection after independent study sessions and respect learners' privacy. Some important findings that had an impact on the definition of requirements were learners' reluctance to share their personal data with others by default and to get rewards to keep them engaged in self-monitoring.

The specification of the requirements for Feeler functional prototypes motivated additional research in order to find solutions that align to learners' wishes and expectations. Part of this work involved benchmarking main non-invasive techniques to monitor biomarkers such as attention and meditation (see Durall & Leinonen, 2015). Based on this work, I concluded that EEG had a great potential to track biomarkers connected to learning, such as attention, meditation, stress and emotions. In addition, recently EEG self-monitoring tools have gained popularity in the last years. In open dissemination sessions of Designs for Learning research[3] where I showed some apps and tools based on EEG monitoring, attendants showed a great interest in getting feedback about their attention and relaxation levels. Thus, informed by benchmarking and people's feedback, I decided to use EEG measurements to monitor attention and relaxation.

The functional prototypes were tested with graduate students (see Table 2). The data collected during the tests helped refine the prototypes as well as clarify the context of use and students' experiences of use.

Table 2. The research-based design process in the Feeler prototype design.

Research stage	Description	Main outcomes
Contextual Inquiry	- Six semi-structured interviews with graduate students; five subject-expert interviews. - Four days of observation and field note-taking in a university library environment.	- Recognition of self-awareness and meditation as valuable skills in learning and well-being. - Challenges to reflect and remain focused on the academic tasks due to constant access to social media.

[3] Information about Designs for Learning project available at http://lead.aalto.fi/

	- Literature review. - Three focus group interviews (n=14) conducted with graduate students to explore the relation between learning, well-being, and physiological data. - Questionnaire distributed to 15 graduate students before and after the participatory design sessions.	- Gap between research and practice regarding the use of physiological data in learning. - Positive attitudes regarding self-monitoring.
Participatory Design	- Three participatory design workshops (n=15) with graduate students; a design game was created to improve communication with the participants and support the data collection. - Three presentations and feedback sessions during the lab's open-door event on the first two lightweight prototypes made out of cardboard and plywood.	- Participants' artifacts had a shared interest in proposing: - Design solutions that respect data ownership and privacy. - Other forms of self-monitoring (emotions, time dedicated, etc.). - Reflection as a separate task at the end of the process.
Product Design	- Design studio work produced four prototypes, two of which were functional.	- Design concepts. - Personas. - Scenarios with use cases. - Feeler paper prototype. - Feeler plywood prototype.
Prototype as Hypothesis	- Production of functional prototypes in a Fab Lab (hardware) and design studio (software).	- Feeler v.1.0 - Feeler v.2.0

3.3 Data Collection Instruments

To a greater or lesser extent, designers rely on empirical data to gain insights and make judgments. This means that the collection of data is an inherent part of the design process that occurs throughout its different phases. Because of the multidisciplinary nature of design practice, designers must consider different types of data. To this end, designers may borrow from different disciplines, such as anthropology, ethnography, psychology, social sciences, cultural studies, and engineering.

In Feeler, the research instruments for collecting data focused on understanding learners' behaviors and included interviews, focus groups, participatory design workshops, questionnaires, and feedback sessions (see Table 3). Depending on the moment when the data collection took place, the emphasis was different. For instance, the instruments used at the beginning and during the contextual inquiry were more open and general than, for instance, the interviews that followed the tests conducted during the *prototype as hypothesis* phase. In order to foster learners' participation and creative thinking, I purposely created specific design props that visualized the key areas of the research. The design props were created to support communication with participants as part of the data collection endeavors (see Table 3).

Table 3. The research instruments used during the Feeler research-based design.

Research stage	Instrument	Design props	Participants	Data format	Purpose
Contextual Inquiry	Semi-structured interviews	Inspiration cards	Graduate students (n=6)	Audio	These interviews were expected to support an understanding of how students perceive well-being in relation to their studies.
	Subject-expert interviews		Researchers and experts in neuroscience, psychology, health and well-being, and HCI and learning technology (n=5)	Notes	The aim was to understand what type of physiological data connected to learning would be more meaningful to monitor and what type of feedback could be valuable for students.
	Focus group interview[4]	Workshop: -Concept mapping -3D prototyping	Graduate students and university teachers (n=5)	Notes, Images	To explore the relation between learning, well-being, and physiological data.
	Focus group interview[5]	Workshop: Design opportunities and challenges mapping. Idea generation tackling one of the identified challenges.	Graduate students (n=4)	Notes, Images	The aim was to explore the relation between learning and well-being.
	Focus group interview	Playing with a design game about reflection on self-monitoring	Graduate students (n=5) at Aalto Medialab (Finland)	Notes, Images, Video	This session sought to bring insights into students' perceptions and practices regarding self-monitoring and learning.
	Questionnaire		Graduate students taking part in the PD sessions (n=15)	Online form	The questionnaire was distributed before and after the session. It aimed to develop an understanding about students' habits and receive feedback after the PD sessions.
Participatory Design	Three PD workshops	Collaborative design game: Participants played a game in which they were asked to design visualizations of self-monitored data related to well-being and learning.	Graduate students (n=15) at Kyushu University (Japan)	Notes, Images, Video	The artifact-based discussions sought to develop an understanding about students' preferences regarding self-monitoring, reflection, and behaviors connected to learning.
	Feedback from open sessions[6]	Mockups	Teachers and graduate students	Notes	The design concept was demoed through mockups in order to obtain feedback about

[4] This focus group was framed as part of the "Design Explorations of a Visual Dashboard for Learning and Wellbeing" workshop. It took place during the 2nd Multidisciplinary Summer School on Design as Inquiry (Helsinki, 2013).

[5] The focus group was part of the "Student Well-being in Future University" workshop. This workshop took place during the "Aalto Goes Accessible" 2015 symposium.

[6] The Feeler concept and prototypes were presented in open sessions. These sessions included Aalto Researchers' Day (2013), the closing meeting of Designs for Learning (2014), and the Aalto Medialab Demoday Festival (2014 and 2015).

					the concept and the design artifacts.
Product Design	Think-aloud interviews	Paper prototype test	Teachers and graduate students (n=5)	Notes	The intention was to identify major usability issues in the tool design.
Prototype as Hypothesis	Semi-structured interviews	Functional prototype (v.1.0) test	Graduate students (n=6)	Notes, Audio recording	The aim was to obtain feedback about Feeler's proof-of-concept test, validate the design concept, and gain insights into the tool's potential for supporting reflective thinking.
	Questionnaire		Graduate students taking part in the test sessions of the Feeler v.2.0 prototype (n=6)	Online form	The questionnaire was distributed before the test in order to gain an understanding of participants' study habits and of how familiar the participants were with self-monitoring.
	Semi-structured interviews	Functional prototype (v.2.0) test	Graduate students (n=6)	Notes, Audio recording	Each participant was interviewed after each of the three test sessions were conducted with Feeler v.2.0. The interviews aimed to provide information regarding the participants' experiences with using the tool and the tool's impact on the participants' self-regulation behaviors.
	Focus group		Graduate students (n=6)	Notes, Audio recording	The focus group session took place after the test sessions of Feeler v.2.0 with the same participants who took part in the tests. This session aimed to allow participants to share their experiences and engage in group reflection regarding the use of the tool.

In the user-centered and participatory design traditions, there is a strong emphasis on direct contact between design researchers and the people who may use the design solutions. From these perspectives, qualitative data collected from interviews, observations, and workshops are expected to bring richer and more valid information to create new technologies than quantitative data (Hyysalo, 2003). Some authors (Leonard-Barton, 1995) have claimed that qualitative, design-oriented methods that support deep comprehension of the context of use and empathic understanding of the existing attitudes and practices of people toward technology provide design researchers valid information when there is little knowledge on the technological outcomes and end-users. Similar to Hyysalo (2003) and Leonard-Barton (1995), Bleijenbergh, Korzilius, and Verschuren (2010) claim that when dealing with real problems, qualitative research strategies are more adequate than approaches based on quantitative data. As Hyysalo notes, "The accountability of these methods has been sought by claiming that they produce more valid information, while the reliability of the data is grounded on qualitative assessment and the subjective experience of the investigators" (2003, p.118). Considering that this study aimed to explore the possibilities of the use of emerging technology based on physiological data monitoring, the use of qualitative methods was regarded as the most promising option to attain valid outcomes.

3.4 Evaluation of the Feeler Functional Prototypes

Building prototypes has become a key endeavor of interaction design research. In approaches like research-oriented design (Fallman, 2003), research through design (Zimmerman et al., 2007), and research-based design (Leinonen et al., 2008; Leinonen, 2010), prototypes embody theories and act as physical hypotheses that can be tested under different conditions (Koskinen, Zimmerman, Binder, Redstrom & Wensveen, 2011; Stappers, 2007). In Information Technology (IT), scholars have argued that researchers must engage in building and evaluation activities (March & Smith, 1995). In this regard, evaluation has also been recognized as a central activity of design research (Venable, Pries-Heje & Baskerville, 2012). Evaluation focuses on assessing how well the artifact under evaluation achieves its purpose. According to Cleven, Gubler, and Hüner (2009), prototypes are a valuable evaluation method in design science research.

Based on the conditions in which the evaluation takes place, scholars have distinguished different types of evaluation methods. For instance, Venable (2006) differentiates between artificial and naturalistic evaluation. Artificial evaluation includes methods such as laboratory experiments, field experiments, and simulations. Naturalistic evaluation focuses on analyzing the prototype performance in a real environment. This type of evaluation is more complex than artificial evaluation because more factors may affect the use of the design artifact. The methods used in naturalistic evaluation include case studies, field studies, surveys, ethnography, phenomenology, hermeneutic methods, and action research.

Because design activity is iterative, evaluation is an important part as it provides valuable feedback to guide the subsequent iterations of the design (Alan, March, Park & Ram, 2004). During the research on Feeler, the functional prototypes were tested and evaluated twice. In IT design research, the use of different types of evaluation methods during the design process has been regarded as complementary (Wolf, Carroll, Landauer, John, & Whiteside, 1989). Thus, this research combined artificial and naturalistic evaluation methods to assess Feeler prototypes.

Because the prototypes were built at different instances throughout the research, the evaluation methods differed according to the purpose of the research stage. As Koskinen et al. (2011) state, "Experimental work typically happens in concept testing and selection and in the evaluation of the prototypes" (p.51). The Feeler tests may be considered experiments in which different hypotheses were tested before the design work was advanced. While the first study served as a proof-of-concept in which the participants used the prototype in a controlled environment, the second round of tests occurred in a natural setting—the university Learning Hub, which is a space reserved for students to work on their own. These tests were part of an exploratory study that analyzed how the prototype supported different dimensions of SRL. During the exploratory study, the participants used the prototype during several weeks and worked on study projects that were relevant for them.

The Feeler proof-of-concept prototype (v.1.0) aimed to validate the design concept and identify the main design flaws of the prototype. To this end, it was important to obtain feedback from the students regarding the usefulness and relevance of the design solution. The study also aimed to identify to what extent the prototype fostered students' reflective thinking. Six graduate students participated in the study. Each participant used the prototype once. During the study phase, the participants performed some predefined tasks, such as solving a 3D puzzle and reading a text. The participants were asked to think-aloud their thoughts while reviewing the data collected during the session. The think-aloud protocol was followed by a semi-structured interview. The individual interviews were recorded, and the data was analyzed using a qualitative data analysis software (Atlas.ti). The thematic analysis of the interviews (see Article III for a detailed description of the proof-of-concept research) helped to identify and analyze patterns among the participants' behaviors. The results yielded empirical evidence that contributed to validate the design concept and to identify the areas that required further improvement.

The second functional Feeler prototype (v.2.0) was built based on the feedback obtained during the proof-of-concept study. This prototype was functionally stable, and more attention was paid to aspects related to the look-and-feel and the experience of use. This round of tests focused on observing whether the prototype affected the students' ability to self-regulate while engaging in independent study work. To this end, it was important that the participants worked on real tasks and that the use of the prototype took place in a natural setting and over a long period of time. Six graduate students agreed to use Feeler for three weeks while working on their research projects. The data collection was performed similarly to that in the proof-of-concept study: after the session, the participants vocalized their thoughts while reviewing their data. This was followed by a semi-structured interview (see Article V for a detailed description of the study). Again, the thematic analysis of the interviews recordings was conducted using a qualitative data analysis software (Atlas.ti). Both evaluations used a coding scheme to guide the thematic analysis. However, the process of building the coding scheme was slightly different in each case. While the evaluation of the proof-of-concept followed an inductive and deductive approach for the elaboration of the coding scheme, in the second study the coding scheme was defined based on an existing theoretical model. A different approach was adopted to define the coding scheme because the second study sought to validate the prototype hypothesis, which was theory-driven. Conversely, the proof-of-concept research was practice-driven and emphasized the identification of the types of themes that emerged from the data.

3.5 Ethical Considerations

This research followed the guidelines of the Finnish Advisory Board on Ethical Principles of Research in the Humanities and Social and Behavioral Sciences and Proposals for Ethical Review (2009). Throughout the research, I paid special attention to providing the participants with adequate information, ensuring the participants' voluntary participation, and respecting their autonomy. To this end, I organized information sessions with the people interested in taking part in the research study well in advance of the study's initiation. The participants received written descriptions of the research and its objectives and they were also informed of their right to withdraw from the study at any point. Before the study began, the participants gave their consent to use data, such as audiovisual recordings and images, for analysis and dissemination of the research. The participants did not receive any financial compensation for taking part in the study.

Throughout the research, it was important to create situations in which the participants' knowledge would be recognized, and it was important to provide the participants with opportunities to learn. The participants were considered equals, rather than research subjects, with the ability to influence the design of future research work. To this end, I tried to keep the research advances open and share the research results throughout the process. Finally, the data collected during the process was anonymized and stored according to the guidelines provided by the Finnish Advisory Board on Research Integrity[7].

[7] http://www.tenk.fi/en

4. Research Contribution 1: The Feeler Prototype

4.1 Description: Functionality and Interaction Design

Feeler is a learning tool for self-monitoring attention and relaxation during independent study work. It is a software and a set of computing objects that guides learners' actions during an independent study session in which learners collect and assess data about their cognitive states. The Feeler prototype also uses an EEG device to capture data about learners' attention and relaxation during the study session (Figure 6).

Figure 6. A learner using Feeler during an independent study session.

The prototype aims to support learners to reflect on and self-regulate their learning by guiding learners through a set of actions that encourage awareness and self-knowledge about their cognitive processes during independent study. Informed by previous studies (Choe, 2014; Li et al., 2011; Rivera-Pelayo et al., 2012), this design research builds on the idea that self-monitoring can help learners engage in reflective thinking and self-regulate their learning processes.

Guidance is understood as providing a context in which learners can monitor their activity in a meaningful way. For this, each session is divided into three different phases: Meditation, Study, and Play[8]. The activities in all three phases require that learners remain focused on the task at hand. By capturing data about cognitive states and digital activity as well as recording learners' subjective impressions, learners can observe the relation between their attention and relaxation while performing different tasks and can analyze how these values affect their study performance.

In Feeler, the software running on a computer is the central element of the Feeler system. Learners access the Feeler software in order to start a self-monitoring session and to review data from their previous sessions. During a self-monitoring session, the software collects data from different sources (learners' digital activity, learners' self-reports, and the EEG device) and guides learners' activity by communicating with the computing objects (Figure 7).

Figure 7. Communication between Feeler elements.

The combination of multiple interfaces (tangible in the computing objects and screen-based in the software) is a distinctive trait of Feeler design. Although learners' interaction with each interface happens separately, there are specific moments when learners need to switch between interfaces. The transition between interfaces works smoothly providing learners a unified experience. This is quite a novel approach to the design of interfaces for TEL tools, where the interaction tends to focus on a single interface.

Functional versions of the Feeler prototype software (v.1.0[9] and v.2.0[10]) have been developed using processing programming language[11]. Moreover, the hardware of the boxes is built with Arduino[12] microcontroller boards, sensors, vibrators, and light-emitting diode (LED) lights. Both Feeler v.1.0 and v.2.0 use

[8] In Feeler functional prototype v.1.0, the phases were slightly different and consisted in Meditation, Study and Reflective questions. The results of the testing of prototype v.1.0 informed another iteration round where the last phase was redesigned becoming a memory game.

[9] Feeler prototype v.1.0 was developed by Niklas Pöllönen. Juan F. González designed the prototype logo.

[10] The technical development of Feeler v.2.0 was performed by Niklas Pöllönen, Régis Frias, and Joaquín Aldunate. Juan F. González collaborated with the design of the visual identity and the dissemination materials of the prototype.

[11] https://processing.org/

[12] https://www.arduino.cc/

Neurosky Mindwave[13] to collect the learners' EEG data. The Mindwave captures data about brain waves and transforms them into attention and relaxation values. The Mindwave helmet has a single-channel EEG dry sensor, which is placed on the forehead.

The simple design of the Mindwave makes the device easy and fast to set up with very little preparation. Although current versions of Feeler are only compatible with the Mindwave helmet, the Feeler software and hardware are open source[14] and therefore can be modified to be used with any EEG hardware. The use of the Mindwave model for prototyping is due to its easy setup and user friendliness, which allow EEG data collection without disturbing the learner. Considering that user friendliness and smooth interaction foster engagement and active participation, the adoption of an EEG device that met these requisites was important to allow participants to develop relevant subjective experiences of using the Feeler prototype. In addition, several studies of brain computer interfaces have used Neurosky dry sensors (Chang, Nelson, Pant, & Mostow, 2013; Crowley, Sliney, Pitt, & Murphy, 2010; Luo & Sullivan, 2010).

4.1.1 Interaction with the Computing Objects

Each of the computing objects, the boxes, is associated with a particular phase that calls for specific behavior and actions from the user (Figure 8). The boxes give visual, audio, and haptic feedback to guide learners' actions. The meditation and the study boxes have a timer, and a gentle vibration indicates to learners that time is over and that they can proceed to the subsequent phase. Learners start a new phase by placing the subsequent box next to the one they just completed. The magnets located at the sides of the boxes help connect the boxes in the right order. A vibration confirms that the connection was successful.

Figure 8. Feeler boxes dividing a study session into three phases: Meditation, Study, and Play.

[13] http://www.neurosky.com/

[14] All Feeler software is licensed open source (GPL3) and available online (https://github.com/eduraga/feeler).

Once learners start a session with Feeler, they are asked to perform a five-minute meditation exercise. It is a basic exercise that consists of focused attention meditation. This type of meditation has been recognized as beneficial to develop skills for sustaining attention (Lutz, Slagter, Dunne, & Davidson, 2008; Tang, Ma, Wang, Fan, Feng, Lu, Yu, Sui, Rothbart, & Posner, 2007). The meditation-box guides learners' breathing rhythm through a pulsating light that provides a fixed point to look at (Figure 9).

Figure 9. A learner holding the meditation box while performing focused attention meditation.

After meditation, the learners start the study activity. Inspired by time management techniques that use intervals of time, the study-box time is set to 20 minutes. Depending on the learners' attention and relaxation levels, the software takes a screenshot of their digital activity. As time passes, a grid of LED lights placed inside the box illuminates gradually and provides the learners with a visual indicator of the remaining time (Figure 10).

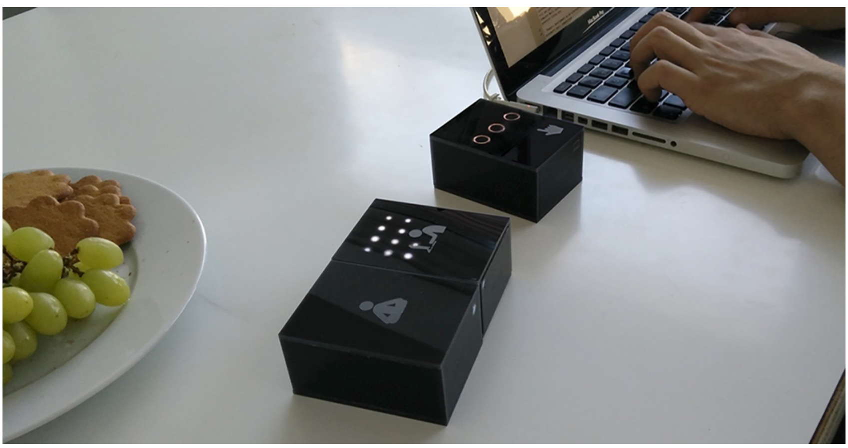

Figure 10. The visual feedback provided by the study box during the study phase.

Once the learners connect the third box, a game activates. The play-box consists of an adaptation of the 1980s electronic Simon Says game. A light and sound sequence is displayed through the three buttons on the box. Learners are invited to repeat the sequence by tapping the buttons (Figure 11). Each time the learners repeat the sequence successfully, another step is added. Whereas initial sequences are short and do not require much cognitive effort from the learners, the addition of steps requires the learners to pay more attention in order to memorize increasingly longer sequences. When learners make a mistake, the three buttons illuminate simultaneously. A new game can be started by pressing one of the buttons. Because there is no time limit set for this box, learners can play the game as long as they want. To end the game, learners access the Feeler software running on the computer.

Figure 11. A learner playing the with the play box.

The three boxes provide a tangible interface with which learners interact while working on their independent study projects. In this way, the software application can be minimized, and learners do not need to check it again until they conclude the session. Data about learners' behavior and their cognitive states are collected in the background, without interrupting the main activities. This allows learners to fully focus on their activities and to prevent learners from diverting their attention to check the software.

4.1.2 Interaction with the Software

After ending the game, learners are asked to report about their level of satisfaction (bad, neutral, good) and to assess, on a scale from 0 to 100% and according to their subjective impressions, how attentive and relaxed they were throughout the session phases (Figure 12).

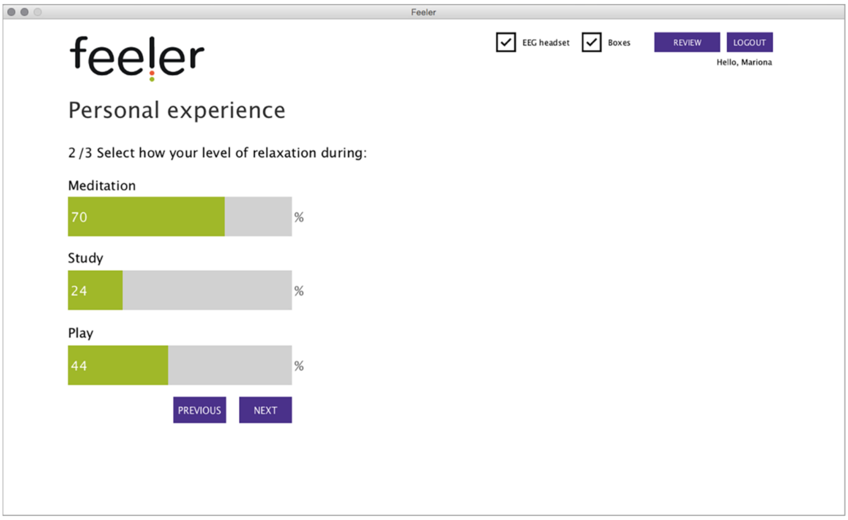

Figure 12. A screenshot of the assessment questionnaire about the estimated relaxation levels that corresponded to an independent study session.

Learners' data are presented in a visual dashboard. In it, each session attention and relaxation values collected through self-reports and through the EEG device are averaged and presented in a dot chart. Learners can see their progression over time and select the session they want to review (Figure 13). Unlike other systems that capture physiological or behavioral data about people (see for instance the *AttentiveLearner* described in Pham and Wang [2015], and Szafir and Mutlu's [2013] adaptive content review system based on attention monitoring), in Feeler the data collected by automatic means, like the EEG device, and the data collected by asking learners about their personal experience are considered equally valid. These two data sets are averaged in order to display the attention and relaxation values corresponding to an independent study session.

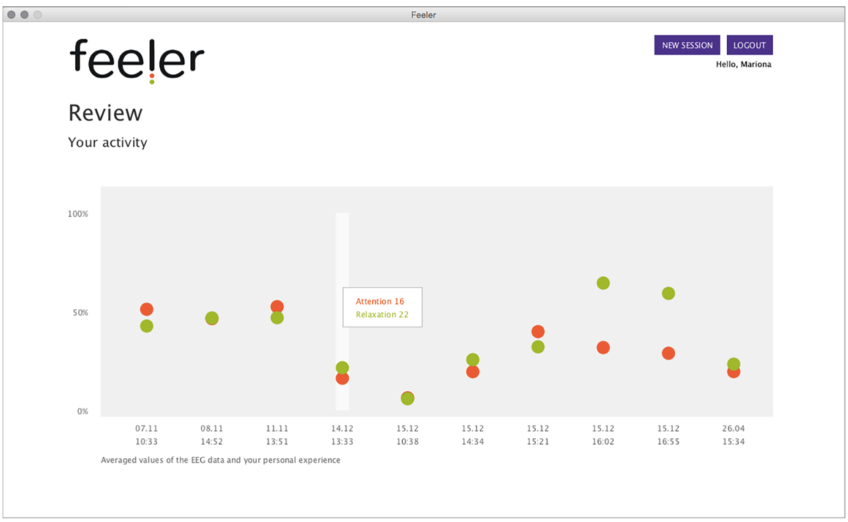

Figure 13. A screenshot of the first-level visualization of the attention and relaxation values throughout several sessions.

When reviewing data from one session, learners' self-reports about their attention and relaxation values are juxtaposed to the values provided by the EEG device (Figure 14). The juxtaposition of these two data sets is expected to trigger comparisons and curiosity to understand the possible differences between them. When compared to other QS tools (see for instance the *Moodlight* [Snyder, Matthews, Chien, Chang, Sun, Abdullah, & Gay, 2015], the *MAHI* [Mamykina, Mynatt, Davidson, & Greenblatt, 2008] or the *CaReflect* [Müller, Divitini, Mora, Rivera-Pelayo, & Stork, 2015]), Feeler's design is novel in its way of capturing and presenting data collected by the technology and the self-reported feelings. Further detail about each of the data sets is provided in the third-level visualizations (see Figure 15 and Figure 16).

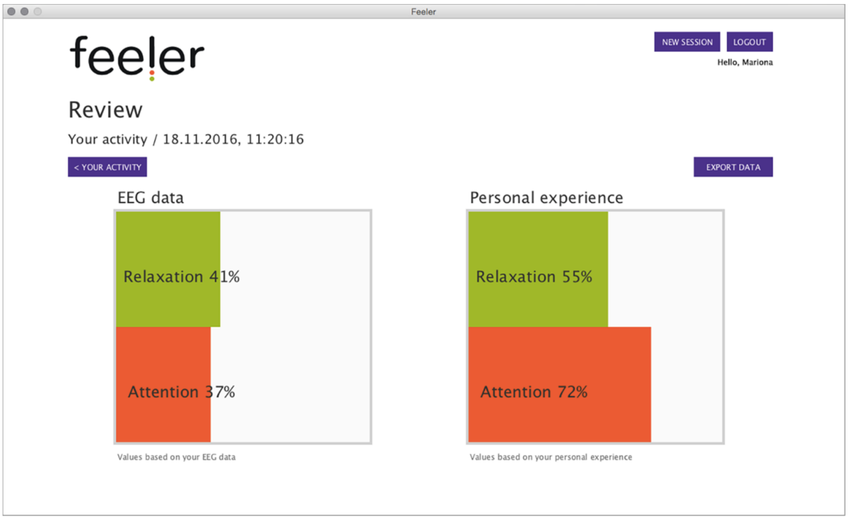

Figure 14. A screenshot of the second-level visualization of the attention and relaxation data collected by the EEG device and the self-reports that corresponded to a single session.

The third-level visualization of the attention and relaxation levels obtained through the EEG device includes screen captures of what the learner was studying or working on at the computer at specific moments (Figure 15). The screen captures help to contextualize the EEG data collection and enable learners to relate their behavior to their cognitive states.

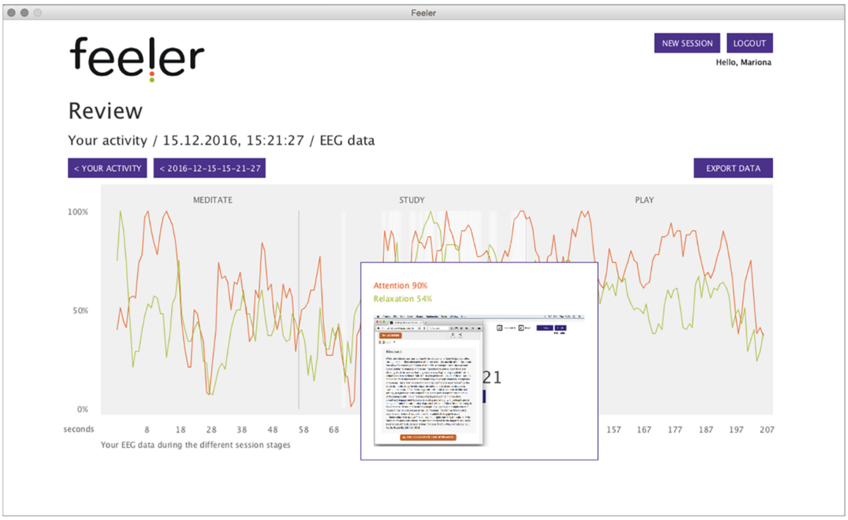

Figure 15. A screenshot of the third-level visualization of the attention and relaxation data collected by the EEG device linked to the screen capture of the study material the learner accessed at a particular moment during one independent study session.

In parallel, the third-level visualization of learners' self-reported data shows learners' satisfaction levels about their performance during the different phases of the independent study session (Figure 16). The aim of the third-level visualizations is to support learners' deeper understanding of their data and to encourage them to reflect by drawing relations, posing questions, generating hypotheses, and triggering free exploration and personal inquiry processes.

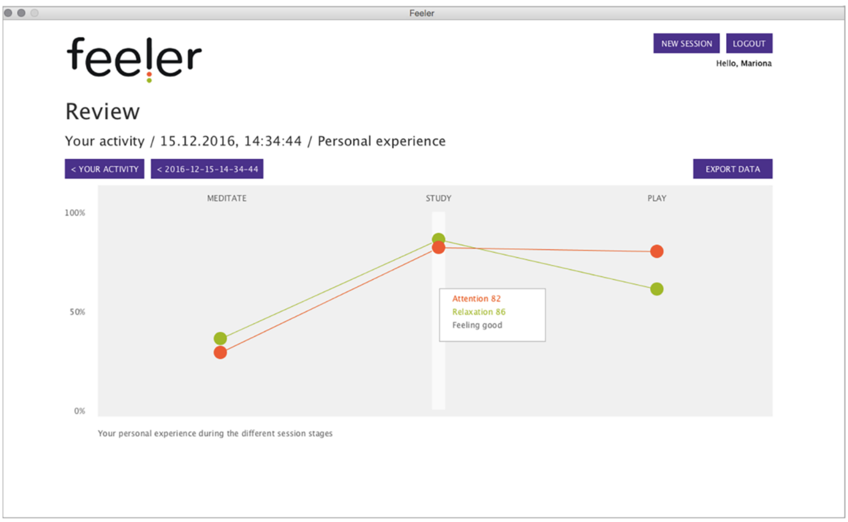

Figure 16. A screenshot of the third-level visualization of the data self-reported by the learner that corresponded to a single session.

4.2 Design Qualities

As presented in section 2, an important volume of research on technology design has called attention to the role of values that guide the design of interactive systems. In learning and education, the values that guide the design of learning tools relate to different approaches to learning and teaching, which are translated into pedagogical foundations and use qualities. In this section, I introduce the pedagogical principles and approaches to learning that were influential to the design of Feeler. I also highlight the use qualities that inspired the Feeler interaction design and exemplify how these ideas have been implemented when designing feeler functionalities.

4.2.1 Pedagogical Foundations

The Feeler design adopts a learner-centered approach and is inspired by perspectives that advocate that learners are the ones who build knowledge (for a review, see Amineh & Asl, 2015; Phillips, 1995; Steffe & Gale, 1995). From these perspectives, learning is considered an active process during which learners build knowledge through inquiry and discovery (Bruner, 1961; Papert, 1980). This approach stresses the importance of creating meanings from experience, rather than acquiring them (Dewey, 1929; Jonassen, 1999). In this line, the Feeler design aims to provide a context in which learners can develop an experience through self-monitoring and reflecting on it.

This research is based on the assumption that learning is a complex process that benefits from various types of activities. Thus, to contribute to a collaborative project, one should conduct some independent learning to create ideas, develop insights, and identify diverse solutions that can be shared with other group members. This is similar to what happens in collaborative knowledge building, as in order to make meaningful contributions to the group discussion it is necessary for individual members of the group to prepare and investigate the topic at hand on their own. So, effective, collaborative, inquiry-based, problem-based, and project-based, knowledge building requires independent study (Hmelo-Silver & Barrows, 2008; Kessler & Bikowski, 2010).

In Feeler, learners are asked to recall their subjective impressions and self-report about their perceived levels of attention and relaxation during the independent study session. The comparison of these data with the values captured by the EEG device is expected to trigger reflective thinking and personal inquiry. In some cases, learners may feel motivated to understand why the data collected by the system contradicts their initial thoughts. The inclusion of different types of data in visualizations of Feeler data is also expected to enrich learners' interpretation of their past experiences by allowing them to see the same situation from different angles.

The practice of building, which consists of physical or conceptual artifacts, has also been regarded as relevant for learning. Researchers with this perspective advocate that learning should be based on doing, construction, and discovery (Papert, 1980; Kafai & Resnick, 1996). Therefore, learners should be able to control and manipulate the tools— especially those used in learning—as this can help learners develop their own understanding of how these tools work. According to this view, the hardware, software, and data captured by monitoring tools should be accessible and open to learners. The Feeler design borrows from these ideas and allows learners to download the software code and the hardware design to study and modify the code and the hardware. Learners are also encouraged to tinker while using Feeler, as the boxes are easy to open. Thus, learners can look inside each box, understand how it works, and hack it. This approach is inspired by the free software and the free hardware design (Stallman, 2002).

The notion of openness, understood as having access, but also control, is extended to the data collected by the system. In this regard, Feeler design follows a human-centric approach to personal data management, inspired by initiatives like Mydata (Poikola, Kuikkaniemi, & Honko, 2015). This is another distinctive trait of the Feeler design, since most TEL designs do not give learners such level of access and control over their personal data. In Feeler, learners can access all their data stored in the software in a machine-readable format. The download file includes the raw data of the EEG readings in order to enable learners to explore the data in different ways and build their own interpretations.

Feedback has been recognized as an important tool to support learning (Haltie & Timperley, 2007; Mory, 2004). In Feeler, the visualization of learners' attention and relaxation data provides learners feedback at the end of the study session. The display of different types of data (the values provided by the EEG device, the screenshots of user activity captured by the software, and learners' subjective impressions) is expected to help learners realize how certain activities affect their performance, and therefore, to develop self-control behaviors during future independent study sessions that help them achieve their goals.

Unlike systems based on behavior change, Feeler does not include any explicit feedback of how to modify behavior but invites learners to draw their own interpretations. This approach aligns with views that claim feedback should engage students in thinking and reflection (Akcan & Tatar, 2010; Fund, 2010; Jonassen, 1991). To this end, Feeler avoids assessing learners' performance through social comparisons or externally set standards and instead encourages learners to create their own standards. By emphasizing self-reflection, Feeler may help learners gain insights into how certain behaviors affect their mental states, and vice versa, and therefore help learners improve their self-knowledge.

The Feeler design draws inspiration from theories of SRL to support skills that contribute to autonomous and independent learning. In particular, special attention is dedicated to approaches that advocate supporting learners' active involvement in aspects connected to metacognition, motivation, and behavior (Pintrich, 2004; Zimmerman, 1989).

Metacognitively, Feeler aims to encourage the development of key skills for self-knowledge, such as self-awareness, self-monitoring, and self-assessment. In the prototype, learners need to report their impressions regarding their attention and relaxation levels throughout the session before accessing the visualization of the data collected by the EEG device. This self-assessment exercise is expected to help learners gain self-awareness because, as learners become familiar with the Feeler, they become accustomed to self-monitoring their mental states during independent study sessions.

Some approaches to SRL stress the importance that learners adopt cognitive strategies that connect to key mental processes for learning (Bandura, 2001; Schunk, 2001, 2008; Winne, 2001). Researchers have acknowledged that the appropriate use of cognitive strategies can affect learners' motivation, as the use of cognitive strategies helps learners gain confidence in their ability to control their behavior and reach their goals (Bandura, 1997; Zimmerman, 2000). Following this approach, Feeler aims to expand the cognitive strategies that learners' use to regulate their behavior when performing independent study tasks. To this end, the Feeler boxes guide learners to implement and test different strategies that can help them regulate their attention and relaxation while performing different activities (meditation, study, and play). Depending on learners' judgment, the strategies are adopted and become part of their repertoire of learning strategies.

4.2.2 Use Qualities

According to Löwgren, use qualities refer to "properties of digital design that are experienced in its use" (2002, p.1). These properties emerge when people interact with a digital product and can be considered a language in themselves (Löwgren, 2002). Use qualities have also been connected to outcomes, as these are the long-term impacts that occur after interaction (Cockton, 2006).

The Feeler prototype aims to support learning experiences in which learners develop an awareness of their study habits and make sense of how attention and relaxation may affect their performance. To this end, the design of Feeler integrates a set of qualities that support learners' engagement during interaction. These qualities consist of invisibility, intuition, simplicity, and playfulness.

The Feeler interface design renders the technology behind Feeler invisible in order to help learners engage in their study activity. For instance, the different devices (the EEG helmet, the computer software, and the boxes) use wireless communication, and the signals are synchronized using the Feeler software. Learners do not need to check the connections because the software notifies them in case of error. Feeler interface design approach connects to Norman's claim that technology should remain invisible to the user (1988). While Norman (1998) uses the term *invisibility*, Löwgren (2002) uses the term *transparency*. According to Löwgren, an important use quality is that "the interface is transparent, such that the required operations can be carried out without distractions" (p.10). In both cases, Norman (1998) and Löwgren (2002) stress the importance of supporting smooth interactions in which people can focus on achieving their goals rather than figuring out how to use the tool.

Supporting intuitive use is a strategy to make technology invisible. Feeler's tangible interfaces (the boxes) provide different types of feedback in order to guide learners' actions and avoid confusion during the study session. In addition to visual and audio feedback, the boxes incorporate magnets and motors to provide haptic responses.

Moreover, the use of simple interfaces with few functionalities is another strategy to support intuitive use in the software and the boxes. The software information architecture of Feeler follows a hierarchical structure and has few levels in order to ensure user-friendly navigation. Each box is associated with a different phase of an independent study session in order to provide a simple and visual structure. According to Löwgren (2002), functional minimalism consists of the combination of power and simplicity. Inspired by functional minimalism, the Feeler prototype defines a narrow range of functionalities and actions to perform at each phase of the independent study.

Intuition and playfulness work together to foster engagement when interacting with the Feeler. The boxes seek to create a tangible and playful user experience by stimulating diverse senses. For instance, the size and shape of the boxes encourage learners to touch and "play" with the boxes. When touching and playing with the boxes, learners receive different types of feedback. This tangible interaction replaces textual instructions while contributing to immersive experiences.

Learners are expected to use the different elements of the Feeler system at different moments of an independent study session. While the software is intended to be used before and after the independent study session, the boxes are meant to be used during the study activity. This distinction aims to create a temporal flow and encourage learners to engage in the task at hand. Furthermore, the use of the different elements relates to different goals. Thus, during the study session learners are expected to regulate their attention and relaxation to benefit their cognitive activity, whereas after the study session learners are encouraged to reflect on the collected data.

The Feeler design uses the design qualities of invisibility, intuition, simplicity, and playfulness to support reflective and SRL experiences. In design practice and research, researchers discuss whether it is possible to design experiences because users are the only ones who can construct experiences (Sanders, 1999; Wright, McCarthy, & Meekison, 2003). Therefore, it is not possible to guarantee that learners will reflect and self-regulate their activity by using the Feeler. However, this does not prevent Feeler from creating conditions that are suitable for certain types of experiences. The extent to which the Feeler prototype helps to trigger reflective and self-regulated learning experiences is reported in section 5.

5. Research Contribution 2: Findings on Monitoring Tools and their Implications for Learning

After defining the areas to which this study contributes and describing the tool and the research design, I revisit the findings presented in the articles in order to identify key transversal issues connected to the use of monitoring tools in learning.

There are several elements that must be considered in the use of monitoring tools for learning purposes, such as the values and cultural and socio-economic discourses embedded in the design of technological objects. Thus, when designing or appropriating techno-monitoring practices for learning purposes, it is necessary to identify such values and discourses because they create opportunities for and challenges to teaching and learning practices.

Second, there are issues connected to the design of monitoring tools for learning purposes. As shown in section 2, some views on technological development claim that the design of monitoring tools is not a neutral, value-free process. Therefore, the design process of technology should be a matter of reflection. The design approach determines the type of relations research-designers build with participants and affects the notions of power and authority embedded in the tool design.

Third, the use of monitoring tools in education affects learning. A key aspect is the role of the learners, but equally important are the skills monitoring tools help learners to develop. The theoretical and empirical analysis of monitoring tools and techno-monitoring practices conducted in this research have contributed to the development of an understanding about the mutual relationship between learning and the monitoring of learning.

Although the findings of this study are presented in a linear fashion, the findings are interwoven. The iterative nature of the design process requires revisiting different aspects and design decisions throughout the whole process. For this reason, the articles should be regarded as a network in which issues connected to the socio-cultural implications, the design, and the impact of monitoring tools on learning have been continuously reviewed.

5.1 Considerations in the Use of Monitoring Tools and Techno-Monitoring Practices

Throughout the discussions held with participants at different phases of the design process, I observed the existence of a set of well-accepted ideas regarding monitoring technologies. These ideas permeated participants' speech so much that I concluded participants considered some aspects of monitoring tools designs as natural properties of these tools. It is essential to unpack these assumptions to define the socio-cultural perceptions of monitoring technologies.

Whereas Article I provides a theoretical analysis of general issues connected to the implications of monitoring tools for learning, Articles III, IV, and V focus on participants' comments during the test sessions with the Feeler prototypes. This research is based on a dialogue between theory and practice, in which practice-based articles contribute to advance an understanding of social perceptions on techno-monitoring practices by confirming the theoretical assumptions and highlighting new aspects connected to monitoring practices based on technology.

As a medium, monitoring technology may be regarded as a tool to augment human senses. Actually, monitoring technology is expected to act as a sixth sense that helps people obtain hidden information that otherwise would not be accessible. No matter what type of data is being captured, the visualization of data is expected to bring new understandings that will increase knowledge and lead to wiser decisions. Despite critical voices concerning monitoring technology, especially regarding data privacy, ownership, and access, techno-utopian views are well spread and tend to prevail. From this perspective, monitoring tools are expected to improve well-being, productivity, and efficiency, as well as to support continuous development and self-improvement. In fact, the participants of the study presumed that monitoring tools would help them achieve their goals, even when the goals were not clear or even contradictory. For instance, even if the ultimate goal was to increase well-being, the emphasis on productivity could increase anxiety. This became evident during some test interviews in which the participants expressed concern about procrastination behaviors. According to their views, time is a resource that should be used efficiently. However, as one of the participants acknowledged, in creative domains the distinction between leisure and work time is difficult to establish. As a result, people tend to feel anxious if they are dedicating time to other things that are not connected to work because they assume they are procrastinating. Although they are not an inherent property of monitoring tools, these assumptions connect to the cultural and socio-economic context in which this technology flourishes.

The empirical and theoretical analysis conducted in Articles I, III, IV, and V showed that techno-monitoring practices connect to an individualistic value system. Users of monitoring tools are encouraged to self-improve and achieve their own individual goals. At the same time, users are concerned about how well they are performing in comparison to others. As discussed in Article IV, techno-monitoring practices, such as the QS, are embedded in a competitive culture that stresses productivity and self-improvement.

Articles III, IV, and V describe participants' interest in and reliance on social comparisons to assess their work. The participants were not accustomed to developing and evaluating their performance based on their own standards, and they preferred to rely on externally defined standards. In fact, some of the participants requested the inclusion of a tool feature that compared their performance to that of others in order to help them interpret the monitored data. By delegating assessment to external tools, the participants were giving up opportunities for developing their skills for self-regulated and autonomous learning.

While monitoring tools are expected to lead to personalization and adaptation, they also require a certain level of homogenization in order to compare performance. As argued in Article I, this homogenization is based on standards that contribute to define a character-building agenda that consists of perseverance, dedication, and hard work. In addition, when monitoring requires some conscious action from the users, it is necessary that the users remain committed to collecting data on a regular basis. Such commitment demands a high level of motivation and identification with the values supported by these techno-practices.

In techno-monitoring practices, the collection of data is expected to lead to evidence-based decisions. Because the data are considered neutral and objective, the analysis of these data is thought to provide an exact and reliable picture of what is happening. In Articles III, IV, and V, the participants received the data expecting the data would offer them an accurate portrait of their attention and relaxation levels. In some cases, the EEG data provided by the monitoring device was considered more reliable than the participant's subjective impressions, which led some participants to change their self-perceptions.

Although monitoring tools can help to collect a diverse range of data, they tend to target specific data types. Quite frequently, these data focus on observable events that can be quantifiable. Articles I, III, IV, and V show that the interpretation of quantitative data is a challenging task for many people, primarily because of the lack of data literacy skills. During the tests, the participants acknowledged the difficulty of interpreting the data collected by the EEG device. In addition, the participants' efforts to make sense of the data had some cognitive bias. As Article IV describes, when reviewing the data collected through the EEG device, the participants focused on details that confirmed their subjective impressions, such as how meditation contributed to improve their attention during the study session. This confirmatory bias gave more credibility to existing beliefs based on personal experiences rather than to the analysis of the quantitative data. This could be why the participants did not show much interest in getting a copy of their sessions raw data to perform their own alternative analyses and visualizations.

Data illiteracy not only creates a divide based on access and data skills, but also affects how people relate to data. Articles III, IV, and V, report that attitudes toward data collected by monitoring tools range from skepticism to trustful reactions. As observed in the tests with the Feeler prototypes, while some of the participants rejected monitoring tools and the data they provided, others accepted these tools and data uncritically and without an awareness of their limitations and potential biases.

5.2 Insights into the Design of Monitoring Tools for Learning

Articles II, III, IV, and V discuss design methods and approaches that support equal relations among research-designers and participants and foster reflective and critical dialogue. The discussions that took place during the design process of Feeler contributed to the development of an understanding of how monitoring tools and techno-monitoring practices embody certain conceptions of power and authority in the context of learning. This understanding was critical to explore alternative solutions inspired by democratic and human-centered design approaches, especially in learning contexts.

Design practice involves imagining what can be possible and how to best achieve it. In order to accomplish these tasks, designers must define concepts that play a key role in in the design solution. Sometimes, designers need to use existing technology. The chosen technology brings with it a set of already given definitions and concepts that designers need to integrate in their projects. For instance, as discussed in Articles III, IV, and V, the use of an existing EEG device as part of Feeler implied adopting some ready-made definitions of attention and relaxation. During the interviews, the participants reflected on and questioned these definitions. The fact that the EEG device used proprietary algorithms hindered efforts to gain an understanding of how attention and relaxation values were obtained and generated distrust among the participants.

The opacity of the algorithms used in the EEG device evidenced a power relation were the users were expected to accept the values provided by the device without having the possibility to understand how these values were created.

When discussing power and authority in technology design, openness is an issue that goes beyond software and hardware. Quite frequently, the objectives of the technology itself are presented ambiguously. For instance, many LA tools are said to be oriented toward student success (Siemens, 2013). However, the definition of student success is problematic. Whereas many define student success as supporting students to learn better, from an institutional point of view, this could also mean preventing student dropouts and ensuring that students graduate on time. While these two definitions are not necessarily contradictory, they have very different meanings. In this regard, clarifying definitions is a first step to ensure a shared understanding and to build relations based on equality.

Productivity is another concept that was frequently discussed in the interviews held with the participants after they tested the Feeler prototype (see Article IV). Defining productivity is controversial because the goals that users are expected to achieve stem from the definition of productivity that is established. In monitoring tools that follow a quantitative approach, productivity is understood as an increase or reduction of specific values. Defining productivity based on quantitative data excludes qualitative information that would allow users to assess the relevance of those actions for attaining their goals in a contextualized and deep manner. Therefore, it is important to problematize the definition of key concepts during the design process of a monitoring tool. Creating definitions is a complex task related to power and authority, as creating definitions also requires the establishment of goals and assessment methods.

Monitoring tools enable surveillance, whether surveillance is exercised by the user or by other agents. Designs based on cloud computing applications take control of the data away from the users' and blur the line regarding who has access to and ownership of the data. The students who took part in the Feeler tests (Articles III, IV, and V) were aware of the potential misuses of their personal data and were distrustful of how institutions and companies would use these data in the future. As stated in Article I, surveillance through digital traces can enhance classification and prediction, which may lead to statistical discrimination. In addition, as a result of surveillance students can develop specific subjectivities.

As Article IV argues, Feeler can be considered a speculative design artifact because it seeks to support reflection on monitoring physiological data during study activities. Feeler confronted participants with a challenging but possible scenario regarding the use of monitoring tools in education. At first, the participants' reactions ranged from enthusiasm to skepticism toward the integration of monitoring technology in the Feeler design. However, over the course of the sessions the participants engaged in a reflection process that helped them develop a more elaborate and critical stance on the uses of monitoring tools in learning.

Design researchers have explored diverse approaches and methods to support reflection (see, for instance, the work of Dunne and Raby [2001, 2013], Hallnäs and Redström [2001], and Sengers et al. [2005]). In the participatory design tradition, scholars have stressed the importance of enabling the people who would receive the design to have a voice during the design process (Bødker., Grønbæk & Kyng, 1995; Ehn, 1993; Greenbaum & Kyng, 1991). As Article II presents, the adoption of participatory design methods during the Feeler design process supported dialogues that contributed to define the design space. The participants' contributions were extremely valuable for understanding current monitoring practices performed by students, as well as the possibilities and limitations of digital technologies. Recognizing the students' expertise at early stages of the design and creating opportunities for collaboration were key for enriching the design process.

Article II describes the several participatory design methods that were used during the Feeler design process, such as scenarios, storytelling, design games, and co-design workshops. These methods helped to enhance communication and to develop a shared understanding between design researchers and participants. Among those methods, design games were found to be particularly suitable to support empathy and foster reflection regarding diverse aspects related to monitoring.

In order to contribute to the design process, participants must work in an environment where they feel comfortable to freely express their thoughts and collaborate with others. Thus, the conditions for participation must be structured. During the contextual inquiry and participatory design phases of the Feeler research-based design, much attention was paid to the objects with which the participants would interact during the sessions. For instance, in Article II the design game that synthesized the different stages of self-monitoring for changing behavior was regarded as an object to support thinking and reflection. By presenting the participants a narrative that provided plausible situations of use and motivations to monitor their own behavior, the participants could make connections to personal experiences and contribute their expertise about specific topics. The game also encouraged those participants who had not had any previous experience with self-monitoring to contribute to the design process. The use of storytelling techniques encouraged the participants to put themselves in their characters' shoes and imagine how they would feel and act when self-monitoring for learning and academic purposes.

The design game helped bridge the gaps in knowledge among the participants and between the participants and the research designer (see Article II for a detailed analysis of the design game used during the contextual inquiry of this study). Certain elements of the game design contributed to foster negotiation during the discussion that followed the play session. One such element was the modular design of the board squares. During the follow-up discussion, participants questioned the order of certain decisions connected to self-monitoring. By rearranging the squares of the board, the participants created a decision sequence that aligned with their own views.

Individuals not only participate during the design process, but also while they are interacting with technology. In this regard, the Feeler prototypes aimed to encourage the people who would use the prototypes to participate actively, instead of treating these people as passive providers and consumers of data. Thus, as Articles III, IV, and V present, for this purpose it was considered crucial to recognize and build from learners' experiences.

5.3 Implications of Monitoring Tools for Learning

The uses of monitoring tools are diverse and may overlap. A common use of monitoring tools is helping users to change their behavior for the better. The tools oriented to this end tend to follow a behaviorist approach in which the focus is on reinforcing positive behaviors. As discussed in Article I, the adoption of behaviorist ideas in learning has been questioned due to its inability to help people learn skills to become independent learners. In McLuhan's tetrad of media effects, behaviorism is presented as a learning approach that monitoring tools retrieve and that was previously regarded as obsolete.

Moreover, monitoring tools are used to improve performance. In this line, in order to support progress toward goals, monitoring tools frequently include services to guide users' actions. This approach is characterized by an instrumental use of data. In the test sessions (Articles III, IV, and V), the participants' expectations reflected these views. For instance, most of the participants assumed that they would become more relaxed and would pay more attention during the study activity if they used Feeler on a regular basis. In order to achieve these goals, some of the participants requested to add coaching features to the prototype design.

In addition to changing behavior and improving performance, monitoring tools are used to develop self-knowledge. Self-knowledge plays a role in self-regulation, which is connected to mental health and well-being. In learning, self-knowledge is necessary for the self-regulation of learning because it helps learners set their own goals, identify solutions, and foresee how comfortable they will be with those solutions. Monitoring tools designed from this perspective tend to encourage learners to build their own understandings by supporting reflective thinking.

By recording data on activities and allowing users to revisit that data, monitoring tools support reflection. Through reviewing and visualizing data, users can find patterns, draw connections, and develop new perspectives. By engaging in this reflection, users can change their practices. This approach can be time consuming because it requires that users undergo a self-understanding process before being able to identify what they should modify. Furthermore, merely presenting data does not guarantee that users will engage in deep reflection (see Articles III, IV, and V for a discussion on how monitoring tools can support reflection). Although some participants reported that they modified their habits after using Feeler, the most evident outcome from the test sessions was increased self-knowledge (see Articles III, IV and V).

Articles III, IV, and V discuss the several strategies that were employed to foster reflection skills using Feeler. Such strategies included recalling personal experiences, challenging assumptions, supporting the contextualization of the data, and avoiding the provision of explicit advice or suggestions. The analysis of the Feeler test sessions (see Articles III, IV, and V) demonstrated that learners engaged in activities that triggered reflective thinking. In particular, some of the design features of Feeler, such as the comparison between subjective impressions and the data collected by the EEG device, triggered the learners' reflection by presenting the learners with conflicting views of the same situation. The contradictions that the participants found when reviewing their data provoked a state of surprise, puzzlement, and doubt that led them to develop personal theories and engage in personal inquiry. This influenced the participants' goals for future sessions because they developed hypotheses that they wanted to validate in subsequent uses of Feeler.

Article III analyzes the levels of reflective thinking supported by Feeler v.1.0 according to the hierarchical levels of reflection described in the literature. The results indicated that the prototype successfully supported participants to gain awareness of and reflect on their cognitive states when performing academic tasks. After using the prototype, the participants generated questions and drew their own interpretations. As Article III argues, these behaviors represent middle to high levels of reflection.

Building on the results of Article III, Article V investigates how Feeler v.2.0 supports learners to self-regulate their activity during independent study. The potential of monitoring tools to support reflection and self-regulation of behavior is brought up in Article I when it analyzes the effects of monitoring tools on learning activity when such tools are taken to their limits. Following this line, Article V highlights the power of monitoring tools to support self-regulation behaviors, such as self-control, self-observation, and self-judgment.

Article V argues to what extent Feeler v.2.0 supports learners to become metacognitively, motivationally, and behaviorally active participants of their own learning processes. From a metacognitive point of view, Feeler helped learners develop self-awareness and acquire self-monitoring and self-assessment skills. These skills have been recognized as key for self-knowledge. The analysis of the test interviews demonstrated that Feeler affected learners' motivation by increasing their confidence in their ability to control their attention and relaxation. In this regard, Feeler provided learners a structured environment for self-monitoring where they were invited to use different strategies to control their attention and relaxation. For instance, some participants realized that practicing meditation before engaging in independent study helped them to clear their mind and stay focused. Learning a new strategy improved their self-confidence because they felt able to control their attention and avoid undesirable behaviors like procrastination.

From a behavioral perspective, certain features of Feeler, such as the automatic recording of learners' activity and the visualization of these data, provided valuable feedback that helped participants identify the impact of certain practices on their cognitive states. The Feeler prototypes do not include any guiding system that assists learners in setting goals and assessing how well they are progressing to achieve those goals. Instead, Feeler seeks to encourage learners to develop their own self-standards to self-assess their performance. As Articles III, IV, and V indicate, learners found it challenging to interpret their data and asked for explicit feedback regarding their performance in comparison to others, as well as for the inclusion of some sort of guidance. These findings suggest that learners are accustomed to receiving corrective feedback in which social comparisons are a key measure to evaluate performance. The fact that learners were able to adapt their behaviors based on the feedback provided by Feeler and to try new strategies suggests that, given the appropriate circumstances, learners are able to set goals for themselves and direct their learning (Article V).

According to the participants, the Feeler boxes were helpful to remain focused on the task at hand and self-control their behavior. As demonstrated in Article V, the boxes relieved the learners from performing certain tasks, such as controlling the time, and thus allowed the learners to become fully immersed in their activities. In addition, the presence of the boxes in the learners' study environment acted as a reminder of monitoring, which increased the learners' self-awareness. As participants reported, the boxes had a more powerful effect on their self-awareness than the actual tool used for self-monitoring their EEG activity.

The analysis of the tests with Feeler v.1.0 and v.2.0 presented in Articles III, IV, and V yields promising insights to guide the design of monitoring tools in learning. As stated in Articles I, III, IV, and V, the findings from the research indicate that monitoring tools in learning should focus on fostering self-knowledge and self-regulation by triggering reflective thinking.

5.4 Summary of the Research Findings

In this section, I presented a transversal review of the main results of the research. Moreover, I provided numerous references to the articles in order to show how the research results were grounded on empirical evidence.

First, I discussed the socio-cultural implications of monitoring tools and techno-monitoring practices. Among these, I highlighted the positive perceptions according to which monitoring tools are expected to help improve well-being, productivity, and efficiency. The emphasis on self-improvement is connected to an individualistic and competitive culture that requires shared standards to assess performance. Another characteristic of this socio-cultural environment is the value of data, especially quantitative data. The data collected through monitoring tools are trusted and expected to be accurate, even if people lack the skills to assess the reliability of these data. There is a divide based on who has access to data and who has the skills to analyze those data. People without the skills to analyze the data collected by monitoring tools often adopt attitudes based on skepticism or trust rather than critically reflect on these data.

Second, I demonstrated how the design practices embodied notions of power and authority that influenced the final design solutions. Special attention was paid to the design approach and the methods used in the Feeler research-based design because they contributed to building relations based on equality, which fostered reflective and critical dialogue among the education stakeholders and the research designers. Another area of controversy in the design process related to decision making. In particular, I problematized certain decisions regarding concept definitions, goals, and forms of assessment in the design of monitoring tools. Monitoring tools are a sensitive area because they may involve surveillance, which can lead to the adoption of certain subjectivities by those who use the tools, depending on how power relations are balanced. As discussed in the Feeler analysis, design approaches, such as critical and speculative design, can foster critical discussions about the socio-cultural implications of future technologies. In addition, the adoption of participatory design methods during the design process of learning tools can help develop empathy and a shared understanding between education stakeholders and research designers. From this perspective, it is considered crucial to support education stakeholders' active participation during the design process, as well as during interaction with the learning technologies.

Third, I explored the implications of monitoring tools for learning. I distinguished the main approaches to monitoring tools depending on if they focused on behavior change or self-knowledge. Moreover, I argued that approaches based on self-knowledge are connected to reflective thinking and self-regulation, which are important skills in learning. I also highlighted several strategies to support reflection using Feeler and discussed to what extent the prototype supported reflective thinking. Regarding the self-regulation of learning, I argued that Feeler supports metacognition, motivation, and behavior, which are important dimensions of SRL. As discussed in the analysis of the tests conducted with Feeler, from a metacognitive perspective the prototype supported self-awareness, self-monitoring, and self-assessment. By encouraging the learners to try new strategies, Feeler may have helped the learners increase their self-confidence in their abilities to regulate their attention and relaxation and therefore may have positively affected their motivation. Regarding the behavioral dimension, the feedback provided by the prototype and the boxes helped the learners to self-regulate their behavior. Finally, I concluded that monitoring tools have great potential for supporting learning and I advocated for approaches that focus on self-knowledge, reflection, and self-regulation.

The analysis of monitoring tools requires considering socio-cultural aspects, design practices, and conceptions of learning. These areas are not independent but are strongly interrelated and affect each other. Feeler can be taken as an example of the challenges and opportunities that monitoring tools pose to learning.

6. Implications for the Design of Monitoring Tools in Learning

In this section, I elaborate on the key themes and design implications of the findings presented in sections 4 and 5. The key themes include learners' self-knowledge, learners' reflection, learners' self-regulation, and agency-oriented technology. In my analysis of these key themes, I build on the work of Sas et al. (2014) to classify the design implications of this research.

According to Sas et al. (2014), design implications are ideas with the potential to influence further design actions. Design implications are based on empirical findings and provide knowledge that can inform future designs. The different types of design implications include sensitizing concepts, abstractions, instantiations, and prescriptions.

Sensitizing concepts highlight emerging social concepts that are considered relevant for technology design. These social concepts can generate new design agendas that require further elaboration in order to be implemented. To provide more developed design implications than sensitizing concepts, abstractions identify general design principles and functionalities for specific types of technologies. Abstractions can focus on particular aspects of sensitizing concepts and propose new perspectives that may be translated into concrete tool designs. Like abstractions, instantiations express design principles elicited from fieldwork data. However, unlike abstractions, instantiations are concrete examples of design concepts. Sas et al. indicate that instantiations "can be realised in working exemplar prototypes" (2014, p.1973). These prototypes can be a source of inspiration for technology designers. Finally, prescriptions are concrete recommendations for implementation. Because they specify how certain features can be developed in a specific design, prescriptions are highly context dependent and are difficult to extrapolate to other settings (Sas et al., 2014).

The main design implications of this research are abstractions and instantiations regarding the design of self-monitoring learning tools. By materializing the instantions that derive from the abstractions identified in this study, the Feeler prototype can be considered a "working exemplar prototype." The abstractions and instantiations are grouped under the following key themes: learners' self-knowledge, learners' reflection, learners' self-regulation, and agency-oriented technology (see Table 4).

6.1 Encouraging Self-Knowledge through Free Exploration and Personal Inquiry

The emphasis on self-knowledge in the design of monitoring tools may be regarded as an alternative approach to the design of monitoring tools, as most monitoring tools are inspired by behavior change and persuasive technology postulates. Furthermore, self-knowledge has been recognized as an important skill for self-regulation processes, which require reflective thinking (Bandura, 1991). The empirical results of this design research suggest that students appreciate and are interested in technology-mediated experiences that enhance their self-knowledge through self-monitoring. Thus, I highlight self-knowledge as an important theme that encompasses several design implications of this study (see Table 4).

In line with previous research, this study highlights the value of free exploration and personal inquiry as two strategies that support self-knowledge through reflection (Boud et al., 1985; Dewey, 1933; Moon, 1999). Articles III, IV, and V indicate free exploration and personal inquiry as guiding principles (abstractions) to support self-knowledge and reflection through monitoring tools. For instance, the design of the Feeler prototype supports free exploration by displaying data visualizations that have multiple levels. In particular, learners build their own interpretations by combining and drawing relationships between diverse types of data from different sources. In addition, Feeler enables learners to access all the data collected by the system in different formats, which allows learners to further explore the data based on their own interests.

By presenting learners with incomplete information, Feeler encourages learners to engage in personal inquiry. In order to complete the information, learners must create hypotheses and test them in subsequent sessions using the prototype. Because Feeler provides immediate feedback, learners can evaluate their hypotheses, and, if necessary, develop new ones that help learners better understand their behavior and gain self-knowledge. In this regard, Feeler exemplifies how to support personal inquiry through hypothesis building and hypothesis testing.

6.2 Openness and Control in Agency-Oriented Technology

A central issue in discussions on the ethics of technology concerns human agency. The design of monitoring tools is not exempt from these debates, and, to date, it is possible to identify diverse positions based on different understandings of the role of humans and their agency when using monitoring tools. Articles I, IV, and V shed light on different issues related to learners' agency when using monitoring tools as part of their learning process.

Considering that people use tools to accomplish specific goals, many scholars have argued for acknowledging that human agency is mediated by artifacts (Vygotsky, 1987; Wertsch, Tulviste, & Hagstrom, 1993). While it may not be possible to predict how a tool would be used in a certain context, it is possible to anticipate a tool's uses or possibilities (Albrechtslund, 2007). To a certain extent, the physical properties of tools (i.e. their technological affordances and constraints) can enable particular events to happen (Brey, 2005).

When using monitoring tools for learning, openness to and control over the monitored data are important design implications that allow learners to make choices. Thus, openness and control are considered abstractions for agency-oriented technology. Because it is designed based on these abstractions, Feeler works as an instantiation of them (see Table 4).

The Feeler software code and hardware are open, in that they allow learners to study them and make modifications. In this way, students can have control over the system. From a wider perspective, these types of decisions involve distributing initiatives and responsibilities between people and technologies. In a way, making the system open encourages learners to accept responsibility and act if they do not agree with some aspects of the system. This approach builds on the ideas outlined by Levy (1984) and Stallman (2002), who advocate for freedom and decentralization of information.

Another design principle that enables learners to play an active role in their learning is control over the personal data tracked by the system. As mentioned in section 5, people are concerned about their data privacy, partly because they are uncertain about what data are tracked, how data are used, and with whom data are shared (Acquisti, Brandimarte, & Loewenstein, 2015). In addition, the increasing number of Brain-Computer Interfaces that collect physiological data such as EEG to support interaction between humans and computers opens questions regarding the potential of neuro-surveillance for capturing information about a person’s psychological traits or even private information (Farah, Smith, Gawuga, Lindsell, & Foster, 2009; Martinovic, Davies, Frank, Perito, Ros, & Song, 2012; Moore, 2017).

Recommendations concerning data privacy have stressed the need to adopt policies that protect individuals without assuming they are well-informed and able to make rational decisions, as people's privacy behavior varies depending on context and external influences (Acquisti, Brandimarte, & Loewenstein, 2015). Thus, the Feeler design adopts a restrictive approach toward sharing personal data through social media and does not include functionalities for sharing the data collected by the Feeler system through third parties. People using Feeler can share their data if they want, as the software enables exporting the data captured during the independent study sessions.

In Feeler, another design decision for ensuring people’s control over their personal data consisted in avoiding cloud-computing services. Practitioners and scholars have warned of security and privacy challenges in services that store data online (Pearson, 2009; Takabi, Joshi, & Ahn, 2010), and some have advised against the use of cloud-computing altogether, as it exposes people’s data to surveillance (Stallman, 2002). Considering the challenges that data storage in the cloud poses for ensuring people's data privacy and control over their personal data, the Feeler software stores data in learners’ computers.

6.3 Triggering Reflection through Parafunctionality and Estrangement

The ability to reflect has been regarded as a high-order thinking skill (Strampel & Oliver, 2007) that is key for achieving deep understanding and supporting decision-making. In addition, reflection has been considered valuable for taking control of one's own life (Gelter, 2003).

As discussed in section 2, several scholars have explored how to support reflection through technology. Drawing on previous research and the empirical findings presented in Articles III and IV, I identify two abstractions for fostering reflection through monitoring tools: parafunctionality and estrangement (see Table 4).

According to Löwgren and Stolterman (2004), parafunctionality refers to the potential of an artifact to foster reflection on people's relations to technology. In this research, the Feeler prototype seeks to trigger reflection on the social and cultural values embedded in the design of monitoring tools (see Article IV for further elaboration on the strategies used to support reflection on cultural values regarding monitoring technologies). The prototype provokes parafunctional thought through the inclusion of physiological data in LA. Like this, Feeler instantiates the notion of parafunctionality by presenting an extreme but plausible scenario of use that encourages learners to consider the limits of monitoring as well as their own assumptions regarding productivity or procrastination.

In addition to parafunctionality, estrangement, which consists of the adoption of a distanced point of view, is an important design principle for sparking critical reflection. In this study, estrangement is developed through ambiguity and surprise (see Table 4), which have been proposed by interaction design scholars (Löwgren & Stolterman, 2004) as powerful tools to support reflection through use.

Some authors regard ambiguity as an opportunity to inspire and provoke reflection by creating questions without imposing answers (Gaver et al., 2003). These authors distinguish ways to produce ambiguity depending on whether they focus on information, contexts, and relationships. In addition, as Gaver et al. note, ambiguity can be used as a strategy to overcome technology limitations and to support reflection (2003). The Feeler design integrates ambiguity in different ways. First, the Feeler data visualizations treat the data collected through the EEG and the data from the participants' subjective impressions in the same manner. This means that data collected from different sources are considered equally valid. This creates *ambiguity of information*, as learners initially tend to regard the EEG data as more reliable than their subjective impressions.

Second, the Feeler data visualizations do not specify how attention and relaxation values are created. Again, this can be framed as ambiguity of information because the lack of clarity regarding how certain concepts, such as attention and relaxation, are constructed creates doubt and skepticism. In addition, the Feeler system does not define how attention and relaxation are connected nor how they affect study performance, which creates ambiguity regarding the relationship between attention and relaxation. As Gaver et al. (2003) describe, the *ambiguity of relationship* derives from pointing things out without explaining why they occur.

Third, the Feeler software does not include additional explanations that assess how well the learner is performing. Similarly, the system does not define what goals the learner should aim to reach. Such design decisions create ambiguity because learners tend to assume that data interpretation and goal-definition are performed by the monitoring tools, as these are common features of monitoring tools. When learners realize that the system does not provide the expected information, they engage in a reflection process in which they seek answers to the open questions that arise after using the Feeler prototype (see Articles III, IV, and V for further elaboration).

The literature on reflective thinking acknowledges the value of surprise and confusion as elements that can spark reflection (Boud et al., 1985; Dewey, 1933; Moon, 1999). In Löwgren and Stolterman's view, surprise and confusion are part of problem-solving processes that require exploration and reconsideration of initial assumptions (2004). Articles III and IV offer an extended view on how monitoring tools can use surprise and confusion to trigger reflection on learning. As presented in the articles, the Feeler design exemplifies how to provoke learners' surprise and confusion through the contradictions that appear between their subjective impressions and the data monitored by the EEG device.

6.4 Supporting Self-Regulation by Fostering Self-Awareness, Self-Control, and Self-Assessment

Research on self-regulation has shown that this skill is strongly connected to well-being (Ryan & Deci, 2000). In learning, scholars have proposed several models and frameworks to approach the different aspects involved in the self-regulation of learning processes (see section 2). Drawing on the close connection between self-monitoring and self-regulation, this study identifies self-regulation as an important aspect to consider when designing monitoring tools.

This design research highlights several abstractions for the design of monitoring tools that support SRL. In particular, as argued in Article V, monitoring tools can support important processes in SRL, such as self-awareness, self-control, and self-assessment. These processes are considered powerful abstractions, as they can influence the design of learning tools based on monitoring technology (see table 4).

Self-awareness is a metacognitive skill that plays an important role in self-regulation (Bandura, 1991; Pintrich, 2000; Zimmerman, 2002; Winne, 2011). In learning, as in many other life activities, awareness of one's own behaviors and emotional states is a first step to identify how comfortable one is with a given situation. Once a person develops self-awareness, it is possible for her or him to determine if any change is necessary in order to reach a desirable state. Feeler works as an instantiation of self-awareness in learning by urging learners to think about their subjective impressions and feelings during a study session. The questionnaire on personal experience that learners are requested to fill after the study phase seeks to trigger learners' self-awareness of how attentive and relaxed they felt when performing cognitively demanding activities, as well as how satisfied they were with their performance. Based on the observations and analysis presented in Article V, I argue that including subjective information contextualizes the data captured by monitoring tools.

The literature on SRL identifies self-control as an important skill to regulate behavior during performance (Hadwin et al., 2011; Pintrich, 2000; Zimmerman, 2000). In particular, the effective use of self-regulation strategies has been connected to students' confidence in their ability to control their behavior and reach their goals (Zimmerman, 1986). As reported in Article V, the interviews with participants after the Feeler test sessions showed that Feeler introduced participants to different strategies that affected their ability to focus. The participants' realization that they could control their attention by performing certain activities, such as practicing meditation before the study task or working on single tasks during longer periods of time, generated self-confidence. In this regard, Feeler can be considered an aid for learners to explore new ways of doing things and gain confidence when trying new practices that support the acquisition of SRL skills.

Finally, self-assessment is another abstraction connected to self-regulation. In the main models of SRL, the last phase of the SRL cycle consists of appraisal, which includes the evaluation of outcomes (Puustinen & Pulkkinen, 2001). The appraisal or evaluation phase is critical for further SRL efforts because it affects learners' motivation and learning goals. Thus, the ability to self-assess has been considered key for the self-regulation of learning (Panadero & Alonso-Tapia, 2013). As Panadero notes, self-assessment is "the qualitative assessment of the learning process, and of its final product, realized on the basis of pre-established criteria" (2011, p.78). This means that self-assessment is a reflective process that helps learners understand the causes of their mistakes and achievements.

Zimmerman and Moylan (2009) include self-assessment as a type of self-judgment that occurs during the self-reflection phase. According to Zimmerman (2013), self-assessment based on self-comparisons is more fruitful than self-evaluations based on social comparisons because self-assessment based on self-comparisons requires learners to develop their own self-standards. In line with Zimmerman's (2013) argument, the Feeler data visualizations do not display information about the other students' performance in order to foster learners' self-evaluation based on self-comparisons (see Articles IV and V for additional information) rather than on social comparisons. Although students are accustomed to monitoring tools that include social comparisons, this research advocates that learning tools based on monitoring technologies should encourage learners' self-assessment based on comparisons to their previous performance. Like this, Feeler instantiates how monitoring tools can support self-assessment based on self-comparisons.

Table 4. The relations between the key themes, abstractions, and instantiations mentioned in this study.

Key Themes	Abstraction	Instantiation from the Feeler prototype
Self-knowledge	Free exploration	Data visualizations with multiple levels of information: The data displayed in the Feeler visualizations are structured in different levels to support learners to explore the data based on their interests. Inclusion of different types of data: The Feeler data visualizations present different types of data in order to enable learners to draw links and connections. Access to the data collected by the monitoring tool: Feeler software allows learners access to their data in different formats.
	Personal inquiry	Presentation of incomplete information: Feeler presents incomplete information in order to motivate learners to build their own hypotheses and test them in further study sessions with the prototype. Feedback to support hypothesis-testing: Feeler provides immediate feedback that helps learners test and evaluate their hypotheses.
Agency-oriented technology	Openness	Free software and free hardware: In Feeler, software code and hardware are both open to allow people to study and make modifications, if they want to change some aspects of the system.
	Control	Protecting data privacy: The Feeler design does not consider the sharing of data as a default option and thus does not include functionalities for sharing through social media. In order to ensure learners' control over their data, the Feeler software stores data in learners' computers and avoids using services based on cloud-computing.
Reflection	Parafunctionality	Critical reflection on the technology design: Feeler incorporates parafunctionality by supporting speculation around the inclusion of physiological data as part of LA. This makes learners reflect on the limits of monitoring and critically reconsider some of their initial assumptions toward monitoring tools.
	Estrangement	Ambiguity as a strategy to trigger questions: Feeler creates different types of ambiguity in order to provoke reflection. The prototype creates ambiguity of information by treating data from different sources as equally valid and ambiguity of relationship by not explaining how certain concepts like attention and relaxation are related. In addition, learners are not instructed about what goals they should aim to reach when using the prototype. Surprise and confusion to challenge assumptions: The Feeler design uses the contradiction between the monitored data and learners' subjective impressions to create surprise and confusion and thus trigger reflection.
Self-regulation	Self-awareness	Learners provide input about their subjective impressions: The Feeler software includes a questionnaire that urges learners to think about their subjective impressions regarding the study session.
	Self-control	Providing guidance when trying new practices: Feeler structures self-monitoring and guides learners when trying different strategies that may affect their ability to remain attentive or relaxed. Encouraging learners to try new strategies: Feeler encourages learners to learn strategies to control their attention and relaxation. By adopting the strategies embedded in the Feeler design, learners gain confidence in their ability to regulate their attention and to relax.
	Self-assessment	Self-assessment based on self-standards: The Feeler data visualizations allow learners to self-evaluate based on self-comparisons.

7. Discussion

In this section, I discuss the research questions in light of the contributions presented in sections 4, 5, and 6. The research questions of this study are as follows:

- RQ1. What opportunities for and challenges to learning do monitoring tools and techno-monitoring practices introduce?
- RQ2. What approaches to the design of monitoring tools contribute to the balance of power relations when adopting techno-monitoring practices in learning?
- RQ3. How can monitoring tools support learners to reflect on and self-regulate their learning?

7.1 Opportunities and Challenges of Monitoring Tools and Techno-Monitoring Practices in Learning

The first research question (What opportunities for and challenges to learning do monitoring tools and techno-monitoring practices introduce?) focuses on general aspects related to the use of monitoring tools in learning contexts. Determining the challenges to learning posed by monitoring tools and techno-monitoring practices is necessary to identify the opportunities that these monitoring tools and techno-monitoring practices have for learning.

As argued in Articles I and IV, the key challenges associated with the adoption of monitoring tools and techno-monitoring practices to learning concern datafication and managerialism (see, e.g., Selwyn [2015]), as well as fostering particular subjectivities based on competition and individualism, with an emphasis on efficiency and self-improvement (Lupton, 2013) (see Article IV for a more elaborate explanation).

Monitoring tools and monitoring techno-practices enable surveillance (Knox, 2010) and thus endanger individuals' privacy. Learners' may modify their behavior because they feel they are being observed (Dawson, 2006). Furthermore, as discussed in Article I, monitoring tools based on a behaviorist approach may foster student passivity and create dependency (Shum & Ferguson, 2012), which may challenge—if not impair—students' ability to perform autonomously based on their interests. These aspects are regarded as challenges because they dissuade learners from behaviors that are considered key for learning, such as experimentation, personal inquiry, and risk-taking (Knox, 2010) (see Article I for further analysis).

Another important challenge associated with the adoption of monitoring tools and techno-monitoring practices in education concerns unbalanced power relations that derive from different levels of access and control over data (Land & Bayne, 2005). In addition, in many cases learners lack the skills that would enable them to understand and manage their data, which exacerbates the power unbalance. In this regard, monitoring tools and monitoring techno-practices that expose learners to continuous surveillance may make learners feel they do not have control over their personal information (Maltby & Mackie, 2009).

Throughout this design research, specifically during the contextual inquiry and participatory design activities, the learners expressed concerns about the privacy of their personal data. Such concerns were carefully considered during the product design stage and affected the design of the Feeler prototypes. This research identifies control as an important design principle for protecting people's personal data privacy (see section 6). As monitoring tools and monitoring techno-practices integrate in learning environments, it will be more urgent to address the challenges that monitoring tools pose to the privacy of learning data. For this reason, I consider that the privacy of data related to learning is a sensitizing concept with important implications for design practice in TEL.

As discussed in Article I, monitoring tools allow students to enhance their learning by supporting self-knowledge (see Article V) and developing skills such as reflection (see Articles III, IV and V) and self-regulation (see Article V). In the design of monitoring tools, some scholars recognize the importance of developing designs oriented toward self-knowledge (Li et al., 2011; Rapp & Tirassa, 2017). Considering the link between self-knowledge and mental and physical health (Wilson, 2009), people must develop accurate self-perceptions in order to make decisions that contribute to their well-being (Carlson, 2013). However, as Vazire and Mehl (2008) point out, people's self-perceptions are often inaccurate. Self-monitoring tools allow people to review their self-perceptions and improve their self-knowledge through self-awareness and reflection (Li et al., 2011; Pirzadeh, He & Stolterman, 2013).

7.2 Approaches to the Design of Monitoring Tools in Learning

The second research question (What approaches to the design of monitoring tools contribute to the balance of power relations when adopting techno-monitoring practices in learning?) concerns involving learners in the design of monitoring tools and ensuring learners have the opportunity to influence the design process. Hence, the answer to this research question introduces issues related to agency and participation in the design of technological systems.

The conceptualization of technology has implications for key issues in the ethics of technology, such as agency. The current designs of monitoring tools are strongly influenced by approaches that present technology as an extension of the human senses. In a way, monitoring technology is expected to act as a human cognitive enhancement tool; this is similar to Engelbart's (1962) view on how computers augment human intellect. As presented in Article I, such expectations regarding monitoring technology are common among TEL developers and students. These views on technology consider artifacts have inherent properties that can change practices, beliefs, or social relations. In other words, such conceptions suggest technological systems have agency (Brey, 2005).

Cognitive enhancements through technology may be regarded as aids for autonomous and independent thinking. According to Bostrom and Sandberg, “Insofar as cognitive enhancements amplify the capacities required for autonomous agency and independent judgment, they can support a person lead a more authentic life by helping to base choices on more deeply considered beliefs about unique circumstances, personal style, ideals, and the options available” (2009, p.327). As further elaborated in Article V, monitoring tools offer opportunities for learners to engage in cognitive enhancement by supporting autonomous and independent learning through reflective thinking and SRL.

Technology has been also regarded as a mediator that influences the way people act in and perceive the world (Verbeek, 2005). Building on Ihde’s (1990) description of different types of relations between humans and technologies, monitoring tools establish a hermeneutic relation between humans and technology, as the data collected by these tools must be interpreted in order to be meaningful. Theoretical approaches that explore the nature of experience state that technology interactively co-shapes relations between humans and the world. This perspective recognizes that tools help to define what counts as “real” and that this is not a neutral process (Verbeek, 2005). Articles I and IV argue for supporting learners’ critical reflection on the type of data and concepts that monitoring tools make “real” in the context of learning and cognitive work. In a way, the Feeler prototype works as a technology mediation. Drawing from Verbeek’s (2011) classification of technological mediations, Feeler helps to anticipate the potential effects of introducing monitoring tools in learning contexts.

According to Bjögvinsson, Ehn, and Hillgren (2012), in order to support agency it is necessary to not only “focus on participation in design Things, but also on strategies for ‘infrastructuring’ them” (p.103). This approach builds on a notion of agency that is distributed between design researchers, education stakeholders, and non-human actants, such as monitoring tools. This research draws from this perspective to recommend participatory design and critical design approaches when designing tools to express *matters of concern* in TEL.

Approaches to the design of learning tools based on human-centered design and participatory design, such as research-based design (Leinonen, 2010), recognize learners and education stakeholders as critical and creative thinkers, whose feedback can significantly enrich the design process. In the Feeler design process, the adoption of techniques from human-centered and participatory design traditions respond to what Kiran, Oudshoorn, and Verbeek consider a moral obligation from designers and technology developers to “take into account the shaping impact technologies have on persons.” (2015, p.13). In line with participatory design and human-centered design traditions, designers and developers should go one step beyond taking people’s needs into account and allow and encourage learners to not only have a voice in but also participate in the design of technology that, to some extent, is going to shape their learning experiences. In this regard, the adoption of a participatory design approach relates to the acknowledgement of people's agency, which extends to the design process.

However, involving people without technical expertise in the design process poses some challenges. One of these challenges concerns communication between designers and participants (Ehn, 1993; Wilson, Bekker, Johnson, & Johnson, 1997). To overcome this challenge, throughout the design research learners and education stakeholders were invited to engage in critical reflection and debate about monitoring tools and monitoring techno-practices in learning (see Table 3 in section 3.3 for more detailed information on the design props that were used to support reflection and dialogue). Such discussions were important to enable participants to envision how monitoring tools and techno-monitoring practices would alter their learning processes and allow them to voice their concerns and expectations (see Articles II, III, IV, and V).

As reviewed in section 2, technology design scholars have proposed several approaches to provoke reflection on technology and reflection through technology use. As Bjögvinsson, Ehn, and Hillgren highlight, design should go beyond solving the immediate needs of a project or group of stakeholders and support *design after design* (2012). Approaches like speculative design can help design scholars envision the future consequences of emerging technologies and can support critical reflection and democratic debate among learners (Auger, 2013; DiSalvo, Lukens, Lodato, Jenkins, & Kim, 2014). Article IV elaborates on the adoption of critical and speculative design approaches to support reflection on monitoring tools and techno-monitoring practices. In the context of speculative design, Feeler can be regarded as a plausible scenario of the use of monitoring tools in future learning environments.

7.3 Supporting Reflection and Self-Regulation in Learning Using Monitoring Tools and Monitoring Techno-Practices

Intellectual autonomy is an important element for successful independent learning. In order to achieve intellectual autonomy, learners must take an active role in their learning process. As discussed in section 2, key skills related to having an active role and developing autonomy in learning are reflection and self-regulation (Bandura, 1989; Winne, 2011). Reflection and self-regulation are key themes related to the third research question, which asks how monitoring tools can support learners to reflect on and self-regulate their learning. This research question elaborates on issues connected to triggering and fostering reflection and self-regulation in learning. In particular, special attention is paid to strategies and approaches to the design of monitoring tools that can support reflective and self-regulation skills.

In learning contexts, the data captured by monitoring tools can be used to provide learners feedback about their activity. Scholars have already highlighted the connection between feedback and reflection (Anseel, Lievens, & Schollaert, 2009), and recent research in TEL has claimed that monitoring tools like LA can support reflection (Durall & Gros, 2014; Govaerts, Verbert, Duval, & Pardo, 2012; Greller & Drachsler, 2012). From this perspective, monitoring tools offer opportunities to engage in different levels of reflection (see section 2 for further review).

However, the effectiveness of monitoring tools to support reflection has been questioned, partly because of the difficulties in proving that people are actually reflecting when using these tools (Jivet, Scheffel, Drachsler, & Specht, 2017; Sumsion & Fleet, 1996). In addition, scholars investigating reflection in learning have raised concerns regarding the difficulty to assess learners' level of reflection (Fleck & Fitzpatrick, 2010). Articles III, IV, and V elaborate on the type of reflection that a self-monitoring tool like Feeler can support. The articles build on the data collected during the tests of Feeler v.1.0 and v.2.0 to analyze learners' reflections after using the prototype. Despite acknowledging the difficulty to ensure that learners reflect on the data provided by the monitoring tool (in these cases, the Feeler prototypes), the analysis of learners' speeches revealed that the tool supported advanced levels of reflective thinking (see Article III for a detailed analysis). Some of the strategies used to support reflection consisted in creating personal experiences, challenging personal impressions, and contextualizing the data. Building on the results of the Feeler prototype tests, I propose two design principles to support reflection with monitoring tools: parafunctionality and estrangement (see section 6 for further detail).

Although Jivet et al. (2017) argue that LA dashboards should go beyond supporting awareness, awareness has been identified as a first stage of reflection that learners need to engage before getting into further levels of reflective thinking (Kolb, 1984; Mezirow, 1991; Dewey, 1933; Peltier et al., 2005; Kember et al., 2000). Thus, this research identifies self-awareness as an abstraction for the design of monitoring tools for learning because it is a relevant skill in SRL. The Feeler prototype encourages learners to reflect on their own behaviors and states and thus to become self-aware by asking them to fill a questionnaire about their subjective impressions of the study session (see Article V for a more detailed explanation).

Reflective skills are key for self-assessment (Boud, 1995), which in turn is a key process of self-regulation (Panadero & Alonso-Tapia, 2013). According to Boud (1995), "Self assessment is concerned with learners valuing their own learning and achievements on the basis of evidence from themselves and from others" (p.15). Learners develop their learning skills through self-assessment, which helps them become more autonomous. Feedback has been used to support reflection and self-assessment (Anseel, Lievens, & Schollaert, 2009; Boud, 1995). From this perspective, reflection is considered a form of feedback that occurs in loops (Clow, 2012; Schön, 1983). In the context of monitoring tools, the data captured by these systems is regarded as feedback that can motivate learners to reflect and plan future actions. The round of tests performed with Feeler v.2.0 showed that the feedback provided by the prototype affected the subsequent sessions in which the prototype was used (see Article V).

The design of the Feeler prototype does not include feedback on peers' activity, as this information can lead learners to engage in social comparisons and thus prevent them from developing their own self-standards (see see Articles III, IV, and V for further elaboration on these design decisions). As presented in section

6, self-assessment constitutes an important abstraction for the design of monitoring tools for learning. In this design research, self-assessment was supported by encouraging learners to create their own self-standards to evaluate their activity.

Studies on SRL have shown that self-awareness and self-evaluation are connected to the self-control of behavior (see Zimmerman and Moylan's [2009] model of SRL). Being able to control one's own behavior can positively affect motivation (Schmeichel, Harmon-Jones, & Harmon-Jones, 2010). In this regard, monitoring tools may support self-control by increasing learners' self-awareness. However, learners may modify their behavior when using monitoring tools just because they feel surveilled (Dawson, 2006). For this reason, it is important that monitoring is voluntary and that learners understand the potential benefits that monitoring may bring to them (Durall & Gros, 2014). In this study, self-control is highlighted as another abstraction connected to the theme of self-regulation. Some of the strategies used in the design research to support self-control deal with encouraging learners to try new practices and providing guidance when performing these practices. These strategies were embedded in the design of the Feeler prototype (see Article V for a further explanation).

The main models of SRL highlight reflection and monitoring—self-monitoring in particular—as important factors for developing self-regulation skills (see Puustinen and Pulkkinen [2001] and Panadero [2017] for a review of the main models of SRL). This design research stresses the great potential of monitoring tools to support the self-regulation of learning (see Article V for further analysis on how self-monitoring technology can support SRL) and therefore contribute to learners' intellectual autonomy.

From a learning perspective, autonomy may be associated with the ability to successfully undertake independent learning. In recent years, research on self-regulation and autonomy have been applied to other disciplines, such as design. For instance, in technology design scholars have investigated design judgments that influence self-regulation and autonomy in personal informatics, as well as how to support independence and self-efficacy in TEL (Calvo, Peters, Johnson & Rogers, 2014). In this regard, I want to pinpoint design for autonomy as a sensitizing concept in TEL. While recognising the diversity of ways to foster intellectual autonomy, this research points to reflection and self-regulation as important design principles for the design of monitoring tools oriented toward fostering learners' autonomy.

7.4 Validation of the Design Research

During the last decades, scholars have strongly debated the validation of findings in design research. While several scholars have argued for the need to develop metrics and standards to evaluate rigor (Forlizzi, DiSalvo, Bardzell, Koskinen, & Wensveen, 2011; Zimmerman, Stolterman, & Forlizzi, 2010), others (Bartneck, 2007; Gaver, 2012; Stolterman, 2008) have warned about the danger of reproducing "inappropriate 'scientific' models of research and theory for the field" (Gaver, 2012, p.938). In response to this challenge, several scholars claim that research through design should be conducted on its own terms (Cross, 2001; Bartneck, 2007; Gaver, 2012; Stolterman, 2008). This means acknowledging research through design as a generative activity in which theory is embodied in design artifacts.

Despite conflicting views on whether a design science should be established, scholars have recognized the need to assess quality and rigor in research through design (Forlizzi et al., 2011; Stolterman, 2008; Fallman & Stolterman, 2010). According to Fallman and Stolterman (2010), rigor and relevance in interaction design must be assessed based on the purposes and outcomes of the design activity. In the case of design explorations, Fallman and Stolterman (2010) consider that rigor depends on how successfully the design exploration opens a design space that challenges established design assumptions in a critical and creative way. From this view, the relevance of design explorations relies on the impact of the design outcomes at a societal level.

As discussed in section 1, this study is framed as a design exploration. Through the development of design artifacts, I explored the implications of monitoring tools for learning. Based on this exploration, this research points to data privacy and design for autonomy in learning as sensitizing concepts for future TEL designs. Although the research findings presented in the articles have been considered valuable in TEL and design communities, it may still be early to evaluate the real impact of design exploration. As Fallman and Stolterman (2010) note, "relevance has to be seen and evaluated using a longer time frame" (p.271). To date, the feedback obtained from academic venues (conferences and journals) and open-events addressed to a general audience suggest that the research is timely and relevant.

In recent years, Sas et al. (2014) identified a set of criteria for evaluating design implications based on their analysis of interviews with 12 expert HCI design researchers. As Sas et al. (2014) note, these criteria pertain both to scientific and design practice and consist of validity, generalizability, originality, generativity, inspirability, and actionability. These criteria offer good grounds to evaluate the implications of this design research.

Validity has been connected to accuracy, and a distinction between internal and external research validity has been drawn. In qualitative research, the notion of validity has been widely discussed (Guba & Lincoln, 1981; LeCompte & Goetz, 1982; Mishler, 2000, Stenbacka, 2001). Some authors (Koro-Ljungberg, 2008) advocate for the use of the term *validation* instead of *validity* in order to emphasize the diverse ways of developing and legitimizing research, as well as the active role of all the people involved in the research endeavors.

Internal validity refers to how well the research observations and conclusions represent a particular reality. In Sas et al.'s (2014) report of interviews with HCI reserchers, the authors distinguish between empirical validity and theoretical validity. To a certain extent both terms, can be regarded as equivalents of internal validity. According to Sas et al., empirical validity is "supported through explicit accounts of how such knowledge is grounded in fieldwork data or acquired through reflection on the evaluation of developed technologies" (2014, p.1977).

Sas et al. highlight that in design research the practice of testing is key to evaluate empirical validity (Sas et al., 2014).

As part of this design research, several tests were conducted (see section 3 for a complete overview of the methods deployed throughout the design process). In the analysis of the tests conducted with the Feeler prototypes, the connection between the fieldwork data and the design implications was carefully presented (see Articles III, IV, and V). In research, triangulation strategies that consist of the adoption of different methods and data sources and that involve multiple researchers are necessary to develop valid representations (Golafshani, 2003). In the qualitative analysis of the interviews with the participants of the Feeler tests, I adopted several measures that involved triangulation in order to increase validity and reliability (see Articles III and V for a detailed explanation of the analysis procedure).

Theoretical validity refers to the connection between the design implications and theoretical foundations of human and social sciences (Sas et al., 2014). In this design research, I clarified the theoretical grounds that support the Feeler design as well as the implications of the Feeler design. Moreover, I discussed the implications of the Feeler design in relation to TEL (see Articles I, III, and V), media studies (see Article I), and HCI (see Articles II, III, IV and V).

The generalizability of the design implications constitutes external validity. In HCI design research, generalizability refers to the extent to which the design implications can be applied to contexts other than the ones in which the design research was conducted and tested. As Sas et al. (2014) recognize, ensuring the generalizability of the design implications is challenging due to the differences between settings. In addition, the fact that design practice deals with ultimate particulars (Stolterman, 2008) may be problematic for the formulation of generalizable theories. In a similar line of thought, Gaver points out that "research through design is likely to produce theories that are provisional, contingent and aspirational" (2012, p.937). Moreover, external validity has been challenged in qualitative research, as in some cases the focus of such research is on formulating research questions and hypotheses to guide future work rather than on testing them (Sandelowski, 1986). This study is framed as a design exploration and therefore, one of its main outcomes is the generation of questions regarding the use and design of monitoring technologies in the context of TEL.

This research is original because it addresses a novel technology (monitoring technologies) and identifies its implications in learning contexts. In particular, I suggest an alternative perspective in the design of learning tools that use monitoring technology based on supporting learners' self-knowledge, agency, reflection, and self-regulation.

Sas et al. (2014) introduce specific criteria related to design practice, including generativity, inspirability, and actionability. Regarding the generativity of this design research, the Feeler prototypes addressed the attention on sensitizing concepts dealing with data privacy and design for autonomy in learning and demonstrated potential for opening a new design space for the use of monitoring technologies in education. The definition of key themes in the design of monitoring technology for learning and the abstractions that stem from those themes (see Table 4) can inform a new range of design explorations on monitoring technologies in learning contexts. As Sas et al. indicate, “abstractions and sensitizing concepts are more inspirational than prescriptions” (2014, p.1979). Although I cannot ensure to what extent other designers would feel motivated to explore these issues, I consider that this design research contains elements that may inspire the HCI and TEL research communities.

Finally, this design research presents actionable design implications by outlining particular design qualities that support learning experiences based on self-knowledge, agency-oriented technology, reflection, and self-regulation. The Feeler prototype works exemplifies how these qualities can be implemented as technological properties.

7.5 Research Limitations and Recommendations for Further Research

Research through design initiatives has been criticized for producing qualitative, context-dependent research outcomes that are difficult to generalize. This design exploration faces similar limitations; thus, the results from the analysis of the Feeler prototypes tests must be interpreted with caution. In the tests, using a limited number of participants allowed for the development of a qualitative, in-depth exploration of the participants’ experiences with monitoring tools in learning contexts. However, the limited number of participants also precludes strong, generalizable claims regarding the nature of monitoring technology and its scenarios of use. Future work requires the development of diverse design concepts and prototypes that can be tested with larger groups of participants in longitudinal studies.

The Feeler design focused on individual experiences when using a monitoring tool in a learning context. Although it was necessary to first understand the individual experiences that the tool supported, it is unfortunate that the study did not explore the use of monitoring tools by groups of students. Future studies should focus on the opportunities for and challenges to collaborative and cooperative learning and work introduced by monitoring tools. Another area that would require further exploration deals with the nature of the data analysis. If agency is regarded as distributed between humans and non-humans, it becomes necessary to address issues connected to the biases that each type of actant may introduce into the data collection and analysis processes.

Through the development of prototypes, this design exploration approached issues related to the ethics of monitoring technology and its application in learning situations. Unfortunately, there is a lack of a debate regarding the ethical aspects related to the design and use of monitoring tools in learning, in particular of tools that monitor physiological data. Considering the rapid path of development and the integration of sensor-based technology that monitors large amounts of personal data in learning tools, I consider this is an important debate for the TEL community, as well as for education stakeholders. For this reason, further work in TEL through monitoring tools must tackle the ethical dimensions of these emerging technologies from a humanistic perspective.

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Publication I

Durall, E., & Leinonen, T. (2015). Why do we want data for learning? Learning analytics and the laws of media. In B. Gros, Kinshuk, M. Maina (Eds.), *The Future of Ubiquitous Learning. Learning Designs for Emerging Pedagogies* (pp. 59-72). Berlin Heidelberg: Springer.

Chapter 4
Why Do We Want Data for Learning? Learning Analytics and the Laws of Media

Eva Durall Gazulla and Teemu Leinonen

Abstract With the increase of online education programs, learning analytics (LA) tools have become a popular addition to many learning management systems (LMS). As a tool for supporting learning in an educational context, LA has generated some controversy among scholars. Therefore, in this text, we aim to provide a theoretical and analytical understanding of the approach and its implications for teaching and learning. To achieve this, we apply McLuhan's semiotic analysis of media (1988). The "Laws of Media" questions are asked about LA tools: What do they enhance, make obsolete, retrieve, and reverse into. By answering these questions, we outline which practices of teaching and learning are more likely to become common when LA tools are taken into use more widely and which others will be relegated. In the analysis, we point out that LA tools enhance prediction and personalization of learning, while they displace certain teachers' skills, personal interaction between teachers and students, and qualitative interpretation and assessment of learning. Simultaneously, LA retrieves behaviourist views of learning and urges discussion about data literacy. Taken to the limits, LA reverses its effects and becomes a tool for supporting awareness and reflection in teaching and learning. We consider these contributions relevant for understanding and reflecting on the type of pedagogies that LA supports, the implicit values it holds, and the changes it introduces into educational practice.

Keywords Learning analytics · Teaching · Learning · Semiotics

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4.1 Introduction

The use of analytics in an online education focuses on the collection, analysis, and reporting of data about students' online actions (Lockyer et al. 2013; Society for Learning Analytics 2013). Learning analytics (LA) has raised academic institutions and teachers' interest by displaying information that was not available before, enabling them to better understand how students learn and therefore take informed actions to support this process (Dawson et al. 2014). In this chapter, "learning analytics tools (LA tools)" refers to the software tools that aim to display information about how students learn.

The data sources used in LA tools may come from a range of academic systems such as student information, library services, learning management systems (LMS), student admissions, and grades (Lockyer et al. 2013). Among those sources, research on LA has tended to focus on the possibilities of using the data in LMS. Despite discussion about the uses of data in LMS, there is a wide consensus on the idea that monitoring and interpreting this information can benefit learning and teaching (Drachsler and Greller 2012). According to Verbert et al. (2012), potential uses of LA are connected to the following areas: (1) prediction of learner performance and learner modelling, (2) suggestion of relevant learning resources, (3) increase in reflection and awareness, (4) enhancement of social learning environments, (5) detection of undesirable learner behaviours, and (6) identification of learners' emotions. So far, these areas have been the most popular approaches adapted in the development of LA tools.

The LA research field is interdisciplinary, since it combines the aspects of educational data mining, social networks analysis, artificial intelligence, psychology, and educational theory and practice. In LA research, it is important to distinguish two closely related areas: learning practice and organizational development. Both of these make use of educational data, although with different interests. While in learning practice, analytics focuses on improving learner success, in organizational development the pressure has been on productivity and business-oriented solutions. In the organization domain, analytics combines learners' information with institutional data to improve managerial effectiveness (Siemens and Long 2011).

The literature on LA tools also suggests that it can be used to approach data from a variety of perspectives. Some of most prominent ones are social network analytics, discourse analytics (De Liddo et al. 2011; Ferguson and Shum 2011), content analytics (Drachsler et al. 2010; Verbert et al. 2011), disposition analytics (Crick et al. 2004), and student-centred analytics (Kruse and Pongsajapan 2012), among others. In all of them, LA tools are expected to improve teaching and support students' success.

Despite the high expectations placed on LA, a review of the literature indicates controversial views on whether this new technology will improve learning and teaching. One of most critical aspects deals with the type of data monitored. Although many LA tools tend to focus on learners' actions, there is little evidence about what data are more relevant and useful to track (Verbert et al. 2014). Another aspect that is problematic is that the promising future of LA in the development of learning technology eclipses rigorous analysis on the effects that LA uses might have on teaching and learning. The lack of more critical studies on LA may be due to the fact that the field is quite young, and education researchers are still exploring different designs for the tools. Given the current stage of the LA field, we consider it necessary to address issues dealing with the type of pedagogy LA puts forward, the possible embedded values of these tools, and the extent to which LA tools are changing the way we understand teaching and learning.

In order to understand the effects of LA on teaching and learning, we analyse LA technology as a medium. The adoption of this perspective enables us to enlighten some of the in-built assumptions related to the LA approach and LA tools. In addition, our aim is to identify their capability to foster new pedagogical approaches and understand how the new pedagogy could be. We adopt McLuhan's tetradic framework for conducting a semiotic analysis on the implications of LA tools for learning and teaching. In the following sections, we introduce, ask, and provide answers to the questions proposed by Marshall and Eric McLuhan in the "Laws of Media" (1988) by addressing them to LA.

4.2 McLuhan's Tetrad Framework

McLuhan's Laws of Media are based on the idea that all artefacts have effects on the people and the society that adopts them. From this perspective, every new tool that is introduced becomes an extension. The word "extension" alludes to the idea that by building new things, humans are augmenting their bodies and these changes are, in the long term, transforming the social and physical environment. By introducing the laws, framed as questions, McLuhan and McLuhan (1988) raise concern and call for reflection about the effects of media on society. The questions that the Canadian authors introduce for analysing a medium are the following:

- What does it enhance?
- What does it make obsolete?
- What does it retrieve?
- What does it reverse into?

These interrogations seek to shed light upon the relationship between media and the context and how this transforms understanding and views of the world. The laws of media questions are complementary and should be asked in parallel (Fig. 4.1).

Looking at the tetrad, we can identify two groups based on its complementary relation: enhancement versus obsolescence and retrieval versus reversal. In the first case, the emphasis is on the aspects that a new tool brings and the ways of working that are relegated. This process is simultaneous, and while it does not mean that old social practices or human faculties disappear, they lose its mainstream position. In

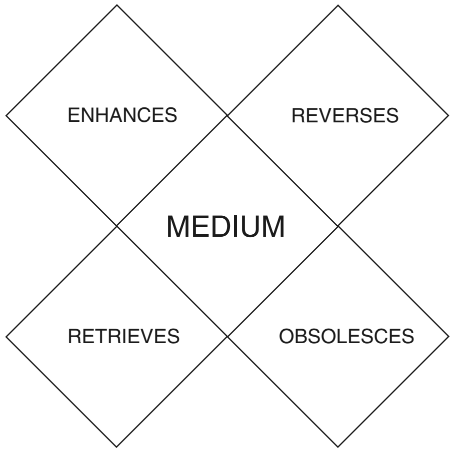

Fig. 4.1 Tetrad of media effects (McLuhan and McLuhan 1988)

the second case, the retrieve–reverse binomial refers to the power of new media in bringing back practices that were considered abandoned and for reversing their original meaning. This last effect is perhaps the most illuminating one. According to McLuhan, when a medium is pushed to its limit, it will become the opposite of what it was originally intended for. The quote "we become what we behold; we first make the tools, then the tools will make us" (McLuhan 1964, p. 23) illustrates the transformation that a medium goes through when it reaches its limit. At this turning point, the medium becomes the message in itself.

From the McLuhan and McLuhan perspective, the laws of media can be applied to any human artefact, whether hardware or software (1988). LA refers to software tools, but like any other medium, its effects go beyond technical solutions. To gain a better understanding of LA tools and their effects on teaching and learning, the following section examines the questions that compose the laws of media for a better understanding of the effects of LA tools on teaching and learning.

4.2.1 What Does LA Tools Enhance or Intensify?

Based on the McLuhan axiom that all media are extensions of people, we analyse how LA tools extend our senses as human beings. The fact that LA tools unveil "hidden" information connects with the idea of a sixth sense, in this case for perceiving learning behaviours that are not visible in any other way. By displaying these data, LA enables another view of what is going on when students engage in online learning.

The expectations of LA go far beyond just having a different view on teaching and learning. In this regard, education professionals and scholars have expressed their hopes that LA will help predict learning performance and identify learning models, customize and personalize learning, control teachers' activity as well as the institution's performance, understand social interaction and participation, and engage students in their learning processes.

The prediction of student success or failure in learning, particularly in e-learning, has received considerable attention. Research in this area has led to the definition of profiles with the aim of modelling different types of learners, as well as the identification of different learning styles. Learning emotions have also been the subject of study since they have been used as an indicator of how students feel about learning and therefore the likelihood of successfully completing their studies. In this regard, we might argue that LA enables the development of customized learning environments that offer continuous support throughout the student's learning journey.

Customization and personalization are at the core of many LA approaches. The data collected about students' online behaviours inform decisions about what kind of learning resources or activities are more meaningful, given the student's current skills and knowledge about a certain issue. By taking into consideration individual aspects, LA tools enhance a wider view of learning that recognizes the importance of building on top of the learners' previous knowledge and competences. LA tools that seek customization are based on the idea that in learning there is not one way or path that works for everyone. Therefore, in order to ensure that students acquire the desired abilities, teaching practice has to adjust to the diversity of needs and challenges that the students face.

In many LA tools, in addition to individual performance, data about group activity are also available. This feature intensifies comparison between the individual and the group, and it indirectly pushes students to work harder when their activity falls behind the group average. The emphasis on student comparison connects with values based on the competition and selection. Educational institutions have used LA for recruiting students (van Harmelen and Workman 2012), and some voices speculate about the possibility that LA would be used by human resources departments in the future. Such a scenario forces individuals to compete in order to ensure access to college or the job market. Since nowadays societies need collaboration and cooperation rather than competition, the idea that education institutions need to prepare students for working in a competitive society has been labelled a myth (Combs 1979). One of the main effects of competition is homogenization: people need to share the same goals and rules in order to compete (Combs 1979). In learning, standardization implies that everyone should learn the same in the same amount of time. Continuous monitoring and pressure for meeting academic expectations can create anxiety and distrust among education stakeholders. Wesley (2002) has studied these phenomena at workplace learning, and he has reached the conclusion that monitoring online learning activity negatively affects workers' collaboration, communication, and knowledge exchange. Although formal education differs from workplace learning, the stress on students caused by complying with their curriculum on time while staying on the same level as the group does not support creativity and innovation (Wesley 2002). Therefore, to the extent LA tools do not recognize the value of experimentation and risk-taking, they intensify a view of learning based on efficiency, in which failure is penalized.

Digital data have become a key element in managerial techniques that are "evidence-based". Education institutions are subject to a similar logic as those of contemporary organizations, which are run based on the use of data and information. A good example of this trend can be found in the university, college, and school ranks, in which the emphasis on indicators has been questioned, since it can hide good practices in teaching and learning. From this perspective, the most critical voices claim that LA, especially academic analytics, intensifies the culture of managerialism in education (Selwyn 2014). From another point of view, some sectors of the academic community claim that analytics can enhance understanding of student engagement and performance (Graf et al. 2011). For teachers, the possibility to access student-generated data allows them to reflect on the instructional design and management of the courses they teach. In this case, LA is presented as a tool that advances educators' awareness and reflection about some aspects of their professional practice.

LA has contributed to research in Massive Online Courses (MOOCs) by collecting data about students' retention. One usual observation of studies on MOOCs is the high level of student dropouts. This information has attracted the interest of institutions and instructors who seek to understand why these courses have low completion rates, frequently between 3 % and 5 % (Coffrin et al. 2014). Even though the educational success of MOOCs is still under discussion, it is important to recognize the value of LA for identifying challenges regarding student engagement, performance, and retention. Thanks to LA, MOOCs have become a rich area for studying student motivation and its connection to engagement and performance. Coming back to the first question outlined in the Laws of Media, we might say that LA has intensified research on key elements affecting students' engagement in learning.

4.2.2 What Does LA Tools Displace or Render Obsolete?

Parallel to the question on what a medium enhances, we need to consider what it relegates. In this case, if we assume that LA extends various human faculties and social practices, we might also need to consider what aspects would no longer be dominant when LA is fully adopted in education.

LA is part of a trend based on decision-making informed by data. From this perspective, the automatic collection and analysis of the students' behaviour data are assumed to be relevant and reliable, or at least more trustworthy than subjective perceptions. The confidence devoted to computing algorithms is not exclusive of LA, and similar attitudes towards data can be found in business, health care, social services, sports, etc. Although education stakeholders recognize that LA enriches teaching and learning, we might question the extent to which LA is affecting the credibility we give to personal impressions. In a society driven by data, can we rely on subjective and qualitative data gathered through individual experiences?

LA modifies certain aspects of the teachers' role, especially in online education. Here, we might say that the reliance on LA data is closely connected to the appearance of fully online educational programs. As Mazza and Dimitrova note (2004), in e-learning courses, students face challenges dealing with, for instance, loneliness, experiencing technical issues, or losing motivation. In these cases, teachers' lack of visual cues that help them recognize when students are poorly motivated, anxious, or overwhelmed is compensated through LA. In the LA scenario, there is the assumption that if students have difficulties following the course, that information would be reflected in the monitored data. So one aspect that LA is killing is the teachers' ability to identify those students at risk of failing and the problems they face in their learning process. LA tools are not only affecting online teaching. In blended learning scenarios, LA impacts the teacher's capability to perceive group feedback since there is an increasing tendency to rely on information collected through back channels during large lectures. The final aim of these efforts is to enhance adaptation and improve teaching. But as McLuhan and McLuhan noted, the simultaneous effect is the disappearance of certain practices. In this case, the praxis that is being relegated is certain teacher's skills for detecting individual and group behaviours.

Excessive trust in LA data might diminish the perceived value of personal interactions between teacher and students. An example of this trend can be found in the approaches based on the personalization of learning, which directly inform decisions about how to best support learning. Since these systems rely on the models built from students' behaviours, further discussion with learners is relegated. Actually, decisions based on learner model data are very rarely contrasted and commented on with the students.

In e-learning, the high student ratio per teacher requires the development of tools that lighten the teachers' workload. Student modelling goes in this direction since the creation of profiles is a key for the design of systems that automate certain decisions, such as what learning resources are more useful for a student, given his current skills or knowledge. In this sense, LA and its different approaches are the result of efforts for coping with overcrowded virtual classrooms. The impossibility for developing a personal relationship between teacher and student and, at the same time, the need to offer a personalized service help to explain the high expectations placed on LA. Although LA might help solve the contradictions of a system that seeks customized mass education, it is making obsolete the need for personal interaction between teachers and students.

Like in many other fields, the automation of tasks questions certain roles and competences. In education, automatic data analysis challenges the role of educators and researchers. To what extent are they needed to interpret the data if a machine can efficiently do this? Given the current scenario, how can these professionals contribute to educational research? Certainly, LA does not make education researchers obsolete, but it demands of them new skills dealing with quantitative data analysis. Sense-making based on qualitative data analysis is not enough in a context where students' performance can be reliably measured with numbers. LA forces educational professionals to adopt quantitative data analysis methods in order to avoid being left behind.

The aspects mentioned in this section do not try to present a dystopian image of what the future of education might be once LA is a dominant practice. Every technology introduces new behaviours and attitudes and relegates other ones. This is not good or bad per se, but it must be acknowledged. Otherwise, we might end up assuming the intrinsic values of the medium without questioning the key elements in teaching and learning and how to best support them. In short, the medium would end becoming the message without us noticing it.

4.2.3 What Does LA Tools Retrieve that Was Previously Obsolete?

LA focuses on observable events of students' performance, specifically on students' behaviours. The monitoring and analysis of external actions enable using LA for building learner models and identifying learning styles and dispositions. This approach connects with behaviourist ideas, specifically with Skinner's radical behaviourism. Quoting an extract of Skinner's Review Lecture: The Technology of Teaching provides a good example of the close alignment with certain approaches to LA: "An effective technology of teaching, derived not from philosophical principles but from a realistic analysis of human behaviour, has much to contribute, but as its nature has come to be clearly seen, strong opposition has arisen" (1965, p. 438). The criticisms to behaviourism alluded by Skinner deal with behaviourist parallelisms between animal and human learning, the extrapolation of conclusions about learning based on laboratory situations designed with a strong emphasis on behaviour reinforcement and contingencies, as well as the inability to teach certain important things, such as learning to learn skills, from a behaviourist paradigm (Skinner 1965). Although LA has been used from very different pedagogical approaches, there is an important trend for designs that connect with radical behaviourist postulates. Considering that the golden age of behaviourist theories took place during the middle of twentieth century, we can state a revival of those ideas in many LA designs.

The type of data analysed when assessing learning performance indicates how learning is connected to certain values. In LA tools, the most commonly monitored metadata deals with (among others): frequency of logins, time spent on the LMS, and completion of activities and tests (Dietrichson 2013). Considering the type of information monitored, these learning environments privilege attitudes connected to perseverance, dedication, and hard work. We can state a character-building agenda in which discipline and commitment to the rules are key elements. The lack of spaces where students can discuss and question what and why certain data are monitored can be taken as an indicator of the top-down approach of these LA designs. This contrasts with socio-constructivist pedagogies, in which students were considered active and responsible for their learning process.

Once more, LA privileges quantitative data, in this case individually assigned marks by the teacher or the system, which are considered reliable indicators of students' effort and learning. This approach challenges socio-constructivist views of assessment, which call for students' active engagement and participation as key elements of successful feedback (Rust et al. 2005). In this regard, LMS that make use of LA tools privilege scores for student assignments, as well as other LA metadata, displacing other popular assessment techniques such as peer and self-assessment, rubrics, and portfolios.

Simultaneously, LA brings back discussions about literacy. The main concerns about data literacy deal with the gap between those who produce data, that is to say the ones who are (consciously and unconsciously) the subjects of monitoring activities, and those who are able to read and understand the data, and therefore use it (Manovich 2011). This has been labelled as a "data analysis divide" (Manovich 2011) and highlights unequal power relations in today's society. This situation has motivated the raising of voices that argue for recognizing the politics of data in education and for taking action against it (Selwyn 2014; Halford et al. 2013). Although the debate is not new, LA requires reflection and discussion among educational stakeholders about what literacy skills are relevant today.

4.2.4 What Does LA Tools Become When Taken to Its Limits?

We are presenting here a biased hyperbole of what the future of education might be if LA becomes the central element through which learning and teaching are defined and managed. Although this might not be a realistic scenario in the middle term, the last question included in the Laws of Media helps to identify the potential for any specific media, in this case LA.

Taken to its limits, LA brings to our homes dystopian scenarios based on data surveillance. "Dataveillance" refers to surveillance of digital data (Monahan 2010), and although it might not be perceived as a threat, it can support classification and predictive actions that enable "statistical discrimination" (Gandy 2012). Some scholars have already warned about the uses of data against those participating in education (Selwyn 2014; Slade and Prinsloo 2013). Certain practices in educational institutions indicate that these concerns are more valid than we might expect. For instance, as Rosenzweig (2012) explains, dataveillance of teachers' activity is an existing "condition of employment" in some schools. On the students' side, the normalization of surveillance in learning environments familiarizes them to high levels of control from a very young age (Taylor 2013). Over time, students become aware of LA continuous monitoring and they develop certain subjectivities and behaviours as a response (Knox 2010; Land and Bayne 2005; Leinonen 2012). In the end, as Knox (2010) highlights, these attitudes go against key issues in learning, such as collaboration and experimentation. In addition to these aspects, other ethical challenges regarding the use of data in LA deal with data analysis, acceptance of the terms of use, privacy and anonymization of data, and categorization and management (Slade and Prinsloo 2013).

LA usage that focuses on prediction connects with ideas of control—assigning to individuals a passive role. Learners' low agency can be connected with the behaviourist approach, in which behaviour is shaped by environmental stimuli. Thus, students learn according to the challenges, comprised of tasks, and learning resources that teachers or an intelligent learning environment present to them. The idea of a highly controlled learning environment based on behaviour prediction is quite an extreme view of LA, but it helps in understanding some current criticisms and fears of this media. In this regard, some authors have already noted the limitations of predictive models which portray "only a portion of the wide range of behaviours that constitute the universe of social interactions" between students and an institution (Subotzky and Prinsloo 2011, p. 182). Other concerns are based on the idea that LA can increase students' passivity by making them dependent on institutional feedback (Shum and Ferguson 2012).

Quite frequently, the idea of efficiency is embedded in LA designs. Actually, this is one of the main arguments used for justifying the monitoring and analysis of students' and teachers' data. Thus, the goal of LA tools is to support effective learning, which can be understood as, in addition to acquiring certain skills, successfully completing the course and the education curriculum. Even if the last goal is more connected to the academic analytics agenda, we might hypothesize that, taken to its limits, LA can be more focused on ensuring students' graduation rather than in helping them become successful learners.

Although some critical voices have warned that LA could disempower students, other authors have highlighted the potential for supporting awareness and self-reflection skills (Duval 2011; Durall and Toikkanen 2013). In fact, LA can enhance several key processes mentioned in Zimmerman's model for self-regulation (1989, 2000), such as self-control, self-observation, and self-judgement. From this perspective, LA can help students become aware of key elements in their learning activity and reflect on their performance. So, taken to its limits, LA tools can support self-directed and self-regulated learning (Durall and Gros 2014; Drachsler and Greller 2012). Views that favour this approach support placing student needs at the centre (Duval 2012; Clow 2012; Kruse and Pongsajapan 2012). Considering the students as active and autonomous subjects, able to take responsibility for their learning, is key for designing learning environments that empower its users. In learning, empowerment can be understood as a process by which individuals develop self-regulatory qualities dealing with self-efficacy and a sense of agency. According to Cleary and Zimmerman (2004, p. 542) "highly self-regulated learners will often feel empowered because of an underlying self-belief that success is largely dependent on one's skill in effectively using and adjusting strategies". LA tools can contribute to acquire a feeling of personal control by helping the students understand the relations and consequences of their actions in their study performance. In this regard, the visualization of LA data can support sense-making, as well as the identification of connections and the testing of hypotheses. LA tools with these features may empower students to see themselves as growing subjects who are facing obstacles but overcoming them through effort.

4.3 Concluding Remarks

LA challenges traditional ways of gathering information about learning and teaching and enables deeper and more complex analysis of the data. In this regard, LA has the power to transform educational institutions and teachers' pedagogical practices. The value that education professionals attribute to LA is a good indicator of the capacity of this medium for transforming education. Despite the grey areas, LA has come to stay, and its mainstream adoption will certainly affect how we understand teaching and learning.

As we have outlined when answering McLuhan and McLuhan Laws of Media questions, the high expectations placed on LA tools are due to what it enhances: access to data about students' behaviour and teachers' activity that was previously hidden, prediction and personalization of learning through student modelling, and better understanding of students' participation and motivation in learning. In terms of framing an emergent pedagogy, the main contributions of LA would deal with the development of adaptive learning environments.

According to McLuhan and McLuhan (1988), enhancement goes together with obsolescence. In this case, LA displaces certain teacher skills, direct interaction between students and teachers about study performance, and qualitative analyses of educational processes. At this point, we might say these changes should be inscribed in a wider context characterized by the rise of online education programs targeted to massive audiences. Rather than being the cause, LA is a symptom of this trend in formal education.

The main aspects that LA retrieves are behaviourist views on learning and discussions about data literacy. Dealing with the latter, LA creates another divide based on the ability to analyse data. At the core of some criticisms raised by the educational community are concerns about the power position of those who decide what data should be collected and for what purposes the data are used for. Although it might not be enough, most educational institutions have already created ethics boards in order to address the challenges that LA poses for privacy, ownership, and management of the data (Drachsler and Greller 2012). These issues are strongly connected to what LA might bring when taken to its limits.

Beyond warnings about the danger of dataveillance at the limits of LA, we can identify a reversal of the effects associated with this medium. This can be appreciated in LA's potential for supporting students' competences dealing with self-directedness and self-regulation of learning. From our perspective, this is the most relevant and transformative contribution of LA to pedagogical practice.

To sum up, we want to again mention McLuhan's view about the social impact of technology. As it can be observed in LA analysis, the effects are ambivalent, which makes irrelevant any conclusive judgments about the benefits or dangers of the medium. However, as Leinonen (2012) points out, "different media can make it easier or harder to perform some actions. When some things are easy to do, it is more likely that they will be done, whereas on the contrary, if something is hard to do with a medium, it is less likely to happen." (p. 58.) By developing a semiotic analysis of LA, we have outlined what aspects of learning and teaching are becoming easier and which ones are being relegated. In order to avoid going blind by the technology, we consider it necessary to do this type of analysis. In this regard, the McLuhan and McLuhan Laws of Media are still a relevant tool for reflecting on the social effects of a medium.

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Publication II

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FEELER REFLECTION GAME

A CASE STUDY ON A DESIGN GAME FOR PARTICIPATORY DESIGN

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ABSTRACT

The paper explores the potential of design games as a method for developing empathetic understandings between designers and end users. With this aim, we have developed the *Feeler Reflection Game*, a board game designed to serve the contextual inquiry and early participatory design sessions of a design research looking for solutions to help people reflect on their well-being and learning. The text includes a description of the game design process, as well as an analysis of the game's use in a workshop. The case study confirms findings of earlier studies demonstrating the power of storytelling, personas, and scenarios in design. Furthermore, the case study shows that by playing the design game, the participants were able to identify themselves with the concept design and with the main situations of use. We conclude that the game acted as a boundary object that allowed participants and designers to engage in an empathic and productive dialogue.

KEYWORDS: *Design Games, Participatory Design, Empathic Design, Design Methods, User-centered Design*

INTRODUCTION

In Participatory Design (PD) tradition, people who are expected to use the product or service have a special role. First of all, because they are experts in the field in which designers want to approach; and secondly, because in the end, the users are the ones who will benefit or suffer from the final design. For this reason, designers must ensure that the solutions provided are truly beneficial and sustainable. In order to come up with innovations that respond to the users' needs and expectations in a certain context, it is necessary to incorporate the users' insights into the design process. The Scandinavian tradition has strongly advocated democratic processes within the design project through the inclusion of points of views, as well as by offering participants the means to understand the design process and have a true impact on it. According to the Scandinavian tradition, users have the right to intervene in the design process.

PD has had an influence in areas such as HCI, user-centered design, interaction design, and information systems development. Key background assumptions and methods of the PD approach, such as the right of people to take part in decisions dealing with their living and working conditions, the awareness of the benefits that users' insights can bring to the design process, as well as the value of techniques like mock-ups, low-fi prototypes, workshops...etc., have been widely adopted (Bannon & Ehn, 2012).

In design, especially in user-centered design, empathy has been stressed as a way to achieve a better understanding of the user and the user's experience. Through empathic design (Koskinen et al., 2003), designers try to get closer to the lives and experiences of end users, in order to design a product or service that truly meets the users' needs. The PD tradition has emphasized mutuality and reciprocity (e.g. Muller, 2003) as means to improve communication and collaboration. The recognition of everyone's knowledge and the possibility to learn from each other are some of the traits that Muller attributes to hybrid spaces, situations that enable new relationships and understandings (2003). It is interesting to consider how different methods in PD, such as workshops, stories, photos, dramas, and games, among others, contribute to this hybridity. Games seem to be a promising option for developing shared ownership, questioning assumptions, achieving mutual learning, synthetizing new ideas, negotiating, and co-creating. In PD, playing games with the end users may improve communication and provide not only new information and space for participants to contribute to the design, but also a shared space for emphatic, communal, and situated learning.

To study the potential of games in PD, we have designed several board games for various design cases. The games are custom made, since the idea is to design a game for each specific design case. In this paper, we present the *Feeler Reflection Game*, a board game designed to serve the contextual inquiry and early participatory design sessions of a design research looking for solutions to help people reflect on their well-being and learning. We describe the experience of designing the game and analyze the use of the game as a participatory practice that enables researchers and designers to develop an empathetic understanding of their participants.

In the following section, we present design games as a research technique for supporting empathy in the design process. We continue describing and analyzing the *Feeler Reflection Game*, a case in which a design game was used with the aim of augmenting understanding about the users' contexts, needs, and expectations. In the discussion, we defend the key role of design games for creating a playful and relaxed atmosphere that facilitates communication and collaboration. We conclude by considering design games as boundary objects that facilitate an empathic understanding between users and designers.

DEVELOPING EMPATHY THROUGH DESIGN GAMES

In order to promote empathy during the design process, a variety of methods and tools have been developed. The Kouprie and Visser (2009) classification recognizes three main classes of techniques: (1) for research, (2) for communication, and (3) for ideation. Research techniques that aim to foster empathy are often focused on promoting direct contact between designers and users. In the PD tradition, Johansson (2005) has noted that 'User involvement enabled the development of a special kind of field studies that is much more design-oriented than traditional ethnographic studies' (2005, p.15-16). Hence, knowledge about the end users and the design context goes beyond descriptive practices, since researchers and designers seek to achieve an empathetic understanding of users' experiences. Mattelmäki (2006) points out the need for creative and collaborative methods that enable designers to develop open interpretations about the design context that will help them to develop empathy. The creative and collaborative practices can be, for instance, the use of *probes* (Gaver et al., 1999; Mattelmäki, 2006), *mock-ups* and *prototypes* (Ehn, 1988), *Make Tools* (Sanders & Dandavate, 1999), *design games* (Ehn & Sjögren, 1991; Johansson, 2005; Brandt & Messeter, 2004), *scenarios* (Binder, 1999), or *drama* (Brandt and Grunnet, 2000).

Some researchers see a lot of similarities between design and games. These are, for instance, their social component, evolving, and rule-based nature. According to Salen and Zimmerman (2004, p.80), 'A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome'. In the case of design, the design problems, the available resources, participants and their roles, as well as the work processes form boundaries for the design work and define the design space in a similar way as the rules in a game define what one can do in it. According to Vaajakallio (2012), games have been used in design for design research (Habraken & Gross, 1988), for building design competences among design students (Iversen & Buur, 2002), for empowering users, like in the 'layout kit' developed by Ehn and Sjögren (1991), and for engaging multiple stakeholders (Brandt & Messeter, 2004). Design games can be tools to define the design space. According to Botero (2013, p.59), a design space can be understood as 'the space of potentials that the available circumstances afford for the emergence of new designs at multiple levels'. Building on this definition, playing a design game can be a tool to intensify the relations among people, things, and activities. When playing a game, end users, designers, and stakeholders in general, can explore different alternatives and make collective design decisions. This transforms and expands the initially given design space by increasing empathy among participants.

Including empathic thinking in design can be a way to find inspiration and creativity about future products or design solutions (Steen et al., 2007); in other words, to broaden the design space. In PD, design games have gained popularity as a method for designers and users to jointly explore design issues on a conceptual level — to involve users in creative activity (Brandt, 2006). From this angle, explorative design games support formatting design dialogues that 'engage intended users, various stakeholders and the design team in joint inquiry into existing practice and participatory design of possible futures' (Brandt, 2006, p.61). Exploratory design games are a specific type of design game named by Brandt and Messeter (2004) that place great emphasis on engaging multiple stakeholders (Vaajakallio, 2012). Brandt (2006) distinguishes four types of exploratory design games: (1) games to conceptualize designing, (2) exchange perspective games, (3) negotiation and work-flow-oriented design games, and (4) scenario-oriented design games.

The capacity of games for creating stories, in which participants step in and play a role, helps to dissolve hierarchies, which in turn promotes a more relaxed participation. In this regard, Kronqvist et al. (2012, p.4) highlight 'Games introduce a way for engaging the participants in a mode of storytelling through the use of certain rules, material props, and visual aesthetics that set the context'. The use of storytelling in games enables players to develop an empathic connection with the situations presented. As Costikyan (2000, p.51) claims, players create experiences when participating in a game, and these generate emotional responses. 'And because a player is involved in the creation of the experience, because the experience of play is at least as much his product as that of the game designer, the emotions he feels can affect him much more deeply than the surface, empathic response you feel when viewing or reading

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about characters in a story'. Design games can take advantage of storytelling as a strategy to produce empathy among participants and, therefore, allow for a better and deeper understanding of the design concept and its challenges.

From the design perspective, storytelling has proved useful for designers. The use of techniques such as the creation of personas, scenarios, storyboards, and role-playing has been applied to help designers gain understanding and empathy towards users' experiences (Buchenau & Suri, 2000). As Fulton Suri states (2003, p.52), empathic design aims at 'achieving greater awareness, an extended imagination and sensitivity to another person's world in a powerfully memorable way'. Building on these contributions, we can claim that games create an enjoyable atmosphere that allows equal communication and facilitates sharing experiences between participants. Smooth communication and willingness to collaborate are key conditions for understanding how people experience things and for developing empathy with their world visions.

FEELER REFLECTION GAME

The Feeler Reflection Game is a board game, where the players are invited on a journey by moving from one square to another in turns. In the game, each player picks a predefined persona from six options. The players' personas are all university students, aged 19 to 23, that have different motivations for self-monitoring (Table 1).

	**JENNA** – 23-year-old medical student Jenna has suffered from migraines and insomnia since she was a teenager. Throughout time, she has learned to listen to her body in order to prevent the headaches and the insomnia. She likes to experiment and find new ways of doing things.		**SAMIR** – 22-year-old business student Samir likes to think that everything has a solution; it's just a matter of having enough data. He also thinks that everyone has the limits one wants to have. He is ambidextrous, and when he was a child he was diagnosed as dyslexic. He is not afraid of mistakes, and he enjoys trying new things.
	**PEKKA** – 19-year-old industrial design student Pekka enjoys testing new gadgets and mobile apps. For him, understanding how something works is a challenge he can't let go. Once he has solved a problem, he completely forgets it. He is quite dispersed, and quite often he has problems staying attentive for long periods of time.		**OLGA** – 20-year-old communication student Olga makes great use of social media. She has traveled a lot, and she likes to stay in touch with all her friends. Feeling part of a group is very important to her. Over the last two years, she has experienced some tiredness and mild depression during the winter term.
	**MING** – 19-year-old computer science student There's nothing Ming enjoys more than work that's done well. She is very organized but has a terrible memory. For this reason, she writes lists of things to do, so she can make sure she doesn't miss anything. Her ability for prioritizing is appreciated when leading group projects.		**TIMO** – 21-year-old art student Timo is very social, but sometimes he wants to have some time for himself. From his point of view, one should focus on the present and experience it with all the senses. Even if he makes use of digital technologies, he is quite skeptical about its benefits.

Table 1. Feeler Reflection Game persona descriptions

Source: Feeler Reflection Game

The goal of the game is to change the behavior of the persona each player is playing in order to improve the personas' learning performance. For this, players need to reach the last square of the game board. Although the game is not competitive, all players should go through all the squares of the board to earn a minimum of eighteen points, which will enable them to move to the final square. The game has ten squares, each one requiring that players perform a specific action. The actions in the squares are:

Square 1: Choose a persona. Decisions are made based on the image displayed in the pawn. Once the selection is made, players receive the character card corresponding to their persona and have some time for carefully examining the profile information.

Square 2: Define the persona degree of motivation for engaging in self-monitoring. On each of the character cards, the persona's level of motivation for improving their well-being is expressed quantitatively. On this square, participants have the opportunity to increase the number initially given by rolling the dice and adding the points earned.

Square 3: Select the type of data to monitor. Players choose from a pre-made list that includes monitoring: a) learning performance and sleep, b) learning performance and physical activity, and c) learning performance, sleep, and physical activity.

Square 4: Define a research question. Participants need to write a concrete question that they can answer through the data. The aim is to gain a better understanding of the persona's condition and, therefore, to be able to find a solution.

Square 5: Pick a device for data collection. Players can choose between the following options for gathering their data: a) by hand, b) mobile app, c) mobile in-built sensor, or d) wearable device. Each device is numerically evaluated according to several features dealing with battery, data management, comfort, cost, and data accuracy. All devices award the same amount of points, but are differently distributed depending on the tool strengths and weaknesses. Players have to make their choice, taking into consideration their character's idiosyncrasy. On this square, participants receive a sticker containing the information about the data collection device chosen that they have to attach to their character's card.

Square 6: Collect the data. In this square, players must choose between two card piles: one dedicated to challenges dealing with data collection, whereas the other one is dedicated to positive aspects. Players roll the dice and, depending if the result is even or odd, they take a card from a different pile. If the player gets a challenge card dealing with a particular feature, some points are subtracted from the total amount assigned to the device. In the opposite case, if the player takes a card focused on the advantages, some points are added.

Square 7: Choose a data visualization type. Participants can visualize their data using: a) a bubble chart, b) a line chart, c) a radar chart, d) a metaphor, or e) a dashboard. Once they have made their selection, they get a sticker with the representation of the data visualization type.

Square 8: Analyze the data. Again, on this square, there are two card piles. In one pile, cards refer to positive aspects of data visualization and give points. In the other pile, cards are focused on data visualization challenges. If players take one of those cards, they get zero or negative points. Players decide from which pile they can take the card by rolling the dice.

Square 9: Determine the readiness for a change. Players count the total amount of points earned during the game in order to determine if they can move to the next square. Those who get more than eighteen points are supposed to have enough motivation, data, and insights to modify their habits and, therefore, reach the last square. Those who haven't gained the necessary amount of points to access the last square must remain in this position.

Square 10: End of the game. Players who reach this square have successfully completed the game.

The game pieces include:

- Pawns with a printed representation of the characters available for players.

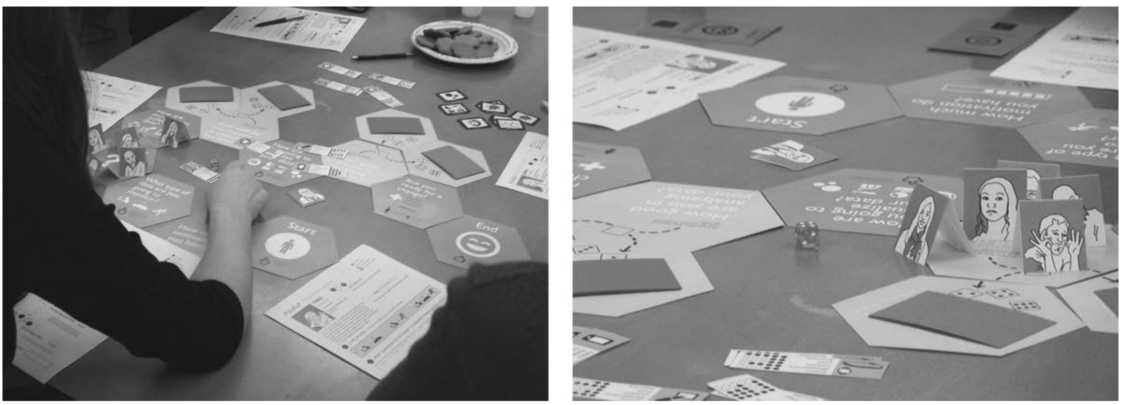

Figure 1. Images of the design game used during the contextual inquiry of the Feeler prototype.

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- Character cards containing the personas' descriptions, in which players can annotate their game choices.
- Stickers of the devices for data collection and the data visualization types.
- Data collection and data visualization cards identifying challenges and possibilities.
- Dice. Although players are expected to consciously make some decisions during the game, on some occasions, they just roll the dice and this determines the consequences.

In the *Feeler Reflection Game*, each pawn is different and is associated with a character card that includes a description, motivation level to solve the particular problem he/she faces, as well as some empty fields that players need to fill in as the game advances (figure 2). The characters portrayed in the game are personas built according to the research developed by Gimpel et al. (2013), as well as to interviews made with potential end users.

The aesthetics of the *Feeler Reflection Game* borrow from traditional game boards. The selected colors and materials seek to recreate a playful, enjoyable environment that arouses players' curiosity. From the beginning, it was considered important to make participants feel confident and willing to experiment. The use of vivid colors, along with simple and roundish shapes, creates a safe environment, which is visually appealing. In order to stress the storytelling side, it was decided not to use photographs and, instead, adopt an aesthetic based on hand-drawing for the characters and icons for the rest of the game materials.

ANALYSIS OF FEELER REFLECTION GAME INTERACTIONS

The *Feeler reflection Game* has been created in the framework of a design research looking for solutions to help people to reflect on their well-being and learning. The game is used to elaborate on a design concept called Feeler, a software and service that is able to visualize learning performance and well-being based on data collected from online learning services and tools capturing physical activities, such as movement, exercise, nutrition, and sleeping. The aim of *Feeler* is to encourage people to reflect on their lifestyle and its impact on their learning capabilities.

The *Feeler reflection game* has been developed for a series of workshops of the *Feeler* prototype. In the following, we focus on the latest, which was conducted with five graduate students of art and design. The three design research objectives of the game and playing it with various participants were to:

1. Develop empathic understanding of participants' practices and needs related to self-monitoring,
2. Share and explore the design challenges with the participants related to reflection and behavior change,
3. Obtain feedback and validate initial design concepts that are based on previous research.

Participants started the workshop by playing the *Feeler reflection game*, lasting approximately 45 minutes. The game was followed by a discussion about several issues dealing with the prototype design, such as motivation, data collection, data visualization, and how to better support behavior change. The data gathered during the game for further analysis included a video recording of the session, participants' character cards on which they annotate their game actions, and the design researcher's notes.

In order to infer to what extent playing a game helped participants develop an empathic understanding of the design goals and challenges, qualitative content analysis was used as a method for analyzing the data. Qualitative content analysis is, according to Sandelowski (2000, p.338), 'a dynamic form of analysis of verbal and visual data that is oriented toward summarizing the informational contents of that data'. The codes used for categorizing the data were generated from the data in the course of the study. In this case, the codes that show an empathetic understanding of the situations presented are identification, role-playing, connection with real-life experiences, and creation of a relaxed atmosphere.

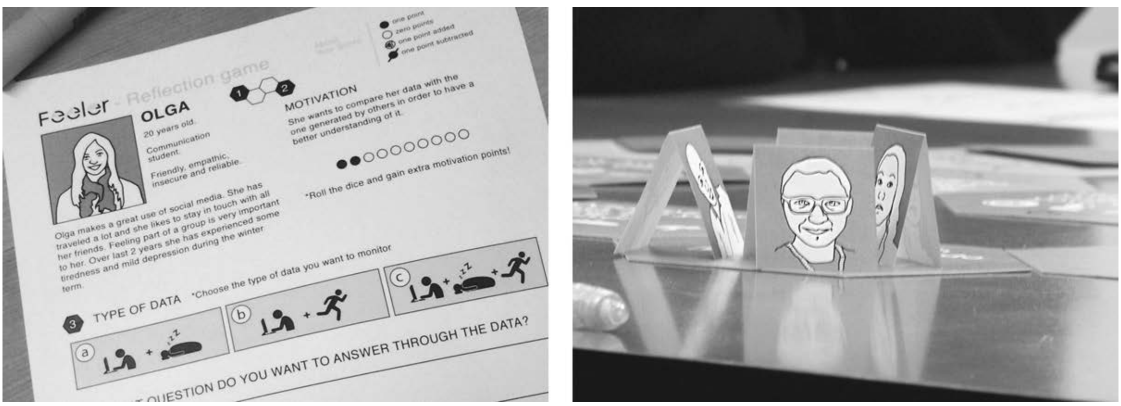

Figure 2. Images of the *Feeler Reflection Game* character cards and pawns.

At the beginning of the game, players picked their character based on the pawns' images. Despite the lack of information, participants' choices showed some sort of identification with the character, mainly based on physical resemblance.

> Player 3: 'I... uhmmm.... Actually I want to be this one (referring to the character). My hair use to be like that'.

Transcript 1. Player picks the character she would use during the game.

After the character selection, players received a characters' card in which they could read a short description of their characters' traits and motivation for engaging in self-monitoring. This background information helped them to make some decisions and to engage in role-playing.

> Player 1: 'I want to get feedback if what I'm doing is good for my health... because I have some mild depressions in winter... and also I feel quite tired so I want to monitor my sleep to see if I can find some relationship between... I don't know yet'.

Transcript 2. Player tries to define a research question to answer through self-monitoring.

One aspect that indicates the players' identification with their characters is the use of first person when referring to their game persona. In some cases, players referred to their character using first person at all times, therefore, showing a high level of involvement in the role-play; whereas in others, they only used third person or alternated between both forms.

> Player 5: 'Pekka has this problem of keeping attention, so then, how long I sleep, but also how I... So, whether if my physical activity and my sleep impact my attention span'.

Transcript 3. Player combines the use of third and first person when talking about her game character.

Another aspect that shows players' empathy towards their characters deals with the connection between real-life and game decisions. In this regard, it is interesting to note that, before playing the *Feeler Reflection Game*, some of the players had experimented with self-monitoring of different aspects of their habits. Curiously, in the game, rather than experimenting with new ways of self-monitoring, some of them replicated what they had tried in real-life.

> Player 2: 'Yes it was. In my case, I was monitoring sleep in the same way I was acting in the game'.

Transcript 4. Player recognizes she self-monitored herself in the same way as in the game.

Despite that self-identification with the characters only happened while playing the game, we can infer that it allowed for an empathic understanding of the personas and scenarios dealing with self-monitoring. From our point of view, role-playing and self-identification contributed to a meaningful and situated discussion about the design challenges of self-monitoring tools.

The use of a game allowed combining formal and informal registers. This was noticeable in the case of the facilitator, who used a more formal register when explaining about the research aims and the instructions of the game and a more informal one while playing. During the game, the use of storytelling techniques enabled the facilitator to abandon the academic register and get into the situation by making jokes, naming players by their characters' names and thus creating a playful and relaxed atmosphere. In this regard, the use of humor contributed to liberate players from prejudices and spontaneously express themselves.

Figure 3. Workshop participants playing the *Feeler Reflection Game*.

Despite the fact that the game board presented a linear timeline highlighting main moments in the process of self-monitoring, participants felt confident enough to bring other topics to the discussion, which were not initially foreseen, such as reward systems or other types of data they would like to monitor, such as stress, weather conditions, or nutrition.

At some point, they also considered it necessary to rearrange the order of the board squares, since, from their point of view, some decisions, such as the definition of the research question, should be approached at the very beginning of the process. The fact that each square on the board was independent from the others enabled the rearrangement of the squares to be fast and easily. In this regard, the visualization of information, either by noting down information on the characters' cards, or by altering the initially given order of the squares, contributed to maintaining the focus and discussing the issues in detail.

During the discussion, participants reflected about the use of a game as a way for presenting academic research. Although they enjoyed playing the *Feeler Reflection Game*, from their

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point of view, it was necessary to improve the game playability. According to the participants' comments, the game was too short and offered few opportunities to make decisions that had consequences later on. Since the game was intended to be used at the beginning of the workshop as a way to present the research topics, it was considered important to keep a time limit. However, according to participants, these initial constraints are not so important, and stress should be placed on creating opportunities for players to meaningfully intervene.

DISCUSSION

The Feeler Reflection Game was designed during the contextual inquiry of the *Feeler* work-in-progress prototype. According to Leinonen (2008, 2010), contextual inquiry is an initial stage of the research-based design process that consists in an exploration of the socio-cultural context of the design. During the contextual inquiry, designers may use rapid ethnographic methods, such as participant observation and user interviews, for exploring design situations and defining design challenges. Although design games have been highly used in co-design sessions in PD (Brandt 2006; Vaajakallio, 2012), we consider that they are powerful tools to use in the early stages of the design process in order to create a productive dialogue (Kronqvist et al., 2012; Vaajakallio, 2012).

Considering that the *Feeler Reflection Game* was used as a strategy for presenting end users' different personas and initial scenarios of the use of the future design, it shares some characteristics with the scenario-oriented design games defined by Brandt (2006). According to this author, 'enacted scenario construction can be viewed as an exploratory design game because it involves a play with props, takes place within a pre-defined location, is limited in time, and follows specific rules' (2006, p.59). In the *Feeler Reflection Game*, the creation of personas allowed participants to interpret a role and develop it further according to their own views. Similarly to the Brandt et al. *User Game* (2008), the *Feeler Reflection Game* aimed to create a shared image, between designers and workshop participants, of the end users, based on the field data.

The generation of scenarios in design is a well-known practice. According to Schön (1983), the creation of scenarios is a design technique that helps to restructure a design situation and provides new insights. The scenarios presented in the *Feeler Reflection Game* described a particular interpretation of a QS tool use situation, but incomplete and open to negotiation (Carroll, 2000). The actions taken and decisions made by players when playing the game contributed to recreating and completing the scenario of use.

> Player 1: 'I could do the same thing (noting down the data by hand as another player decided to do), but I'm a computer science student (referring to the persona she picked), so I use technology (a smart phone with an built-in sensor)'.

Transcript 5. Player explains why her character makes a certain decision.

The game board layout offered participants a comfortable environment in which they could already advance certain aspects, such as the presence of rules and the existence of a certain path, among others (Johansson, 2005). Furthermore, as Kronqvist et al. (2012) highlight, the game board acted as a design medium with a double function: presenting information to participants and engaging them to freely communicate personal experiences and views. The game board was also a great resource for guiding and informing the discussion about the concept design of the future prototype.

The game materials were used as 'things-to-think-with' (Papert, 1980; Brandt, 2006) that participants used to analyze the situation and give new meanings to it. The game offered a common language that helped structuring the argumentation and exchange of people's views (Brandt & Messeter, 2004). In this regard, as Brandt (2006) and Kronqvist et al. (2012) outline, game materials can function as boundary objects (Star, 1989), since they support dialogue between different disciplines and interests.

Finally, we would like to present the design of games as a design work (Johansson, 2005). The construction of a design game requires designers to structure and define what would be at the center of the design process. In the case of the *Feeler Reflection Game*, a lot of effort was put into presenting previous research results in a suggestive and playful way, so participants would feel comfortable to freely express themselves and contribute to the concept design. In this regard, the game design had its own process. A couple of weeks before the workshop, a low-fi prototype of the game was tested, and some aspects were redesigned according to the feedback provided. The experience of creating a game was an interesting exercise for enabling designers to identify with end users and for improving communication techniques with them.

CONCLUSIONS

In this article, we present design games as a useful strategy in PD to develop an empathic understanding of end users from early stages of the design, concretely during the contextual inquiry. Design games act as boundary objects that provide an engaging and pleasurable experience that facilitates players' free expression, and in which participants' concerns are taken into consideration.

According to our experience, design games work in two different ways. In the case of users, the game players, the game offers a unique environment for presenting previous research results, such as scenarios and personas through storytelling techniques. This way, players can easily identify themselves with the personas and scenarios and contribute to the research by helping to envision future practices in design.

From our perspective, as designers and researchers, creating a design game requires putting ourselves in the end users' position in order to present a situation that stimulates end users' communicability and creativity. In this regard, the game works as an example of empathic design since it seeks to find inspiration in end users by empathizing with them. Furthermore, the game works as workshop agenda, since it contributes to presenting the design topics and creating an experience on which players can discuss later. Considering all the above-stated information, design games offer great opportunities for developing mutual learning and empathy among end users and designers.

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RESEARCH

Reflection in Learning through a Self-monitoring Device: Design Research on EEG Self-Monitoring during a Study Session

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The increasing availability of self-monitoring technologies has created opportunities for gaining awareness about one's own behavior and reflecting on it. In teaching and learning, there is interest in using self-monitoring technologies, but very few studies have explored the possibilities. In this paper, we present a design study that investigates a technology (called Feeler) that guides students to follow a specific learning script, monitors changes in their electroencephalogram (EEG) while studying, and later provides visualization of the EEG data. The results are two-fold: (1) the hardware/software prototype and (2) the conclusions from the proof-of-concept research conducted with the prototype and six participants. In the research, we collected qualitative data from interviews to identify whether the prototype supported students to develop their reflective skills. The thematic analysis of the interviews showed that the Feeler's learning script and visualization of the EEG data supported greater levels of reflection by fostering students' curiosity, puzzlement, and personal inquiry. The proof-of-concept research also provided insights into several factors, such as the value of personal experience, the challenge of assumptions, and the contextualization of the data that trigger reflective thinking. The results validate the design concept and the role of the prototype in supporting awareness of and reflection about students' mental states when they perform academic tasks.

Keywords: reflection; awareness; design; self-monitoring; technology-enhanced learning

Introduction

The ability to reflect is considered a high-order thinking skill (Strampel & Oliver, 2007). According to Dewey (1933), reflection consists of active and careful thought about the assumptions that underlie any belief or form of knowledge, as well as the implications that these assumptions might have in the future. Whether reflection takes place during an action, as reflection-in-action (Schön, 1983), or after, as reflection-on-action (Kolb, 1984), reflection has been considered key for creating new understanding (Boud, Keogh & Walker, 1985), making sense of past experiences (Kolb, 1984; Boyd & Fales, 1983), making decisions (Pee et al., 2000), problem solving (Hmelo-Silver, 2004), and changing and transforming (Boud, Keogh & Walker, 1985; Mezirow, 1991). Specifically, in learning, reflective skills have been connected to self-knowledge and self-regulation (Zimmerman, 2002): The more students are aware of their acts and practices and understand why they do them, the more likely students are to make better decisions and control their learning process.

An emerging new media culture, in which ubiquitous information and communication technology surrounds us and provides continuous access to social media and social networking services, provides challenges to focused and reflective learning. The new forms of media, however, may offer opportunities for reflection. Due to the increasing availability of devices that automatically record everyday life events, people can collect various types of personal data and reflect about their behaviors. An example of this trend is the Quantified Self (QS) movement, whose followers engage in self-monitoring in order to increase their understanding of themselves.

In the literature, a growing number of scholars have emphasized that QS devices are powerful tools for engaging people in self-reflection and increasing their awareness (Li, Dey & Forlizzi, 2011; Rivera-Pelayo et al., 2012). Recently, wearable smart objects that automatically collect data have received interest among educators, as well as researchers in the field of teaching and learning. One of the challenges identified and discussed is what data should be collected and how they should be analyzed and used (Durall & Leinonen, 2015). For instance, Lee and Drake (2016) included QS tools to monitor pupils' physical activity and used this data to motivate students to learn about basic data analysis and statistics. In the

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StudentLife study, Wang et al. (2014) collected data with self-monitoring tools about different indicators, such as stress, sleep, activity, mood, sociability, mental well-being, and academic performance, in order to assess student well-being.

The increasing availability of devices that monitor brain activity, such as low-cost electroencephalogram (EEG), has renewed interest in the possibility of cognitive neuroscience to inform teaching and learning. For instance, in educational technology research, EEG has been used to track learners' emotions in distance education (Li et al., 2012), reading comprehension (Yuan et al., 2014), and cognitive workload (Galán & Beal, 2012). In most research of this kind, students are the subjects and are not given access to the EEG data. The data were then used to create models of the students, assess their performance, or advance a specific field of knowledge. In general, the adoption of EEG techniques in education has been marginal. One reason, as Ansari, Coch and de Smedt (2011) pointed out, is the gap between basic research and applied research, which complicates the exchange of communication and knowledge between education and cognitive neuroscience.

In this paper, we present design research that explores whether and how computer-mediated practices combined with self-monitoring brainwave activity augment awareness and reflection to contribute to students' self-knowing. The ultimate goal is to empower students by helping them gain more control of their behavior. The research results are two-fold: (1) a prototype called Feeler and (2) conclusions from the proof-of-concept research conducted with the Feeler prototype.

In the following sections, we present the research design and the prototype we designed: a tool that guides students to follow a specific step-by-step study process that includes meditation, a study session, and reflection with self-monitored brainwave activity (see the Feeler Use Scenario). After presenting the prototype, we describe the results of the proof-of-concept research and identify the elements that support the behaviors related to awareness and reflection in learning.

Background

Reflection has been strongly linked to experience (Schön, 1983; Kolb, 1984; Boud, Keogh & Walker, 1985; Dewey, 1933; Sas & Dix, 2009). According to Boud, Keogh and Walker (1985: 19), reflection can be defined as a

> generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations. It may take place in isolation or in association with others. It can be done well or badly, successfully or unsuccessfully.

Despite ongoing debates about what can be considered reflection and where the boundaries are, research on reflection has recognized different levels of reflection. The seminal works of Kolb (1984), Mezirow (1991), Dewey (1933), Peltier, Hay and Drago (2005), and Kember et al. (2000) all indicate that the reflection process can be divided into awareness, critical analysis, and change. The first stage (awareness) refers to the process in which a person becomes conscious of a previous experience. Recalling actions and being able to describe them to justify certain decisions is characteristic of this stage. The next stage (critical analysis) requires identifying existing knowledge and finding possible alternatives for a specific situation. The cognitive processes involved in critical analysis include making relations, changing perspective, and creating hypotheses and different explanations. The third and last stage is change. The transformation of practices and beliefs is regarded as the consequence of awareness and critical analysis. To achieve this change, it is necessary to ask fundamental questions and challenge existing assumptions. Although in the research literature, different authors (Kolb, 1984; Mezirow 1991; Dewey, 1933; Peltier, Hay & Drago, 2005; Kember et al., 2000) describe different boundaries between the levels, all agree that there is a hierarchy, which means that each level builds on the previous one.

The tasks embedded in reflection consist of making inferences, generalizations, analogies, distinctions, and evaluations, as well as feeling, remembering, and solving problems (Mezirow, 1991). Acquiring reflective skills demands a lot of mental effort because many processes are involved. In addition, the sociocultural context in which we have developed and the learning environment in which we are studying can provide barriers to reflective learning. These barriers, however, can be overcame with critical reflection in which the barriers are recognized and accepted, named, and their origins are studied, and then strategies that can be confrontational or transformative are used (Boud & Walker, 1993).

Some education, as well as, interaction design scholars have recognized the potential of Information and Communication Technologies (ICT) to support reflection (Conole et al., 2004, Fleck and Fitzpatrick, 2010). In education, affordances have been connected to the 'characteristics of an artifact that determine if and how a particular learning behavior could possibly be enacted within a given context' (Kirschner, 2002, p. 19). The potential of QS tools for affording reflection is based on their ability to record data and experiences and revisit them to find patterns, to make relations and to develop new perspectives that can lead to a behavior change.

To the best of our knowledge, QS tools and practices have not been used in education to gather and analyze data to provide insights for students to reflect on and guide their own behavior. Although some students may already use QS tools to monitor everyday activities, such as sleeping and physical exercise, such monitoring does not mean that the students reflect on the activities or make connections to their academic activities. Moon (1999: 165) has pointed out that 'student reflection generally does not just "happen", but conditions can be structured to encourage it to happen'. In other words, if we want to foster students' reflective abilities, we need to design learning tools that support reflection.

Methodology and Research Design

Design process

In design research, theory and empirical research inform the design of new tools that are expected to introduce change that will improve human practices (Nelson & Stolterman, 2003). In this research, the aim is to influence current learning and teaching practices. Similar to design approaches that stress the importance of the artifacts produced, such as research-oriented design (Fallman, 2003), and in the model for interaction design proposed by Zimmerman et al. (2007), the final design of a tool is an important outcome of the research. By adopting this approach, we aim to create a well-informed design that includes the potential effects of the artifact on individuals' practices. Thus, design decisions about the prototype are based on research. With proof-of-concept research, we aim for evidence-based design.

In this project, the design process follows research-based design methodology (Leinonen et al., 2008; Leinonen, 2010) in four phases: contextual inquiry, participatory design, product design, and prototype as a hypothesis. Iterations during the process are frequent, and therefore, the distinction between the different phases indicates the emphasis of the design activity, instead of viewing the process as a linear activity. The process borrows from participatory design and human-centered design traditions. Crucial is a close connection with the people who would benefit from the design. This way, design researchers try to ensure that the tools designed will truly meet the needs of the community (Robertson & Simonsen, 2013).

The contextual inquiry of Feeler research explored the socio-cultural context of the design (**Table 1**). The information gathered during this phase was used to recognize challenges, such as the impact of multitasking behaviors on students' ability to focus. On the other hand, from the literature review we noticed the difficulty to apply basic research findings on design solutions aiming to improve learning. With the contextual inquiry we recognized student's acknowledgement of the importance of self-awareness and their positive views on self-monitoring and meditation practices. These findings were used to define the first design concepts, which were discussed and further developed in the participatory design sessions with graduate students. The analysis of the data gathered during these sessions was the basis for the product design and the development of the prototype that was iterated and tested with users in several following participatory design sessions. **Table 1** shows the design research instruments used during the Feeler prototype design process.

The outcomes for the stages of research-based design process informed the actual product development. During the iterations, including the production of four prototypes, the requirements were revised and updated. The four key requirements were defined: (1) The tool enables reflection on (study) action, (2) the tool encourages users to recall and think about their personal impressions and feelings, (3) the tool helps users compare their own impressions with the data recorded, and (4) the tool does not provide explicit advice or suggestions for future actions by the users.

Research stage	Description	Main outcomes
Contextual Inquiry	6 semi-structured interviews with graduate students; 4 subject-expert interviews 4 days of observation and field note-taking in a university library environment Literature review 3 focus group interviews (n = 15) conducted with graduate students to explore the relation between learning, well-being, and physiological data Questionnaire distributed to 14 graduate students before and after the participatory design sessions	– Recognition of self-awareness and meditation as valuable skills in learning and well-being – Challenges in reflecting and focusing on the academic task due to constant access to social media – Gap between research and practice regarding the use of physiological data in learning – Positive attitudes regarding self-monitoring
Participatory Design	3 participatory design workshops (n = 14) with graduate students; a design game was created to improve communication with the participants and support the data collection 2 presentations and feedback sessions during the lab's open door event on the first 2 lightweight prototypes made out of cardboard and plywood	Participants' artifacts had a shared interest in proposing: – Design solutions that respect data ownership and privacy – Other forms of self-monitoring (emotions, time dedicated, etc.) – Reflection as a separate task at the end of the process
Product Design	Design studio work produced 4 prototypes, 2 of which are functional	– Personas – Scenarios with use cases – Feeler paper prototype – Feeler plywood prototype
Prototype as Hypothesis	Production of functional prototypes in a Fab Lab (hardware) and design studio (software)	– Feeler v.1.0 – Feeler v.2.0

Table 1: Research-based design process in the Feeler prototype design.

Proof-of-concept research
A functional prototype is a combination of role, look-and-feel, and implementation prototypes (Houde & Hill, 1997). The prototype was primarily designed and built to examine the possible benefits users would experience when they use it. To collect real data about the use of the prototype, the look-and-feel, user interface, and user experience were all carefully designed and implemented so that the tool would be functional and usable in real-life study situations.

The meaningfulness of the research, including the design and building of a prototype, is based on the prediction that in the near future the option to self-monitor one's EEG activity will be widely available to students. The specific motivation for building this prototype was to investigate how use of the tool could influence students' study habits and to assess the levels of reflection the prototype could support.

To understand the feasibility of the prototype, we conducted proof-of-concept research with six graduate students (MA and PhD candidates). All participants were heavy users of digital technologies in their everyday lives. The participants originally came from South America, Europe, Asia, and Australia and were fluent in English.

Individual testing of the prototype with the participants lasted 30 minutes. The testing included a simulation of an individual study session and consisted of three parts:

1. An approximate 5-minute meditation exercise
2. An approximate 15-minute study task consisting of reading a text and solving three-dimensional (3D) puzzles
3. An approximate 5-minute analysis of their experience by silently thinking about and answering three reflective questions.

The participants used the prototype to guide them through the three parts. The participants' EEG activity (a feature of the prototype) was monitored while they performed the tasks. After the third part of the test, the participants were given a visualization of the EEG data collected during the test.

The test was followed by a semi-structured interview, which started with the interviewees thinking aloud while they looked at the EEG data visualization. The participants were asked to express their thoughts and interpretations of the brainwave data visualization. Then, the interview focused on general aspects of the design, such as interaction, user experience, and usability.

The proof-of-concept prototype tests and the interviews were video- and audio-recorded, and a qualitative analysis was performed using qualitative data analysis software (ATLAS.ti). To study how the participants assessed the prototype's support for reflective practice, a thematic analysis of the interviews was carried out. Thematic analysis is a suitable method as this approach is oriented to the identification, analysis, and reporting of patterns (themes/categories) present in research data (Braun & Clarke, 2006).

To interpret the interview data, we adopted a hybrid process that combined inductive and deductive thematic analysis (Fereday & Muir-Cochrane, 2008). The analysis followed an inductive approach. We created codes by carefully analyzing the discussions between the interviewer and the users and assigned the codes to fragments of the audio that revealed particular speech patterns related to reflection. We then revised and refined the codes several times in order to detect recurring categories. Once a more stable version of the codes was generated, it was contrasted with the research literature on levels of awareness and reflection in learning (Kolb, 1984; Mezirow, 1991; Dewey, 1933; Peltier, Hay & Drago 2005; Kember et al., 2000). Then, we generated another coding scheme and applied it again to the interview data.

To determine the applicability of the coding scheme, we invited a researcher who was not involved in the process but who was familiar with the literature to code the raw data again with the coding template (**Table 2**). The categories and the codes were found to be applicable, although some behavior found in the data was analyzed more closely and discussed among the researchers in order to make a decision about the final codes.

The codes were grouped under three categories: C1/Non-Reflection, C2/Recognition, and C3/Reflection. These categories were defined and organized according to the hierarchical levels of reflection described in the literature (Peltier, Hay & Drago, 2005; Kember et al., 2000). In this hierarchy, different levels are distinguished according to the cognitive effort involved in the task. Thus, C1 (Non-Reflection) involves very little effort, whereas C3 (Reflection) demands higher learning skills.

C1/Non-Reflection refers to situations in which the user expresses not having any particular interest on the brainwave (EEG) data or is not able to create meaning or a hypothesis out of the data visualized. The codes included under these categories are No Expectations and Not Understanding.

The category labeled C2/Recognition includes quotes that suggest the user understands the data but acknowledges only what was expressed in the visualization. Integration and Curiosity are the codes grouped under this category, which connect to Boud, Keogh and Walker's (1985) claim about the key role of emotions in reflection. Curiosity can be a necessary emotion, although it is not strong enough to ensure that reflection happens.

The category C3/Reflection refers to behaviors clearly associated with reflection, such as Puzzlement, Appropriation, and Transformation. Feeling puzzled is connected to the states of perplexity and doubt noted by Dewey (1933). People experience these states when their data do not correspond to their assumptions. Puzzlement also indicates a strong emotion (Boud, Keogh & Walker, 1985) as the person feels her or his assumptions are challenged but lacks the resources to explain why things are the way they are. Appropriation indicates that the person interprets the data and makes connections to her or his personal experience (Kolb, 1984). The term Transformation alludes to perspective transformation (Mezirow, 1991) in which, as a result of reflection, the individual changes her or his beliefs and/or modifies her or his behavior.

C1/Non-Reflection	
C1a: No Expectations	The person does not express a particular interest, question, or expectation about the prototype or the EEG data.
C1b: Not Understanding	The person cannot make sense of the EEG values or the way these data are visualized.
C2/Recognition	
C2a: Integration	The user relates the data to what is already known. The user seeks relations among the data.
C2b: Curiosity	The person expresses interest in the data or in how certain activities affect her or his mental states. The person formulates questions and identifies aspects she or he would like to know more about.
C3/Reflection	
C3a: Puzzlement	The participant feels surprised when he or she discovers values that do not correspond to her or his previous assumptions. The participant is unable to explain why the data monitored by the system differ from what she or he experienced during the session.
C3b: Appropriation	The person interprets the data (makes inferences) and builds her or his explanation for how the raw data connects to her or his experiences. The person identifies how the prototype might benefit her or his learning process. The person also determines the authenticity of the ideas and feelings that resulted during the session.
C3c: Transformation	The user's views about how his or her brain activity affects her or his study activity have changed. This new understanding motivates the user to make a change in her or his study habits or practices.

Table 2: Coding template used to analyze the qualitative data collected from the prototype testing.

Results

The research results consist of (1) the Feeler prototype, a tool designed to help students focus and reflect on their work in individual study situations, and (2) the results obtained from the proof-of-concept research that helps us understand use of the prototype, the learning experience the tool enables, and how it supports awareness and reflection and has a positive impact on students' behavior. In the following section, we present the Feeler prototype and the findings from the proof-of-concept research.

Feeler prototype

The Feeler prototype guides students in self-study, which starts with meditation and ends with self-analysis. During the sessions, students self-monitor their brain activity through EEG. The EEG data are used after the self-analysis stage, to foster students' metacognitive skills by triggering questions about the mental state of studying and then improving it. With Feeler, reflection is expected to happen during the revision and interpretation of the EEG data visualization.

The prototype is composed of the following elements (see **Figure 1**): three smart objects with which the user physically interacts (the blocks), an EEG monitoring device, and Feeler software running on a laptop.

With Feeler, students are guided to follow a script while they perform an academic task, such as studying, reviewing literature, or reading materials to prepare for an exam. The script structures the session in three parts; each part is associated with one of the smart objects, the blocks (see **Figure 2**):

1. Meditation: The first block guides the user's breathing rhythm with a slowly pulsating LED light. When the meditation period is over, the block vibrates and asks the student to move on and use the second block.
2. Study: The block is a timer that provides subtle visual information about the passing time with a grid of LED lights. The time can be set to 20 minutes, for example. When the study period is over, the block vibrates and asks the student to move on and use the third block.
3. Self-analysis: The third block activates questions displayed on the blocks. Each question is illuminated for 1 minute. The questions are as follows:
   - o How did you feel during the session?
   - o What do you expect from the EEG data?
   - o What would you change for the next session?

Inside the blocks are Arduino microcontroller boards with sensors, magnets, a vibrator, Bluetooth components, and LED lights. The blocks communicate the script to users, and very little external instruction is needed to use the blocks. The tangible interaction, playing a little with the blocks, dim lights, and gentle vibrations, is expected to be non-disruptive but still engaging for users.

The data visualized with the software include brainwave frequencies corresponding to delta, theta, alpha, beta, and gamma waves (expressed in Hertz) and attention, meditation, and blink-rate values, which are defined in percentages. The software shows each wave in one color gradation, where the transparency varies according to the value of the frequency in each brainwave (see **Figure 3**). For instance, if alpha brainwaves include values from 8 to 12 Hz, the color is more intense when the values are close to 12 Hz. If the value is near the lower limit, such as around 8 Hz, then the transparency level is almost 100%.

All the data about brain activity were exported directly from the EEG monitoring device as raw data. The prototype did not filter or clean the data but provided a

Figure 1: Feeler blocks, digital app, and EEG monitoring device.

Figure 2: To connect the Feeler smart objects, the user needs to place them next to each other.

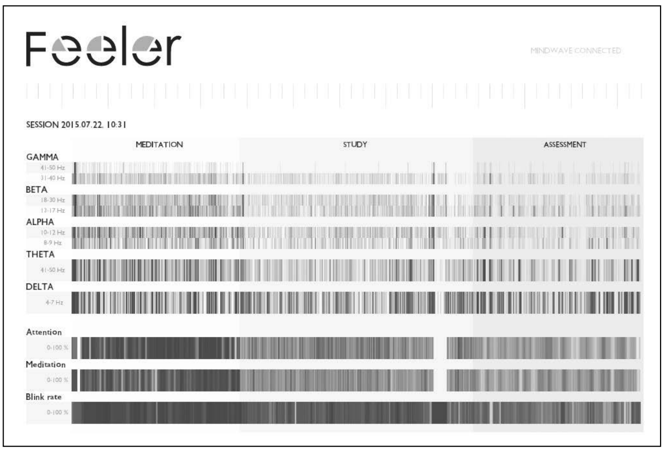

Figure 3: Screen capture of the data visualization for one session.

visualization of the raw data that is expected to be analyzed by the users by comparing, making connections, triggering questions, and creating a hypothesis. Rather than showing empirical evidence about reflection, the visualization of the EEG data in Feeler aims to engage students in reflection by practicing key reflective skills, such as making relations, questioning, and creating explanations. To provide an easy-to-read overview of the entire process, color scale visualization was used instead of waves (common in EEG). It was expected that the visualization would help students identify which brain waves (frequencies) were dominant in each moment. For simplicity, the duration of the stages was the same.

The use of Feeler and a practical use case are described in the following scenario.

Feeler Use Scenario

Timo is a second-year university student in chemistry. He is preparing the final assignment for his Inorganic Chemistry course, which consists of a paper about a specific topic chosen by the student. Timo knows that focusing on studying is difficult for him. Somehow, studying without looking every 5 minutes at what is happening on social media has become very hard. In this study task, he needs to review recent academic publications, define a research question, and design an experiment to test his hypothesis. Timo, in general, is not very familiar with academic research, and each task requires a significant effort. He found that working at home is too distracting, so he prefers to work on his final assignment at the University Learning Center. At the learning service desk, Timo finds Feeler, a tool that supports students to stay focused when working on academic tasks. He feels that this tool could be what he needs and decides to use it while researching and writing his final assignment.

To use Feeler, Timo has to follow a specific script guided by smart blocks and wear a headset that monitors his brain activity. The first task consists of a short meditation exercise. Timo has never meditated before. He tries to sync his breath to the lights of the first Feeler block. When the block vibrates, indicating the end of the meditation period, Timo feels in the right mood to read the literature and to start writing notes. He connects the second Feeler block and starts working on searching for research articles and slowly drafting some text on the computer. After 45 minutes, another vibration tells him to move to the next task, which consists of briefly analyzing his experience by answering three questions. Timo silently answers the questions shown on the blocks.

Then, he checks the Feeler software to access his brain activity data. The visualization of the data surprises him. Apparently, he was more attentive while meditating and not as much when studying. He is curious and spends a bit more time searching for information about how the different brain waves correlate to his mental activity. Over the following days, he keeps using Feeler while testing different hypotheses. For instance, he realizes that multitasking decreases his attention and relaxation and that doing physical activity in the morning works better for improving his attention span than drinking coffee. After several months of using Feeler, Timo feels he knows himself better. The feedback provided by the Feeler software has helped Timo reflect on and modify some of his study habits. For instance, every time Timo needs to work on demanding tasks, he logs out from his social media accounts and sets a time limit before he goes online again. Thanks to these behavior changes, Timo is able to focus and avoid multitasking when he studies for longer periods.

Proof-of-concept

To validate the Feeler prototype, we conducted proof-of-concept research with six graduate students. By analyzing the qualitative data (6 × 1.25 hours of audio and video recordings), we aimed to understand the prototype in use, the learning experiences the prototype facilitated, and specifically how it supported awareness and reflection in relation to helping students become more focused.

Qualitative results

In the first phase of interviews, the interpretation of the EEG visualization was discussed. The visualization presented the data in different color gradients that represented the participant's brain waves recorded during the session. During the interviews, two participants did not understand the EEG visualization. One clearly expressed a lack of understanding of the visualization: 'I don't know [. . .] I don't know how to interpret it. I mean, because here it is dark in the meditation and then is less (referring to the color intensity differences of the visualization)' (user 6).

In the research data, this and similar comments were coded as Not Understanding, which could be explained by the lack of basic information on how to interpret the visualizations. It seemed that the visualization was not easy to read. However, participants who were able to get over their initial confusion soon showed signs of Integration, by comparing and relating information in the graph to their prior understanding of brainwaves and mental states. One participant stated:

> So, technically I have no idea how you can translate this data, but I'm guessing that it's just a, these different brain types are related to different brain activity, considerably relating to study or focusing and this data can be used to understand which part of the brain or what kind of brain activity was happening during different kind of tasks. (user 2)

The participant missed some background information about brainwaves but still made guesses and interpretations regardless of a lack of technical knowledge. The participant was also already showing some signs of integration. The same participant stated the following, a good example of this effort for making relations among the data:

> I think that there was more brain activity during study and assessment. I think study is the most crowded phase or active. I'm basing this solely on the visualization, it's like there are more frequent colors, and there are frequent changes between them. (user 2)

Expressions of Curiosity were heard in many participants' comments. The data visualizations sparked the participants' interest regarding what type of activity they were engaged in at specific times: 'It would be great if you could, somehow, know at what point I was having that thought' (user 3).

In other cases, participants made hypotheses and expressed curiosity about testing whether their impressions were valid: 'I think I was more focused when starting to read this after the meditation, but that's my feeling. It would be actually be nice to test how this it affects' (user 1).

The participants clearly were interested in different aspects of the data and expressed their wish to know more. The participants also described various scenarios for how they could use the data and hypothesized how it could benefit them. One interviewee noted:

> Actually I would be interested how my brain activity works when I'm reading, because you know when I'm doing a task like, practical task. . . I feel that I'm concentrated. . . but while I'm reading sometimes it's really hard for me to concentrate. Sometimes my brain starts to wonder on different things and I'm reading, but I'm actually not understanding anything, so I have to read it again (user 2).

The participants were surprised by some of the conclusions they reached after they interpreted the session data. In some cases, this reaction was explicitly connected to learning. A participant stated: 'I learned that during the meditation all the waves were stronger than in any other task, which is new thing. I didn't actually know that, and I think it's super interesting because in the end you are not doing anything new, you are just breathing' (user 1).

Later in the test sessions, when the participants were familiar with the visualization, they started to associate it with their mental states, activities, and feelings. These expressions were marked with the code Appropriation. For instance, participants made assumptions about the visualization and its significance related to their mental states: 'Based on my assumptions about the purple color, it seems I was more engaged in the meditation part, although I feel I was more engaged in the study part' (user 4).

These examples are clear signs of reflection, and some are more toward Transformation, in which the participants show an interest in changing their habits and practices. Some participants also discussed the difficulty of changing their habits: 'Yeah, I would (meditate). And as I told you, I tried once and . . . it's just—it's hard. Not hard—it just takes time to create the habit' (user 5).

Another participant explained that she used to take the time to meditate, but she had never meditated before studying. She also expressed a real interest in making meditation before studying a practice: 'Of course, concentrating a while and breathing, but not that really sort of thinking: now I focus on meditating [for] 15 minutes, and then I start reading. I don't know why that hadn't occurred to me [before], but maybe I should try [it]' (user 1).

Each comment was assigned to a specific coding category. However, in some cases, the comments were ambiguous. For instance, some comments coded primarily under Curiosity could also be interpreted as including signs of Appropriation. Some of these cases dealt with participants' expressions of surprise in response to unexpected results that contradicted the participants' assumptions. A participant stated: 'I would like to know why my attention was poor when I was in the study mode because somehow, consciously I felt that it . . . that was the time I mostly—I was the most concentrated' (user 2).

This expression of curiosity indicates a certain level of reflection as the participant was interpreting the experience. Despite this, in the analysis, these comments were coded as part of Curiosity because the participants were curious about validating their hypotheses.

In general, participants were positive about the Feeler user experience. They enjoyed the interaction with the physical objects and the feelings that use of the prototype provoked, such as surprise, curiosity, and absorption. The following quotations show the participants' attitudes when they were asked about the boxes: 'I like the simplicity of the interface and the idea that everything is happening inside my brain' (user 2) and 'They are nice boxes, I like them, I like the boxy shape' (user 4).

Regarding the script, participants recognized that the highest levels of engagement happened while they were meditating and studying. Most participants were pleasantly surprised by the effect that meditation had on them: 'I feel relaxed, so the meditation kind of worked for me' (user 5).

Quantitative results

To get an idea what behaviors and interactions dominated the use of the prototype, we performed a quantitative analysis of the distribution of the codes (n = 228) among the categories (see **Table 3**). The codes assigned to the first category, C1/Non-Reflective, were very rare

Category	Code	Number of codes	Percentage
C1/Non-Reflective	No Expectations	5	2%
	Not Understanding	15	7%
C2/Recognition	Curiosity	71	31%
	Integration	48	21%
C3/Reflection	Appropriation	69	30%
	Puzzlement	13	6%
	Transformation	7	3%

Table 3: Distribution of codes found during the proof-of-concept analysis of the Feeler prototype.

(only 9% of the total): No Expectations totaled 2% and Not Understanding 7%. The codes in the second category, C2/Recognition, accounted for 52%, and included Curiosity (31%) and Integration (21%). The percentage of codes assigned to the third category, C3/Reflection, was also high (39%) and included Appropriation (30%), Puzzlement (6%), and Transformation (3%).

The distribution of the codes confirms the hierarchical relation of the behaviors linked to reflection. The distribution also demonstrates that the participants moved from C2/Recognition to C3/Reflection. The high number of comments that were coded as Integration (21%) suggests that the initial reading and interpretation of the visualization were crucial in raising awareness of and interest in the user's own cognitive processes. In connection with the latter, Curiosity about specific points in the visualization led to Appropriation after a period during which the users figured out possible connections between their state of mind, their feelings, and the activities they performed.

As the participants analyzed the visualization, awareness of their cognitive activity rose, and they were able to reflect on changing their practices and routines. By taking the percentages as a reference point, once a user reaches higher levels of C3/Reflection, the behaviors labeled C1/Non-Reflection and C2/Recognition decrease. This trend implies that it is highly unlikely that users engage in higher levels of reflection if they do not first understand and contextualize the visualization.

The number of behaviors coded as Curiosity (31%), Appropriation (30%), and Puzzlement (6%) indicates that the Feeler prototype facilitates reflection about mental states while the user is performing an academic task, such as studying alone, reviewing literature, or reading materials to prepare for an exam. The most relevant behaviors were those where the participants made a connection to their personal experiences (coded as part of Appropriation) and the cognitive disequilibrium that arises when assumptions were challenged (coded as part of Puzzlement). The difficulty in understanding the data monitored by Feeler and the inability to elucidate why the data visualization conflicted with the participants' personal perceptions explain the high levels of Curiosity (31%) shown by participants. These findings suggest that Feeler facilitates inquiry about mental states. The participants were very interested in understanding how different study practices affected their brainwave data.

The results indicate that the Feeler prototype may also support transformation and change. Although the number of behaviors coded as Transformation (3%) was low, its presence suggests that Feeler had an impact on participants' prior perceptions and assumptions about their mental states when the users performed the tasks. During the interviews, most participants recognized they had learned something about their mental activity through use of the prototype. Feeler enabled participants to reach a new understanding of studying, which, in some cases, may also lead to a long-term behavior change. The difficulty in conclusively assessing whether the participants are really planning to change their practices and whether the participants are really able to do so, however, requires longitudinal research.

Conclusion

In this research, we explored potential uses of self-monitoring technology and practices, especially EEG, to support students in acquiring high-order thinking skills, such as awareness and reflection. The design objective was to design and develop a prototype that presents and frames one approach, view, and functionality in which a learning script is combined with self-monitoring of brain activity. The research question for the proof-of-concept research was, how did the prototype support students (or not)?

In evaluating the first part of the results (the prototype), the nature of this study should be kept in mind. In design research, the prototype is considered a result and should be critically discussed by evaluating the concept and its implementation. A meaningful question to ask is whether the prototype solves the challenge (lack of awareness and reflection) in a creative way. The proof-of-concept research aimed to provide insights into the same issue with a traditional qualitative research approach.

The results validated the design concept, as well as the role of the prototype in supporting awareness and reflection about students' mental states when the students perform academic tasks. The participants recognized that the prototype helped them gain a new understanding about themselves and that it led to new questions about how their brain functions when they perform cognitive demanding tasks. Surprise and curiosity were among the most common reactions observed among the participants, which connects to middle and higher levels of reflection. The aspect that was most highly valued in the use of the Feeler prototype was the meditation phase. Participants reported a positive user experience during the meditation phase that in some cases led them to reconsider their study habits. The test also helped us identify aspects that required further improvement, such as the visualization of the brainwave data and the reflective questions included in the last box.

With the study, we also found technological and pedagogical affordances specifically related to awareness and reflection in learning. The script and the prototype introduced students to sense making, inquiry, and reflective practices and then more likely equipped the students with these skills. More research using controlled trials is needed to validate these results.

A limitation of this study is that the use of the smart objects, EEG monitoring, and software might have increased the users' awareness of the situation and reflection on their mental states (similar to the Hawthorne effect). To confirm the results, additional studies with additional subjects and control groups in real-life environments should be conducted.

Finally, the proof-of-concept research also provided valuable insights into specific aspects that influence reflection, such as the focus on personal experiences, the challenge of personal impressions, and the contextualization of the data. Therefore, future versions of the Feeler prototype will reinforce these aspects to help students increase their awareness of and reflection on different behaviors that affect their ability to stay focused. In future pilot tests conducted in real-life situations, we expect to find to what extent the Feeler prototype helps students self-regulate their attention and relaxation.

Competing Interests

The authors have no competing interests to declare.

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Data won't change your behavior: A critical design exploration of quantified self technologies

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Abstract

Data is becoming a ubiquitous phenomenon in our culture. Technologies that collect data about us on our behalf, such as lifelogging and quantified self devices, have been presented as able to help people change behaviors. This paper presents a study exploring the meaningfulness of these devices and their use. To investigate this topic, we designed our own QS device, using a critical design approach, called Feeler. We also conducted an experiment in which five participants used the device. Feeler guides users to meditate, study, and play. When the user is engaged in these activities with the device, it collects biological data (EEG) from the user and further asks users to share their own impressions about their attention and relaxation levels. From the experiment we collected about 7.5 hours of audio data, including think-aloud and semi-structured interviews. The audio was processed by marking interesting sections for further analysis and contextualization. Our results indicate that people are trustful of QS technologies and the ability of such technologies to help them initiate behavioral changes. We also found out that the use of these technologies is targeted towards productivity and self-improvement, such as avoiding procrastination, improving focus, and avoiding social media.

Keywords

Lifelogging, Quantified self, Critical design, Automated data collection, Technology design.

Introduction

We are living in the midst of a data revolution. Automated collection, storage, and analysis of data and media originating from various sources are changing our perception and experience of the world, the society we live in, our social relations, and ourselves. In general, these new forms of data are having a growing impact on our culture. Today data is currency. With it, we pay for the use of social media services. Sometimes data provide us hints of challenges and opportunities for action connected to our goals. Data also supposedly help us to make better decisions and solve problems.

Personal informatics, personal analytics, and quantified self (QS) are areas of research and practices in which individuals collect data about themselves (Rooksby, Rost, Morrison, & Chalmers, 2014; Swan, 2013; Wolfram, 2012). Such practices, including the collecting of *biomarkers*—or indicators of the user's biological state or condition—and *lifelogging*—or wearing computers to capture in various ways the user's entire life—are said to help people reflect on their life (Gurrin, Smeaton, & Doherty 2014). The expectation is that the new and deeper understanding will lead to behavior change and thus better living.

Ubiquitous computing has enabled people to collect data at any time and everywhere in a non-invasive, almost invisible way. Wearable devices based on self-tracking have become affordable and people have started to self-track a myriad of things, including physical activity, location, sleep, emotions, and mental states, to name a few.

The motivations for self-tracking are diverse, although a common theme is the augmentation of human capabilities. For instance, in lifelogging the ultimate reason for engaging in such a data collection endeavor is to surpass the limitations of human memory (Bell & Gemmell, 2009; Mann, 2004). Inspired by Vannevar Bush's (1945) utopia of a Memex—a machine that could contain all the books in the world, as well as personal records of action and communications—lifeloggers pursue the dream of complete recall of everything they have ever done in their life. Although the question of how to retrieve the data or how to transform the massive amount of data into usable information and knowledge remains open, the vision is clear: by recording everything, we can know more and therefore be wiser, better, and more productive human beings.

"Self-understanding through numbers" is the slogan of the QS movement. Similar to lifelogging, QS involves the attempt to record important data about yourself to drive change and access means for personal improvement (for example, wearable sport, wellbeing, and health devices) (Rapp & Cena, 2014). The emphasis is on continuous development. Therefore, many QS systems have some sort of automatic data analysis, coaching services, or gamification in order to motivate users to achieve their goals. The underlying idea is the classical business adage "If you can't measure it, you can't manage it."

Most of the criticism of lifelogging and the QS movement has revolved around concerns about privacy and ownership of data. Often, users of these services are fully aware that the service provider will also have access to the data and will use it for commercial purposes. Although some critical voices have suggested different models wherein users have a right to manage data gathered about themselves, there is very little critical analysis of the practice itself and its more general implications for our culture (see, e.g., O'Hara, Tuffield, & Shadbolt, 2008).

Personal data is also seen to provide power. Knowledge is power, but can lifelogging and QS provide us with knowledge that will truly help us in our lives? If so, in which aspects of life can they be useful? An interesting question is whether lifelogging and QS is driving us deeper into a competitive culture, in which the primary goal is to beat others and where the winner takes it all.

In this paper we present a study exploring the above questions by experimenting with a new practice and a device designed to collect biological data while the participant is studying. We describe the Feeler prototype—a speculative design artifact—which was developed to further understand how people relate to data collected about themselves and how the data may or may not have an impact on their behavior. We conducted an experiment with five participants (students) using the Feeler in 15 sessions of approximately 30 minutes each. In the following sections, we present the Feeler prototype itself, the research conducted, and the main results.

Feeler

Feeler is a set of computer devices with a tangible user interface (Figure 1) combined with an electroencephalography (EEG, also called "brainwaves") data monitoring device. The Feeler system includes software running on a desktop app. The software collects the data and visualizes them after a study session. Feeler software gathers data about the users' attention and relaxation levels from the EEG device (a Mindwave helmet that uses Neurosky sensors) and communicates with the Feeler boxes via a Bluetooth connection. Feeler smart boxes consist of Arduino microcontroller boards connected to sensors, vibrators, infrared lights, and LED lights.

Figure 1. Feeler smart boxes.

When using Feeler, participants follow a specific script that divides a study session into three different stages: meditation, study, and play. Each stage is associated with one of the smart boxes, which leads the student's actions through visual and haptic feedback. The boxes give guidance and monitor the time spent on each activity, indicating the end of each task through a gentle vibration. After each stage, an icon illuminates and asks the user to connect the box to the next one in order to proceed to the next stage. Below we describe the functionalities of the Feeler smart boxes and the stages facilitated by the boxes:

1. Meditation: Before beginning to study, people are invited to perform a five minute meditation exercise through deep breathing. In the meditation box, a pulsating LED light helps the user to maintain a calming breathing rhythm.
2. Study: The study portion is scheduled to take 20 minutes at a time. The study task consists of searching relevant content online and by reading, watching, and listening to the content found. A screenshot of the activities is taken every time a user's attention and relaxation levels surpass certain thresholds based on measurements taken by the EEG device. In the Study box, a grid of LED lights gradually illuminates as time passes. The lights provide visual information to users about the time spent studying and the time remaining.
3. Play: The Play-box is a device with a memory game. Similar to the 1980s Simon Says game, the user must repeat a light and sound sequence by tapping round touch sensors on the box. The game gets more difficult by adding a step to the sequence every time the user correctly completes a level. The game ends when the player makes a mistake. There is no time limit for this box, so the user can play as long as he or she wants.

While using the Feeler boxes, the user's EEG activity is monitored. After completing the Play-stage, the software running on a laptop asks the user to assess how she felt while meditating, studying, and playing. Users are also asked to estimate, based on a percentage scale (from 0 to 100), their level of attention and relaxation during the different activities. After recording this information, the Feeler software shows (Figure 2) a visualization of the EEG data compared to the user's own impression.

When looking at the EEG data visualization and her own estimation of her attention and relaxation levels, the user may reflect on her feelings and performance during the different stages. She may also go back and check from the screenshots what she was viewing when her attention or relaxation levels changed dramatically. This is expected to help users reflect on their study habits.

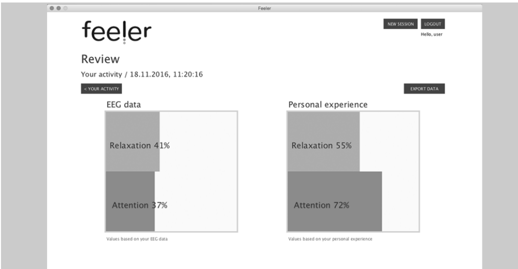

Figure 2. Visualization of EEG data and the user's personal experience from a session in the Feeler software.

Research

To explore participants' thoughts about self-monitoring of biological data, we conducted a study with the Feeler. Our main interest was to determine the key issues and the implications of the integration of self-monitoring technologies into study situations. We did not aim to analyze the EEG data; rather, we wanted to explore how people make sense of the tracked data and how they feel about it. The key questions that guided the research were as follows: How do people react to automatically collected biological data in light of their personal impressions? What happens when the data does not match their personal experiences? Do people modify their thinking or behavior based on the feedback provided by the QS device?

In order to further investigate these issues, we designed Feeler utilizing a critical design approach. In critical design, the aim is not to solve a problem or to find answers but rather to make us think and ask questions. Therefore, it resembles art forms that are critical, provocative, and challenging. One of the main questions asked with critical design is about what we really need (Dunne & Raby, 2013).

Speculative design is a critical design practice that focuses on the production of ideas by presenting possible future scenarios of use in which science and technology play a central role. It provokes questions about the impact of science and technology on people's lives by creating opportunities for interventions with possible products that are brought into an everyday context. As opposed to commercial product development and design carried out in product development units, critical design and speculative design bring possible products under public criticism (Dunne & Raby, 2013; Malpass, 2013).

A key aspect of Feeler is the juxtaposition of two data sources: (1) the EEG measurement, which in our time and culture is broadly considered to be objective and scientific, and (2) the participants' own impressions provided after using the Feeler boxes. By presenting different types of data, users are expected to reflect on the possible differences between the different data sources and to identify existing assumptions regarding attention and relaxation.

As part of our research we designed an experiment in which five graduate students would use the Feeler. Students taking part in the experiments were between 25 and 33 years old, originally from Finland, India, Colombia, and Poland. All were fluent in English and the sessions were held in English. The experiment consisted of a session lasting approximately 30 minutes using Feeler (Figure 3), followed by a think-aloud protocol and a semi-structured interview. Students committed to use Feeler once per week over the course of three consecutive weeks. In total, 15 sessions of 30 minutes each were conducted. The study work that participants agreed to perform during the sessions consisted of searching for online information related to their independent study projects. Before the participating in the sessions, participants answered an online questionnaire that collected information about their backgrounds and study habits.


Figure 3. Typical Feeler experiment session.

Students' main motivation for taking part in the study was personal curiosity. It is important to mention that none of them considered themselves to have extensive difficulties with their study work. In addition, most of the students were familiar with the concept of QS and with self-tracking practices. Specifically, 66% of them had, in the past, collected data about some aspect of their life, such as sleep, exercise, or nutrition habits.

We followed a qualitative approach for analyzing the audio recorded from the Feeler experiment. By listening to the recordings of the sessions (N = 7.5 hours), we identified a set of themes connected to our research questions and, from those, expanded our interpretation to wider contextual questions related to the use of biological data in human activities.

Results

From the recording of the think-aloud and semi-structured interviews, we recognized and marked interesting insights presented by the participants. The marked sections were then analyzed and contextualized to the wider research context presented earlier in this article.

Initially, we tried to extract from the participants' interviews how they reacted to the automatically collected brainwave activity data. Four out of five expressed strong trust in the data captured through the EEG device.

"It's interesting that I thought I was attentive, but I was actually not attentive" (participant 1).

It seemed that, somewhat surprisingly, participants assumed that the data collected by the EEG device and computer were more accurate than their own impressions. In one case, this belief reached the point of changing the participants' perception of self.

"I'm actually surprised with the relaxation thing. I perceived myself as being too tense when I was researching but I realized that I was not that tense. I think it was actually positive to see it happening or see it being measured" (participant 3).

Second, we examined the participants' verbalized thoughts about mismatches between the results from the two different data sources. We discovered that the mismatch between the EEG data and the personal impressions from the first time participants used Feeler affected their assessments in the following sessions. Since participants were aware that their impressions would be juxtaposed with the data captured by the EEG device, they tried to match their impressions to the results they thought the Feeler system would return.

"I learned from previous data, from the EEG data. I kind of felt that (...) however much I think that I paid attention, I'm not actually paying that much attention" (participant 1).

Third, we analyzed whether people modified their thinking or their behavior based on the feedback provided by the QS device. According to the experimental design, Feeler was used three times during three consecutive weeks. This allowed us to observe whether participants modified their thinking or behavior after using Feeler.

Although behavior change is a long process that involves many factors, we can report that, to a certain extent, Feeler contributed to a change in participants' perceptions about their study habits. In a few cases, participants tried to develop new habits (it is impossible to assess via this study whether this experience led to lasting, long-term behavior change). Interestingly, what seemed to motivate students' changes (in their ways of thinking or their habits) was more connected to their personal experiences using Feeler than to the collected data. The observation and analysis of the EEG data played a role, but it only led to a change when participants connected this data to their experiences.

For instance, one participant was motivated to try meditation on her own in order to gain focus when studying. In this case, as well as in others in which participants mentioned their interest in meditation, the collection of data was considered less relevant than how they actually felt after meditating.

"I tested the meditation [aside from the experiment sessions] and I feel that it helps when writing my thesis or when I'm studying for an exam" (participant 5).

Another way students made sense of the data, was to use the collection and visualization of data to confirm their existing ideas. One of the participants explained that, before the experiment, he had been considering trying to focus on the same task over a continuous period of time. Because he was hesitant about the benefits of adopting this new habit, he never made the effort. However, once he realized the effects of task switching on attention, he became convinced about the need to modify his behavior.

"It's [decrease of attention when switching tasks] raising interesting thoughts for me, about, for example, doing some continuous work for a long time (...). It's strange because I felt I had felt this first, or like I was addressing this consciously sometime during the last year or two, that it is good for me, for example, to read a book in a continuous manner for a few hours but (...) I do something so rarely continuously for few hours that I think it's crazy (...), being like this. So I think that brings that up more strongly. And now I feel like scientific data is backing it up" (user 4).

In other cases, rather than thinking about how to change their behavior, the participants were more interested in getting more automated data analyses that incorporate suggestions for behavior changes. Participants found it difficult to make sense of the EEG data and wanted some help from the system to develop new insights and modify their behaviors.

"If I get something like this [referring to Feeler], then okay, I have taken one step to do something about my lack of concentration (...). And then, this should help me through that process" (participant 2).

In the last session of the experiment, two participants reported having tried new practices when studying on their own as a result of the Feeler sessions. The fact that all participants recognized having learned something during the sessions using Feeler allows us to infer that, to a certain extent, the tool did modify their thinking.

Through this research—by developing a speculative design artifact and running an experiment with it—we also aimed to explore whether the method of recording life with lifelogging and QS-type devices can truly help us in our lives. The answer to this question depends on what we want to achieve through these technologies.

According to the participants, technologies based on automated data collection are connected to productivity and self-improvement. Participants took for granted that increasing productivity was the end-goal of using Feeler. In consequence, they expected to see higher levels of attention and relaxation after using Feeler for a period of time.

"I would give it a couple of weeks to see if helps me improve at what I do, because I do all of these things, you know? I use these different techniques… there are productivity blogs and things like that, I do read them and I try to exercise what I read and things like that, so if it helps it's great" (participant 2).

"If you use it on a daily basis, it will definitely make you more relaxed" (participant 1).

The emphasis on individual improvement brought us to conclude that at some level, lifelogging and QS, as cultural phenomena, are part of a competitive culture. Participants seem to have internalized a certain standard of what is considered “desirable,” even if the definition of what is desirable or not has not been discussed before. It is interesting to note that in certain cases, it is not clear who the participants are competing against.

> “Yes, it was a surprise… I don't know what I could do to have more attention, to be honest, because 40%, which it is what I had, I think it is low” (participant 3).

By design, Feeler does not include comparisons between users’ activity nor give indications about what would be the expected attention and relaxation levels. We interpret that this design decision disturbed participants since at some point all of them asked if it would be possible to see other people's data or if it would be possible to know if their levels were similar to the average.

> “I don’t know, does the attention usually go like this? Do some people have it really like this?” (participant 5).

Going back to the question of whether *lifelogging and QS provide us knowledge that will truly help us in our lives,* Feeler research has helped us identify some of the embedded values of lifelogging and QS technologies, such as productivity, self-improvement, and competition. With regard to whether these technologies are truly helpful for life, we can state that they are perceived as tools for achieving individual goals and higher levels of efficiency in a competitive environment.

In light of the results obtained during the analysis of the Feeler participant interviews, we might ask in what aspects of life can lifelogging and QS technologies be useful?

For some participants, avoiding procrastination and maintaining their focus was an important need. For instance, some participants felt that social media is causing a lot of distraction and that they would like to get rid of it.

> “A lot, it [access to social media] really troubles me that I do! But that’s why I have that application that I’m showing you, right? So, normally, if this was part of my system I would sync these two in a way that when I connect this I would also press this. And what this does is that it locks it, so when I’m using *Clear Focus*, like today I will be doing that a lot, I keep my 4G off, so when I put the *Clear Focus* on, I’m not online, and then if I try to open Facebook it should not work” (participant 2).

Do we need to solve problems created by technology with more technology? Although there seems to be an app for any imaginable problem, sometimes the solutions provided by these tools tend to create more problems while encouraging technology dependency.

Even though the design of Feeler can be regarded as similar to other lifelogging and QS technologies, its main goal is to support reflection rather than behavior change. The three sessions scheduled as part of the experiment were not enough to detect or track any significant changes in the ability of participants to be attentive or relaxed. All participants expressed satisfaction with the work conducted during the sessions and most of them were willing to use Feeler in the future. Only one of them showed interest in having access to the data from the sessions. In the end, perhaps it was not that relevant to collect data.

Discussion

Lifelogging and QS technologies act as mirrors that people use for building the “self” and to guide future actions. The values embedded in these technologies connect to wider discourses or metaphors that people live by, as Lakoff and Johnson (2008) described. One of most powerful metaphors presented by the authors consists of considering “the mind as a resource.” A good example of this view can be found in the opening words of Gordon and Gemmell’s book *Total Recall: How the E-Memory Revolution Will Change Everything*. The books starts with the words “I’m losing my mind” followed by the authors claiming that forgetting means that we lose something (Gordon & Gemmell, 2009, p.3). *Total Recall* is the authors’ reflections of the MyLifeBits project, in which the aim was to have lifetime digital store of everything: video of every moment of life, emails, letters, memos, photos, pictures, phone calls, television, and radio programs watched and books read. In the book, Gordon and Gemmell highlight the potential benefits that such e-memory systems could have in different areas, ranging from health to work, learning, and even afterlife.

Gordon and Gemmell adopt a technological utopian view in which increasing the productivity and efficiency of the mind through technology is a desirable future. The data captured by these technologies are trusted and regarded as a neutral and objective truth. However, no matter how much we trust the collected data, one important question to ask at this point is whether it is desirable that technology mediates such intimate experiences as our memories and mental states. Who are the real beneficiaries of such a level of technological dependency?

According to Nye, “The penetration of technology into all aspects of being means that “our new character is grounded in human technology symbiosis,” and that “prior to reflection, technology transforms character”” (2007, p.199–200). The analysis of the interviews conducted during Feeler research highlights the connections between lifelogging and QS technologies and well-accepted values in neoliberal economic systems such as productivity, self-improvement, and competition.

As Winne does in his article “Do artifacts have politics?” (1980), we must question the politics of lifelogging and QS technologies. Feeler speculative design is not able to answer this question, but the research has created the conditions for people to think and talk about the effects of self-monitoring and the value that the collected data might have in people’s lives. Over the course of these sessions, the initial excitement of some of the participants for lifelogging and QS turned into a more critical and hesitant attitude towards the potential benefits of these technologies.

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Publication V

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Self-Monitoring Technology for Self-Regulated Learning: An Exploratory Study Using Prototype Evaluation

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Abstract Self-regulation has been considered a valuable skill that students need to engage in deep-level learning and develop their autonomy in learning. Information and Communication Technology (ICT)–enhanced self-monitoring tools, such as personal informatics and quantified-self tools, may support self-regulated learning (SRL) by enabling students to observe their own behaviors and mental states. This paper explores the use of ICT self-monitoring tools for facilitating SRL. To this end, we designed and developed a prototype to self-monitor attention and relaxation data in independent study situations. The prototype was evaluated through an exploratory study in which six graduate students each used the prototype in three study sessions and participated in a focus group interview. Qualitative thematic analysis of the interviews showed that the prototype supported metacognitive, motivational and behavioral dimensions of SRL. From a metacognitive perspective, the participants reported that the prototype supported the acquisition of skills that contribute to self-knowledge through self-monitoring. In addition, the participants felt that the use of new strategies increased their self-confidence, which may have increased their motivation. Regarding the behavioral dimension of SRL, the results of the evaluation showed that tracking learner's actions facilitated self-regulating behavior because the self-monitored data fostered learners' self-reflection, which is a key skill for effective self-regulation. In light of these findings, this study advances knowledge of technology-enhanced learning by discussing how self-monitoring tools can support SRL.

Keywords *self-regulated learning, self-monitoring, personal informatics, quantified-self, prototype evaluation*

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Informed consent Informed consent was obtained from all individual participants included in the study.

Introduction

Self-regulation has long been associated with a deep approach to learning (Rozendaal et al. 2005). Self-regulated learning (SRL) has been defined as "the degree to which students are metacognitively, motivationally, and behaviorally active participants in their own learning processes" (Zimmerman 1989 p.329). This means that self-regulated learners are actively involved with and able to control their thoughts, emotions and motivations in order to adapt and take the necessary actions to reach their goals; in other words, such learners can direct their learning endeavors autonomously. Existing research recognizes the need to help students in higher education acquire self-regulation skills (Goldfinch and Hughes 2007), as university students are expected to have high levels of autonomy in order to cope with often heavy workloads and to develop professional competences.

Although monitoring aspects of the learning process has been recognized as an integral element of self-regulation, very few studies have investigated how self-monitoring technologies, such as personal informatics and the Quantified Self (QS), can contribute to SRL. This research examines the potential of self-monitoring technologies to support SRL and presents conclusions from an exploratory study conducted in a simulated real-world situation in which six graduate students used a prototype, named Feeler, while working on independent academic projects in three different sessions over three weeks.

In the following sections, we review previous research on SRL, as well as diverse Information and Communication Technologies (ICT) for self-monitoring in learning contexts. We then describe the methodological approach of the study and the Feeler prototype. We continue by describing the model of SRL adopted for analyzing if and how the Feeler prototype supports the metacognitive, motivational and behavioral aspects of SRL. Finally, we present an evaluation of the prototype, describe the results of the qualitative analysis of the exploratory study and discuss how the prototype supports different key components of SRL.

Self-regulation and self-monitoring technologies

Several researchers have studied SRL and proposed models to explain how the process works. Despite differences, the main SRL models distinguish three phases: preparation, performance and evaluation (Puustinen and Pulkkinen 2001). Each phase affects the one that follows: The feedback obtained during the evaluation phase influences future preparatory actions, and thus a new self-regulation cycle begins (Panadero 2012).

In addition to preparation, performance and evaluation, learners engage in several other procedures during SRL. According to social cognitive theories, self-regulation of learning is a complex construct in which metacognitive, motivational and behavioral factors interact (Zimmerman 1990). From this perspective, interventions aiming to support self-regulation of learning should address all three dimensions of SRL (Zimmerman 1990). The metacognitive processes that self-regulated learners implement during several phases of the self-regulation cycle consist of planning, goal setting, organization, self-monitoring and self-evaluation (Corno 1989; Zimmerman 1990). Extensive research has shown that metacognition is connected to motivation and that individuals can learn to control their motivation (Kuhl 2000; Wolters 2003).

Strategy selection has also been connected to motivation. For instance, according to Borkowski et al. (2000), the ability to choose appropriate learning strategies is closely associated with the development of key motivational constructs, such as self-efficacy perceptions and attributional beliefs. Effective learners are aware of the relation between their patterns of thought and the strategies they use. Self-regulated learning strategies refer to actions that learners undertake to support learning and improve performance. The effective use of self-regulation strategies increases perceptions of self-control and efficacy, which, in turn, motivates further efforts to self-regulate behavior during learning (Zimmerman 1986).

Self-monitoring has been identified as a critical factor in the development of self-regulation (Pintrich et al. 2000) and plays a key role at different stages of the learning process (Puustinen and Pulkkinen 2001; Panadero 2017). We believe that learners can acquire SRL skills by using self-monitoring tools.

Self-monitoring has been incorporated in personal learning environments aiming to support SRL skills. Projects like iClass (Aviram et al. 2008), the Responsive Open Learning Environment (Nussbaumer et al. 2015) and Just4me (Garcia et al. 2013) are good examples of holistic approaches that aim to support the main stages and dimensions of SRL, with a strong emphasis on personalization of learning. Although these tools incorporate some automatic data collection, the monitoring that these tools provide tends to strongly rely on students' manual input.

There is consensus among scholars that technology can support self-monitoring by allowing ubiquitous and accurate data collection (Li et al. 2010; Rapp and Cena 2014). In recent years, there has been increasing interest in digital technologies that are able to automatically collect data about an individual. Personal informatics, personal analytics and QS are approaches to self-monitoring that focus on individual endeavors for gathering data about one's own behaviors, biological factors, states, impressions or thoughts.

Self-monitoring technologies have been regarded as powerful tools for supporting awareness and self-reflection (Li et al. 2010; Rivera-Pelayo et al. 2012), self-knowledge (Rapp and Tirassa 2017) and, ultimately, self-regulation (Sas et al. 2018). Li et al.'s model (2010) builds on empirical research to identify five stages (preparation, collection, integration, reflection, and action) and highlight main barriers associated to each of the stages. In their study, Rivera-Pelayo et al. (2012) unify theory on reflective learning to define a framework that applies QS approaches to support reflection based on three dimensions: tracking cues, triggering and recalling and revisiting experiences. In both cases, Li et al. (2010) and Rivera-Pelayo et al. (2012) use their models to propose a set of design implications to drive the design of personal informatics and QS tools to support awareness and reflection.

From another perspective, Rapp and Tirassa (2017) analyze the notions of the self that influence main approaches to personal informatics and propose a theory that recognises the subjective, multiple and changing nature of the self. Building on their theoretical approach, Rapp and Tirassa (2017) present a set of design guidelines for the design of self-tracking technologies that recognize the value of self-exploration, self-discovery and self-modification.

Recently, some approaches to self-monitoring technologies have claimed the potential of these tools for supporting self-regulation and encourage users to create meaning (Sas and Chopra 2015; Sas et al. 2018). For instance, Sas et al. (2018) combine constructive design research and critical design to create prototypes that support the self-regulation of inner states like attention and emotional arousal. Despite the increasing number of studies using self-monitoring tools to support self-regulation, there are not conclusive results and there is still a need of research that looks at the possible connections between self-regulated learning and measurable physiological data.

Personal informatics and QS tools have also been used to collect data about learners' physical/mental states and behaviors in order to support learning and personal development in different areas, such as sports (Ghasemazadeh et al. 2009), music (Van der Linden et al. 2011) and communication (Schneider et al. 2016).

In learning analytics, the growing possibilities to collect data about learning situations offer opportunities to predict performance, personalize learning, develop social learning environments, detect undesirable behaviors and identify emotions (Verbert et al. 2012). Recently, researchers have included physiological data captured through QS tools as part of learning analytics research. For instance, some studies have used eye tracking (Kunze et al. 2013), electroencephalography (EEG) (Szafir and Mutlu 2013) and facial expressions (Littlewort et al. 2011) in learning analytics. Despite efforts to use data from personal informatics and QS in learning analytics, there is a lack of studies that focus on how learners can use self-monitored information effectively (Schneider et al. 2015). As Schneider et al. (2015) claim, such studies are necessary in order to understand how sensor-based technologies can contribute to learning. In this research, we tried to address this knowledge gap by investigating how monitoring technologies can support SRL.

Methodological approach

This study was carried out following research-based design (Authors 2008), which is a methodological approach to the design of learning tools. Research-based design can be regarded as part of constructive design research because the construction of artifacts is inherent to the research activity (Koskinen et al. 2011). From this perspective, the design artifacts are important research outcomes, as they embody knowledge (Fallman 2003; Authors 2008).

Research-based design is theory-based and design-oriented. This means that theory and empirical research inform the design of new tools that introduce positive change in current learning and teaching practices. Research-based design aims to bring design thinking to the design of tools for learning and therefore differs from educational research approaches such as design-based research in which the focus is on designing interventions to investigate learning in real-world situations (Brown 1992).

Prototypes can be seen as ways to investigate real-world situations by allowing people experience hypothetical solutions. According to Frens (2006) and Authors (2008) prototypes can work as potential solutions to challenges. By studying a prototype in a real or simulated-use situation, it is possible to infer valid and relevant conclusions. Simultaneously, prototypes can be used to invite people to reflect and develop new understandings as it happens in critical design (Bardzell and Bardzell 2013).

In Feeler research-based design, we have developed several prototypes, whose designs have been iterated based on the feedback obtained from test studies (see Authors [2017] for a detailed description of the design process and the tests). In the following section, we present the Feeler prototype (v.2.0) and explain how we expect the prototype to support the diverse aspects of SRL.

Feeler prototype

Feeler is a prototype that consists of a software (current version running on macOS) and a set of computing objects that guide learners' actions during an independent study session. When using the Feeler set, the system collects data about the user's mental states. The data is obtained through a self-monitoring device that captures EEG data and transforms them into attention and relaxation levels. Furthermore, the software prompts the user to report their own impressions about their mental states in different phases of using the Feeler.

Feeler aims to foster learners' self-awareness and reflection about the role of attention and relaxation management skills in independent study situations. It is possible to distinguish three different stages: before, during and after the independent study session (see table 1). Before starting a session, learners are expected to set up the equipment and log in the software. Then, Feeler divides learners' performance during independent study into three phases: (1) meditation, (2) study and (3) play (see Fig. 1), each of which is associated to a computing object (a box). Each box introduces learners to strategies that research has shown to be beneficial for learning and self-regulation, such as meditation, time-management and self-rewards. Learners' EEG data are collected throughout independent study performance. Finally, after the independent study session, learners can see their EEG activity. The visualization of the EEG data is expected to help learners become aware of and reflect on how different practices and strategies affect their attention and relaxation.

Fig. 1 Feeler boxes dividing a study situation in three different phases.

Once a new session has been created, learners are invited to perform a basic meditation exercise consisting of calm breathing. In the meditation box, learners are guided to breathe for five minutes in a calm rhythm through a pulsating light (see Fig. 2). When the time set for the activity ends, a gentle vibration indicates that the time period is over. To move on to the next phase (the study phase), learners must connect the first and second boxes by placing the boxes next to each other. The magnets placed at the sides of the boxes help learners connect the boxes in the right order. Once the boxes have been connected, the following phase activates.

Fig. 2 Learner performing calm breathing by following the light rhythm of the meditation box.

During the second phase, learners are invited to work on their study tasks using a computer. The software, working in the background, takes a screenshot of the learners' activity based on the attention and relaxation values captured by the EEG device. The time set for this phase is 20 minutes. The study box provides visual information regarding time progression through a grid of LEDs that illuminates gradually as the minutes pass.

Once the study phase ends and learners connect the third box, a game activates in the third box. The game is a memory game inspired by the 1980s electronic Simon Says game. When playing the game, learners must repeat a sequence by pressing three buttons in the same order as the buttons illuminate and make a sound. Each time learners repeat a level successfully, an additional step is added to the sequence, thus making the game a bit more difficult. When learners make a mistake, all the buttons light up, and the game is over.

When the learners complete the game, the software running in the background on the computer asks learners to report their level of satisfaction during the different phases based on three states (satisfied, neutral, dissatisfied). They are also asked to estimate their level of attention and relaxation (on a scale from 0 to 100%) while they were meditating, studying and playing. This way, learners start becoming aware of how attentive and relaxed they felt during the different phases and develop their own view that later on, they can compare with the data gathered by the system (see Fig. 3).

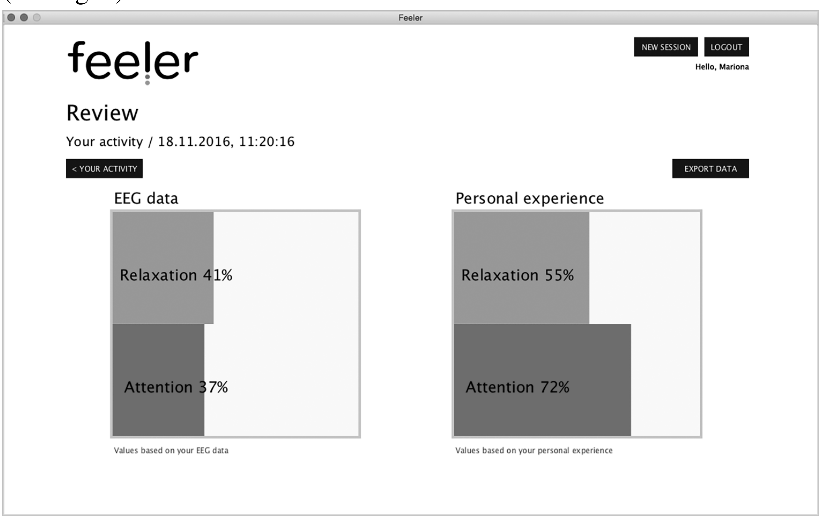

Fig. 3 Visualization of the attention and relaxation data gathered by the EEG device and the learners' estimation based on their personal experience.

Once learners have entered the requested information to the software about their personal experience, they can access the visualization of their data for the previous session. The software includes a visual dashboard where the data collected throughout the sessions are presented in several levels. For instance, the first-level data visualizations enable learners to examine their attention and relaxation values based on the EEG readings and on their personal impressions (see Fig. 4).

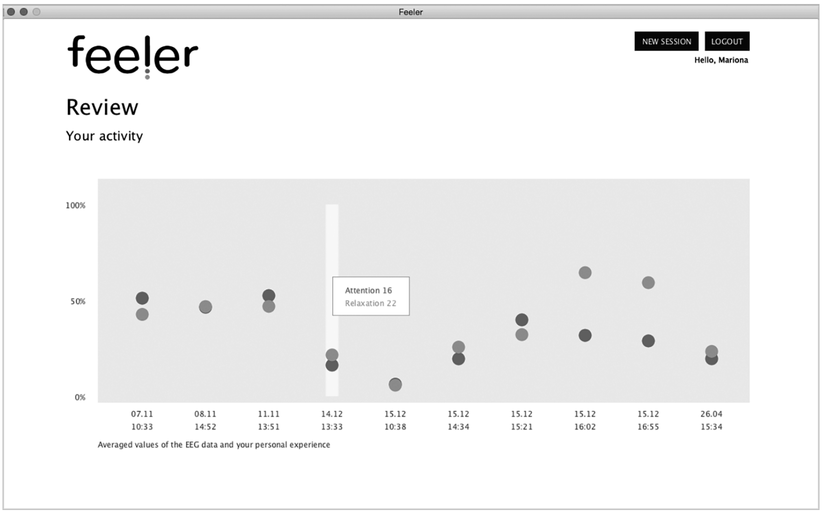

Fig. 4 Visualization of the attention and relaxation data based on the EEG data and learners' personal impressions throughout several sessions.

Because Feeler aims to support self-knowledge through personal inquiry, the tool does not provide recommendations to improve performance. This design decision is based on the hypothesis that without automatic recommendations learners would make connections and create hypothesis to test in further sessions when reviewing their data. Simultaneously, it is hypothesized that learners would engage in self-reflection and assess how well the strategies embedded in the boxes (meditating before studying, managing study time in short study sessions and rewarding and relaxing through play) worked for them.

Table 1 List of learners' actions when using Feeler

Stages	**Learners' actions**
Before the independent study session	Learners wear the EEG device and log in the Feeler software to start a new session.
During the independent study session	
• Meditation	It consists in a five minutes calm breathing exercise using the meditation box.
• Study	Learners work on their study tasks. The Feeler system takes a screenshot of the learners' digital activity based on their attention and relaxation levels. The study box gives visual feedback about the pass of time.
• Play	Once the study time has passed, a memory game activates in the play box.
After the independent study session	
• Self-assessment	Learners fill a personal experience questionnaire where they indicate their level of satisfaction and

	estimate their attention and relaxation levels during the session.
• Review	Data about learners' attention and relaxation levels, as well as their personal experience are displayed in a multi-layered visual dashboard.

The Feeler prototype is an effort to envision scenarios of use and implications of emerging technologies based on the monitoring of physiological data, such as EEG. Rapid technological development leads us to expect that much more powerful sensors will be available in the near future; these sensors will most likely improve automatic data collection and accuracy in data analysis. Therefore, this prototype should be regarded as part of a research-based design that focuses on the implications self-monitoring technologies would have for supporting learning skills, specifically SRL.

Prototype evaluation

Participants

Six university graduate students voluntarily participated in the research and conducted independent study activities with the Feeler prototype. The participants were between 25 and 33 years old and were from Finland, India, Colombia and Poland. All the participants were fluent in English.

Before participating in the sessions, the students answered an online questionnaire in which they provided information about their background and study habits. None stated they had extreme difficulty focusing on their study work, and they reported that they were highly motivated to work on their independent study projects. Most of the participants were familiar with self-monitoring and QS tools. Four out of six of the students had self-monitored their behaviors related to sleep, exercise and nutrition habits in the past.

Study sessions

The independent study sessions that were part of the exploratory study took place on university premises in a space called Learning Hub, which is a room designed for quiet study work. All the participants worked on the literature review of their independent study projects, which made the learning situation natural and meaningful for the participating students.

Each participant used Feeler once a week over three consecutive weeks. During each session, the participants' tool use lasted for 30 minutes. One week after the last session, all participants attended a focus group interview to share their experiences regarding the exercise in general and the prototype.

Data collection and analysis

The research data were collected from the participants' individual, semi-structured interviews conducted after each session. In the interviews, the participants were asked to express their thoughts aloud while they reviewed their data. Then, the interview focused on 1) how the participants felt throughout the session and how satisfied they were with their work, 2) what they learned from the sessions of using Feeler, and 3) what aspects they would like to further explore in subsequent sessions. During the conversations, matters related to self-knowledge, self-control, discovery and inquiry, as well as participants' trust of the data were discussed. Each interview lasted between 30 and 40 minutes. In addition to individual reflections and interviews, we organized a focus group interview with all the participants. During this interview, the participants discussed and shared the feelings they experienced during the session, the impact the Feeler prototype had on their study practices and the relationship between relaxation and attention and productivity and procrastination.

The analysis of the audio recordings (11.5 hours in total) followed a qualitative research approach. Drawing on Braun and Clarke (2006), we conducted a thematic analysis, as this method identifies, analyzes and reports patterns in the research data. In this research, we aimed to identify the presence of key themes connected to the self-regulation of learning in participants' speeches. For this, we built on a previously tested SRL model to define a coding scheme for analyzing the data collected during the research. For the analysis, we used Atlas.ti[1] (v. 8.1.3) in order to conduct a systematic, qualitative analysis based on the pre-defined, theory-based coding scheme.

Coding scheme

The coding scheme developed to analyze the audio recordings of the sessions drew on Zimmerman's (Zimmerman 2000; Zimmerman and Moylan 2009) social-cognitive, cyclical-phase model of SRL. The strength of this SRL model lies in its comprehensiveness, as it connects self-regulation processes to motivational beliefs and learning outcomes.

Zimmerman's model identifies three self-regulatory phases that influence each other: (1) forethought, (2) performance and (3) self-reflection. Forethought refers to the processes and motivational factors that precede learning efforts and include task analysis and self-motivation beliefs. During task analysis, learners define their goals and the strategies they plan to use to achieve those goals. Self-motivation beliefs refer to self-efficacy perceptions, outcome expectations and interest in the task.

Processes that take place during learning are considered part of the performance phase. These processes support self-control and self-observation of one's actions. To carry out a task, learners deploy a diverse range of strategies, such as self-

[1] http://atlasti.com/

instruction, imagery, time management, environmental structuring, help-seeking, interest incentives and self-consequences. Learners must adapt their use of these strategies according to the outcomes of the strategies. For this, learners must engage in self-observation, which can consist of metacognitive monitoring and self-recording. Learners who engage in self-monitoring mentally track performance processes and their outcomes to assess how well the processes worked to reach their goals. When self-recording, learners use external tools to track and keep formal records of their learning processes.

Self-reflection takes place after the learning actions have occurred. Self-judgment and self-reaction are self-reflection behaviors that can contribute to the optimization of future learning performance by helping learners identify and react to the causes of their performance outcomes. Self-reaction behaviors include adaptive and defensive decisions. Adaptive decisions are students' positive reactions to continue using a strategy or modify it in future learning efforts, while defensive decisions consist of students' resistance or hesitation to engage in future cycles of learning. The cyclical nature of the model is due to the strong influence of self-reflection over forethought processes that precede future efforts to learn.

For the development of the coding scheme, Zimmerman's cyclical phase model was revised and adapted to consider aspects related to the prototype design and the exploratory study (see Table 2). Two additional categories (C4/Notable and C5/Feeler) were added to the coding scheme to include relevant information specifically related to use of the prototype.

Table 2 Coding Scheme Used for the Thematic Analysis of the Research Data

C1/Forethought phase
C1a: Task analysis Task analysis includes expressions in which the participants set goals, plan their studies, as well as how and when to do different tasks. *C1b: Self-motivation beliefs* Self-motivation beliefs are statements in which participants present their thoughts about their abilities, interests and motivation to perform a study task. Self-motivation beliefs can include expressions about higher goals and outcomes, such as learning a new skill or knowledge or getting study credits, a degree or some position.
C2/Performance phase
C2a: Self-control Self-control includes expressions in which participants voice their efforts to control certain aspects of their behavior and mental states to improve their performance. Self-control strategies can include time management, self-instruction, environmental structuring, help seeking, interest incentives and self-

consequences. Task-specific self-control strategies refer to participants' systematic processes for successfully completing a task. *C2b: Self-observation* Self-observation includes expressions in which participants acknowledge self-monitoring their actions and assessing their effectiveness for learning. As a result of self-observation, participants develop awareness of their behavior and mental states during a study session.
C3/Self-reflection phase
C3a: Self-judgment Self-judgment includes statements in which participants self-evaluate their performance against a standard. When self-judging their actions, participants make comparisons and create hypotheses in order to identify the causes of their behavior. *C3b: Self-reaction* Self-reaction includes statements in which participants express different levels of satisfaction with their performance. Self-reaction includes expressions regarding how willing participants are to question and modify their study habits.
C4/Notable
Notable expressions are those in which participants articulate their assumptions and beliefs about learning, self-monitoring and data tracking. This type of expressions tends to be general and is not directly linked to use of the Feeler prototype.
C5/Feeler
Feeler expressions consist of direct references to Feeler design elements, such as user experience, usability and specific functionalities.

This research followed Campbell's et al. (2013) recommendations to code semi-structured interview data. As Campbell et al. (2013) suggest, two independent coders deployed the coding scheme with some of the research data (40%) in several rounds of analysis. After each analysis, the coders reviewed the categories assigned to all units of analysis and discussed coding disagreements together. When the coders disagreed on the fragments, they unanimously decided to re-code the fragments. When the coders could not agree, the principal investigator (PI) made a decision on the coding based on her understanding of the research subject matter and the research context. The coding process was repeated twice, until the coding errors reduced to an acceptable point (intercoder agreement=.97).

In order to ensure the external validity of the coding scheme, two independent SRL experts reviewed the description of the categories. The descriptions included examples from the research data that the external reviewers validated (intercoder agreement=.97). The external reviewers' comments were used to refine the coding scheme and to inform another revision round. After this, the PI coded the rest of the research material with the final version of the coding scheme.

Stages of analysis

The codification of the audio recordings of the sessions involved two stages of analysis. During the first stage, behaviors identified in participants' speeches were quantified. The total number of coded behaviors was 1004 at the end of the codification stage. This quantification informed a second stage of analysis, which consisted of thematic analysis of the predominant behaviors.

Self-reflection behaviors accounted for 46% (n=466) of the total number of participants' comments (n=1004), while behaviors identified as part of forethought ("task analysis" and "self-motivation beliefs") corresponded to 11% (n=110), and performance behaviors ("self-control" and "self-observation") represented 20% (n=202).

The second stage of analysis investigated the significant themes present in "self-reflection" as in proportion, "self-judgment" (28%, n=280) and "self-reaction" (18%, n=186) were the most common behaviors.

Results

The results from the qualitative analysis focus on the "self-reflection phase". During the analysis, this category was divided into "self-judgment" and "self-reaction" (see Table 2).

Self-judgment

Self-judgment behaviors are subdivided into self-evaluation and causal attributions. The following subsections present the main themes related to the self-evaluation and causal attributions behaviors identified during the analysis.

Self-evaluation

Self-evaluation refers to comparisons between one's own performance and a standard. In the sessions, participants' self-evaluation behaviors focused on comparing the participants' performance with the EEG data, with their past performance and with other participants' performance.

When reviewing the data collected by the EEG device during a single session, the participants tried to identify the moments when they were the most and least attentive or relaxed. Once the participants identified the distinctive moments of a session, they reconstructed what they had been doing and compared this information to their own impressions. At the beginning of the study, the participants were solely focused on the EEG values of a single session. Visually scanning the session data helped the participants spot distinctive moments around which they built explanations. As the participants took part in more test sessions, Feeler collected more data about their activity, and they were able to compare their attention and relaxation among the sessions: "Definitely, the first session was probably my worst because I was all over the place that day (...). I feel that today session I was the most focused on the task and I was able to do it properly" (participant 2, session 3).

Half of the participants expressed interested in comparing their data with their peers to define a standard through social comparisons against which they could assess their performance: "I was actually going to ask you if it's like do people have also, are people also more attentive than relaxed?" (participant 4, session 2).

Causal attributions

Causal attributions refer to participants' efforts to identify the causes of their performance. When trying to define the causes of a particular mental state, participants needed to reconstruct their activity. For this, they referred to the screen captures taken by Feeler as evidence that supported their reasoning: "For me, because it took the screenshots it was clear that some of the attention peaks were that I found something interesting, so when the interest is higher the frontal globe reacts and then you get the peaks" (participant 6, focus group interview).

Participants did not always manage to explain why their attention and relaxation levels behaved in a particular way. In some cases, it was hard to understand the relation between attention and relaxation and how one affected the other. A participant stated, "I found it very contradictory because I thought, maybe if I pay more attention I would be more stressed, but in some instances, it was just the opposite. So, I'm not even sure how these two terms are even related to each other. It may be mutually dependent or not, so that's something that one can find out" (participant 1, focus group interview).

The contradiction between participants' experiences and the values provided by the system caused confusion. Such contradictions encouraged participants to reflect on how attention and relaxation were defined and calculated through EEG data. "But sometimes [it] is quite difficult even to separate both of them [attention and relaxation] when doing a skilled activity (...), so just defining it this is relaxation state, this is attention state entirely is quite a bit tricky" (participant 3, focus group interview).

While reflecting on attention and relaxation, the participants questioned their assumptions and started developing new understandings based on their personal experiences. By problematizing tacit definitions of attention and relaxation, participants developed a more critical attitude toward how these constructs affect learning.

Self-reaction

After self-judging their performance, the participants reacted in different ways. Participants' eagerness to use Feeler again and their intention to try new strategies were considered part of their self-reactions (n=188), which included adaptive (n=110) or resistant (n=53) behaviors. The analysis dedicated special attention to those cases in which the participants were inspired by Feeler to modify their study habits. These self-reaction behaviors were coded as "change" (n=14).

Adaptive behaviors

Participants self-reacted to their judgments and showed intention to adapt their behavior. For five of the six participants, this type of reaction was the most common. The revision of adaptive behaviors brought to light a set of key themes: 1) willingness to try new practices when engaging in independent study work, 2) reconsideration of their current study habits, 3) interest in finding out how certain behaviors affect their learning, 4) acknowledgment of a positive impact of Feeler on learning and 5) a favorable disposition toward using Feeler again.

Throughout the sessions, five participants recognized their willingness to try new practices when engaging in independent study work. For instance, participants expressed their willingness to meditate before a study session, use different task strategies and play games as a self-reward after working: "That was a very interesting addition, so when I feel myself distracted nowadays I do try sort of stop, while I don't have the boxes I do try to do that kind of focusing or relaxation" (participant 2, focus group interview).

In some cases, trying new practices made participants reconsider some of their current study habits, such as task switching or impulsive behaviors: "So, when I did it in the test it also showed me that (...) I can do it also maybe sometimes during the day when I'm too driven by so many things, I can just take a quiet moment and then find better what is kind of important" (participant 4, focus group interview).

After observing how meditation, study and play affected relaxation and attention, participants were curious about the impact of certain actions on their mental states and, therefore, their ability to learn. Throughout the sessions, the participants were interested in how procrastination, playing games, multitasking, meditation or the use of different study materials, such as paper books, affected their attention and relaxation: "If I, on the next time, I can get as relaxed, then it would be nice to see if there are differences in the study or if it's similar in the study, because that would really support the fact that relaxing before is good to do" (participant 6, session 2).

In general, the participants acknowledged that the prototype had a positive impact on learning. Some of the aspects participants mentioned were how Feeler helped them to meditate and increase their relaxation. In this regard, all participants considered meditation beneficial for their study activity.

Five of the six participants had a favorable disposition toward using Feeler again. Concretely, participants expressed their wish to use the prototype in a more familiar environment and in ways that related to their study habits. In some cases, participants were interested in collecting more data about themselves in order to develop better insights. In other cases, the participants recognized that they may use Feeler occasionally to test a hypothesis and help them gain focus. These participants also wanted to explore the long-term effects of using Feeler for their study activity.

Resistant behaviors

Self-reaction behaviors were connected to participants' resistance to modifying their strategies and using Feeler again. Participants' reluctance to adopt Feeler as part of their learning environments was based on 1) doubts regarding the EEG data, 2) resistance to modify certain behaviors, 3) not considering the use of Feeler as necessary, 4) difficulty analyzing the data and 5) dislike of certain aspects of the prototype.

On many occasions, participants' self-reports about their attention and relaxation levels during the session did not match the data calculated by the EEG device. When facing this discrepancy, some participants distrusted the EEG data because they could not understand the reasons for such a mismatch.

Despite recognizing the positive effects of Feeler, some participants did not necessarily modify their habits. For instance, although meditation was considered beneficial, participants did not practice it outside the test environment. The participants reported that they had not modified their behavior because of a lack of time or because they simply got carried away by their routine and did not consider doing things differently.

When the participants were asked about their intention to continue using Feeler in the future, they gave several reasons for not considering using the prototype. From their view, the prototype was not relevant to their work, and they did not feel the need for it. In addition, during the sessions the participants highlighted that it was difficult to analyze the data. Two participants expressed their wish to get some support or guidance from the system so that they could better understand how the attention and relaxation values related to their ability to learn: "So, this is exciting, the fact that this data exists, but after one or two times, if I'm not able to make actual changes based on this data (…) I won't continue using it" (participant 2, session 1).

The participants also expressed their dislike of certain aspects of the prototype design. Some participants were not comfortable with the pre-defined 20-minute study session, with adjusting their breathing rhythm to a light pattern during meditation or with playing a game at the end of the session: "I didn't do the game ever, because the game actually stressed me out" (participant 4, focus group interview).

Changed behaviors

The reported changes consisted of practicing meditation, gaining self-awareness and increasing reflection about participants' own practices. Four of the six participants reported some sort of change in their study practice after taking part in the exploratory study: “I tested the meditation, and I feel that it helps when I’m writing my thesis or when I study for an exam” (participant 6, session 3) and “I thought a lot more about the meditation aspect of it, so in my five minutes break between sessions I don't tend to go to social media so much (...) so that's one small shift that has happened” (participant 2, session 3).

Although they did not have access to the prototype, participants felt inspired by the different strategies they experimented with during the test sessions and decided to adapt them to their own situation: “For me somehow informed the way I behave and during those weeks I also, when I was about to read something, I took this sort of pause and started with this meditation thing before focus” (participant 4, focus group interview).

Discussion

The Feeler prototype enabled self-monitoring during independent study performance in order to trigger reflection on the self-monitored data. Zimmerman’s social-cognitive, cyclical model was used to analyze to what extent the Feeler prototype supports metacognitive, motivational and behavioral dimensions of SRL. In this section, we discuss to what extent the design of the Feeler prototype supports these dimensions.

Facilitation of metacognitive processes in SRL

The results suggested that Feeler supports metacognitive skills based on self-awareness, self-monitoring and self-assessment, which are necessary for self-knowledge. In particular, self-awareness has been highlighted as an important skill for self-regulation, as people need to pay attention to what they are doing, to the surrounding conditions and to the effects of their activity in order to regulate their actions (Bandura 1991). Feeler may have helped participants gain self-awareness by encouraging them to self-monitor their attention and relaxation levels in specific situations. For instance, the participants arrived at the sessions with various strong emotions: Some were anxious because of deadlines, and others were tired or were simply in a bad mood on that day. Although the participants’ emotions had an impact on their ability to focus, the participants did not pay special attention to how they were feeling. After experiencing practices such as meditation, the participants not only learned a new strategy for controlling their emotions before working on their own, but also started to appreciate and become aware of the role that affective states play when performing cognitive tasks.

Self-monitoring is part of the metacognitive processes that people deploy at different moments of self-regulation (Borkowski et al. 2000; Pintrich 2000; Winne and Hadwin 1998; Zimmerman 2000). Zimmerman and Paulsen (1995) identified four levels for teaching self-monitoring skills: baseline, structured, independent and self-regulated. Drawing on Zimmerman and Paulsen’s classification, Feeler can be taken as an example of structured self-monitoring, as the tool offers learners a protocol for what to measure and how and provides immediate feedback. Therefore, it can be expected that once learners master the skills for self-monitoring introduced by Feeler, they will be able to engage in independent and self-regulated levels of self-monitoring.

Although Feeler gives the user feedback, it does not provide information about the learners' activity in relation to a group of peers or the average population. The rationale behind this design decision is to support learners' ability to self-assess based on their own standards, which is justified by research evidence indicating that self-evaluations based on self-comparisons are more advanced than self-evaluations based on social comparisons (Zimmerman 2013). The exploratory study showed that self-assessment based on self-standards is challenging because learners are accustomed to comparing themselves to others to evaluate their progress. However, learners' ability to self-assess is necessary for them to become autonomous learners. Self-assessment involves high-order thinking skills. For instance, when the participants reviewed their data in order to self-assess their performance, they made a cognitive effort to cross-check the data obtained through different sources. They made connections, reflected on the implications that certain attention and relaxation values had for their study activity and created hypotheses to test in further study sessions. These are demanding tasks that require practice in order to become part of learning activities. For this reason, we argue that despite learners' initial resistance, self-assessment should be a key design feature of learning technologies that support SRL.

Throughout the sessions, participants' self-assessment of their mental states changed significantly. The first time the participants used the prototype, they self-assessed their attention and relaxation with much higher values than those provided by the EEG device. In other words, the participants tended to overemphasize their ability to perform at certain levels. In later sessions, participants' estimations started to approximate the EEG results. However, this finding should be interpreted with caution due to the difficulty of obtaining reliable data on EEG readings outside lab settings. However, despite these limitations, participants reported that the calibration exercise embedded in Feeler encouraged them to self-monitor in order to increase awareness of their mental states when they performed academic tasks.

By supporting self-awareness, self-monitoring and self-assessments, Feeler may have contributed to the development of the participants' self-knowledge. As observed during the focus group, the participants engaged in a reflection process that helped them know themselves better after they used Feeler. Participants adopted a critical and active attitude when making sense of their experiences and discussing different aspects related to learning and self-regulation.

Impact on motivational aspects related to SRL

The elevated proportion of adaptive decisions can be taken as an indicator of participants' motivation to use the strategies embedded in the prototype design. Feeler may have positively affected aspects related to self-motivation, such as self-efficacy perceptions, by enabling participants to experience different strategies and determining how well they worked for them. For instance, some participants reported having trouble with procrastination behaviors. For such participants, practicing mediation before starting an independent session helped them focus and improve their performance during that session. In addition to the immediate effects, learning a new strategy may have contributed to changing participants' self-beliefs about their ability to control their procrastination.

These findings relate to Schunk and Zimmerman's (2003) observations regarding positive effects derived from effective strategy use. After using Feeler, the participants realized that they could control their attention and relaxation and were willing to adopt new practices in order to regulate their mental states. By using strategies effectively, participants felt they could control their attention and establish a state of involvement when studying (Reed et al. 2002).

The exploratory study results confirmed the existence of a self-oriented feedback loop in SRL (Zimmerman 1989). The feedback loop explains how self-reactions affect forethought processes, such as task analysis and motivational beliefs, in a cyclical manner (Zimmerman 2013). For instance, when self-reacting to one's own judgments, the participants made hypotheses about the aspects learners wanted to test in future sessions. These hypotheses were coded as adaptive decisions, but they could have been also considered as goals for the next time they would use the prototype. Thus, drawing on Schunk and Zimmerman's (2003) observations on positive effects derived from effective strategy use, we may consider participants' eagerness to try new practices and set new goals for subsequent sessions as an indicator of motivation.

Aids to the self-regulation of learning behaviors

Scholars have recognized the importance of monitoring in SRL (see Puustinen and Pulkkinen 2001; Panadero 2017). When carrying out a task, learners observe aspects of their performance informally or by automatic means. According to Zimmerman and Kitsantas (1999), recording can improve self-observation, as recording does not require students to depend on their memory and allows for easily tracking changes in students' performance.

The findings from the exploratory study suggest that the automatic recording of participants' digital activity may have contributed to the self-regulation of their behavior. The participants frequently referred to the screenshots captured by Feeler in order to reconstruct their experience. To a large extent, the screen captures helped participants develop causal explanations of their performance, which is necessary for informing self-reactions.

In Feeler, the screen captures, which visually described the participants' attention and relaxation levels, can be considered attributional feedback since they allowed the participants to identify the consequences of certain behaviors. According to Schunk and Zimmerman (2003), attributional feedback facilitates self-regulation. The high proportion of adaptive decisions among participants' comments, as well as the behavior changes reported outside the exploratory study, suggest that Feeler provided feedback that influenced participants' self-regulative behavior.

In addition to the screen captures, other aspects of Feeler were helpful for the participants. Some elements of Feeler, such as the boxes, are specifically designed for use during the performance phase in order to support self-control of behavior. As Zimmerman (2000) highlighted, self-control processes help learners keep their attention on the task and make the best of their efforts. By asking students to start their activity with a short meditation, limit the duration of their study time to 20 minutes and play a memory game, the boxes introduced participants to several self-control strategies for managing their attention and relaxation.

During the interviews, all the participants acknowledged the benefits of meditating before starting a work session. As none had previously meditated before studying, we inferred that Feeler helped the participants learn a new strategy for controlling their attention during their study time. Furthermore, half of the participants reported that they were inspired by the exploratory study and started to meditate before conducting their independent study work. This suggests that the prototype affected some of the participants' behavior and may have contributed to advancing their self-regulation skills.

Conclusions and implications for the design of self-monitoring tools for SRL

The findings from the exploratory study suggested that the design of the Feeler prototype supports three key dimensions of SRL: metacognitive, motivational and behavioral. The article elaborated on the processes and strategies embedded in the prototype design that are associated with each dimension. Although the results related to each dimension were presented separately, the metacognitive, motivational and behavioral dimensions were interrelated and influenced one another.

First, from a metacognitive perspective, the study showed that Feeler supports self-awareness, self-monitoring and self-assessment. During the sessions, participants started to pay attention to aspects that affected their independent study work, such as their emotions and the strategies they chose to perform a task. The collection and visualization of data may have helped participants develop deeper understandings of how certain states and strategies affected their learning. All these aspects contribute to self-knowledge, which, in turn, is required for effective self-regulation. Based on these findings, we recommend that tools for SRL dedicate special attention to aspects related to fostering self-awareness, self-monitoring and self-assessment.

Second, the analysis of the exploratory study illustrated a high proportion of adaptive decisions and participants changing their learning strategies after being inspired by their experiences using the prototype. We believe that Feeler may have increased the participants' sense of control over their mental states, which may have also positively affected the participants' self-efficacy perceptions. Thus, tools for SRL based on self-monitoring technologies should offer learners opportunities to try different strategies, and, in this way, find out by themselves what works best for self-regulating their learning activity. This may be challenging because learners tend to adhere to their habits and do not feel they have the time to experiment. However, considering the benefits reported by the participants of this exploratory study, we believe that in formal education, tools should be oriented toward opening new perspectives rather than focusing on efficiency and productivity.

Third, the exploratory study shed light on how certain design features of the prototype based on automatic recording, such as the screen captures of participants' digital activity, supported self-reflection and may have contributed to behavior regulation. In Feeler, the possibility to review past performance from different perspectives was a powerful strategy to support reflection. We argue that this approach may benefit other tools that aim to support reflection through self-monitoring technologies. An important challenge to take into consideration in that regard concerns learners' data literacy skills. In particular, learners' lack of analysis skills for interpreting raw data may create feelings of distrust or naïve credibility, which hinder critical reflection.

This work contributes to existing knowledge regarding the design of learning technologies by providing insights into how self-monitoring technologies can support SRL. Based on the findings discussed in this study, we suggest that areas to further explore in the development of learning tools based on self-monitoring technologies relate to self-awareness, reflection, discovery and experimentation.

Despite its useful findings, the scope of this study was limited in terms of the number of participants, test environment and number of sessions. Further research on the potential of self-monitoring technologies for supporting self-regulation of learning skills requires increasing the number and diversity of participants who can test the prototype in the wild for longer periods of time. Social aspects related to collaborative sense-making and knowledge building are another important area of self-monitoring that requires further exploration. Furthermore, to develop a full picture of the aspects involved in the design of self-monitoring tools, additional studies that analyze the link between physiological data and psychological constructs are also needed.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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