Reflection and Self-Regulation Using Monitoring Tools in Learning

Critical Design Exploration on Self-Monitoring During Independent Study

Eva Durall Gazulla
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Eva Durall Gazulla

Aalto University
School of Arts, Design and Architecture
Department of Media
Learning Environments research group
Supervising professor
Teemu Leinonen, Aalto University, Finland

Thesis advisors
Teemu Leinonen, Aalto University, Finland
Begoña Gros Salvat, Universitat de Barcelona, Spain

Preliminary examiners
Corina Sas, Lancaster University, United Kingdom
Anders Mørch, University of Oslo, Norway

Opponent
Anders Mørch, University of Oslo, Norway
**Author**
Eva Durall Gazzula

**Name of the doctoral dissertation**
Reflection and Self-Regulation Using Monitoring Tools in Learning

**Publisher** School of Arts, Design and Architecture

**Unit** Department of Media

**Series** Aalto University publication series DOCTORAL DISSERTATIONS 203/2018

**Field of research** Technology Enhanced Learning

**Date of the defence** 2 November 2018

**Language** English

- ✔ Monograph
- ☐ Article dissertation
- ☐ Essay dissertation

**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

**ISBN (printed)** 978-952-60-8244-8  

**ISSN (printed)** 1799-4934  
**ISSN (pdf)** 1799-4942

**Location of publisher** Helsinki  
**Location of printing** Helsinki  
**Year** 2018

**Pages** 188  
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.

I want to thank my pre-examiners Corina Sas and Anders Mørch for their comments and suggestions to improve the dissertation. I am grateful for their time and valuable feedback. I am also honored that Anders Mørch has accepted to act as opponent in my defense.

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 Joaquin 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!

Qualitative data analysis can be a painful process, especially when done alone. I cannot express enough my gratitude to my colleagues, co-writers and friends Tania Rodríguez-Kaarto and Marjo Virnes. Thanks for keeping the calm I did not have and for being able to go through the data as many times as it was needed. I am also grateful to Heidi Uppa with whom academic writing became something I could actually enjoy. I want to express my gratitude to Marjaana Vermaans and Elena Barberà for their feedback and assessment of the research instruments and to Tobias Ley, for his time and comments on the last part of the research.

I have had the privilege to benefit from the knowledge and experience of many people to whom I have asked for help at different moments of the research. Thanks to Veera Mustonen, Brenda Castro, Sebastian Greger, Niklas Ravaja, Michiel Sovijärvi-Spape, Ville Harjunen, Tomi Kauppinen, Oswald Barral, Iolanda García, Irene Trilla, Aleix Canals, Antti Raike, Timo Tapola, Koray Tahiroglú, Héctor Pijeira and many other people I have met in conferences and
diverse type of events. I am also indebted to all those with whom I had good conversations: Miska Knapek, Vladimir Tomberg, Milos Kravcik, Laura Uusitalo, Jonna Rantanen, Sanna Reponen, Leyla Nasib and a long list of smart people I had the honor to meet throughout these years. My especial thanks to members of the former research group, Arki: Kari-Hans Kommonen, Andrea Botero, Mariana Salgado, Sanna Marttila, Joanna Saad-Sulonen and Mia Muurimäki. I want to acknowledge their influence on my work and thank them for their openness and willingness to help.

Many people at Medialab and at the department of media have contributed to make this research happen. In this regard, I want to express my gratitude to Philip Dean and Lily Díaz. I am also grateful to Anna Arsniva and Ilpo Kari for helping with everyday practical issues. Pekka Salonen also deserves a big thanks for solving technical problems (and for watering my plants and offering some healthy distractions). At the faculty level, Maikki Vierumäki, Johanna Glader, Mari Tammisaari and Robert Rahkonen have also contributed to keep things going. Thanks also to Antti Ruotoistenmäki for his timely support when preparing research proposals that allowed me continue this research. My deepest gratitude to Tiina Kotti, Annu Ahonen and Saara Mäntylä for helping me during the last part of the process.

At some moments (quite long periods, actually) the research has absorbed most of my time and energy. My family and friends have suffered the side-effects of academic life and have had to bear with an absent and tired me. Thanks for understanding and for showing your affect in many diverse ways. Gracias, gracias, thanks! A big thanks to my parents and grandparents, for being proud of me despite sometimes it was hard to understand (and for me to explain) what was keeping me so busy. Thanks also to my sister for dragging us to a möki next to a lake. Going to a sauna has never been the same after that! I am also grateful to my niece. Her passion and energy to learn and experience new things every day is inspiring and contagious.

Some things go beyond what can be expressed with words. I am not able to thank Juan enough for his unconditional support and love. He encouraged me to undertake this challenge and he has been always ready to help me in many different ways: from actively contributing to the research work, to taking care of me and reminding me that there are many other things to learn in life. Gracias, nada de todo esto hubiera sido posible sin ti!

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

Tapiola, 30 September 2018
Eva
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<th>Description</th>
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<tr>
<td>EEG</td>
<td>Electroencephalographic</td>
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<tr>
<td>HCI</td>
<td>Human Computer Interaction</td>
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<td>IT</td>
<td>Information Technology</td>
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<td>LA</td>
<td>Learning Analytics</td>
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<td>LED</td>
<td>Light-Emitting Diode</td>
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<td>QS</td>
<td>Quantified Self</td>
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<td>SDL</td>
<td>Self-Directed Learning</td>
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<td>SRL</td>
<td>Self-Regulated Learning</td>
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<td>TEL</td>
<td>Technology Enhanced Learning</td>
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This doctoral dissertation consists of a summary and of the following publications which are referred to in the text by their Roman numerals


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.
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,
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 (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.

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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.

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Article 1</th>
<th>Article 2</th>
<th>Article 3</th>
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<tr>
<td>RQ1. What opportunities for and challenges to learning do monitoring tools and techno-monitoring practices introduce?</td>
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<td>RQ2. What approaches to the design of monitoring tools contribute to the balance of power relations when adopting techno-monitoring practices in learning?</td>
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<td>x</td>
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<tr>
<td>RQ3. How can monitoring tools support learners to reflect on and self-regulate their learning?</td>
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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.](image)

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.](image)

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 (La-vouë, 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,
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, Woodward, 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, 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

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2 Documentation of the “Vital Signs” is accessible at http://www.materialbeliefs.co.uk/~mater15/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.,
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, Rogalevits, 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).](image)

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

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 research3 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.

<table>
<thead>
<tr>
<th>Research stage</th>
<th>Description</th>
<th>Main outcomes</th>
</tr>
</thead>
</table>
| 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. |

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3 Information about Designs for Learning project available at http://lead.aalto.fi/
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>
<thead>
<tr>
<th>Research stage</th>
<th>Instrument</th>
<th>Design props</th>
<th>Participants</th>
<th>Data format</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contextual Inquiry</td>
<td>Semi-structured interviews</td>
<td>Inspiration cards</td>
<td>Graduate students (n=6)</td>
<td>Audio</td>
<td>These interviews were expected to support an understanding of how students perceive well-being in relation to their studies.</td>
</tr>
<tr>
<td></td>
<td>Subject-expert interviews</td>
<td>Researchers and experts in neurosciences, psychology, health and well-being, and HCI and learning technology (n=5)</td>
<td>Notes</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Focus group interview$^4$</td>
<td>Workshop: -Concept mapping -3D prototyping</td>
<td>Graduate students and university teachers (n=5)</td>
<td>Notes, Images</td>
<td>To explore the relation between learning, well-being, and physiological data.</td>
</tr>
<tr>
<td></td>
<td>Focus group interview$^5$</td>
<td>Workshop: Design opportunities and challenges mapping.</td>
<td>Graduate students (n=4)</td>
<td>Notes, Images</td>
<td>The aim was to explore the relation between learning and well-being.</td>
</tr>
<tr>
<td></td>
<td>Focus group interview</td>
<td>Playing with a design game about reflection on self-monitoring</td>
<td>Graduate students (n=5) at Aalto Medialab (Finland)</td>
<td>Notes, Images, Video</td>
<td>This session sought to bring insights into students’ perceptions and practices regarding self-monitoring and learning.</td>
</tr>
<tr>
<td></td>
<td>Questionnaire</td>
<td></td>
<td>Graduate students taking part in the PD sessions (n=15)</td>
<td>Online form</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Participatory Design</td>
<td>Three PD workshops</td>
<td>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.</td>
<td>Graduate students (n=15) at Kyushu University (Japan)</td>
<td>Notes, Images, Video</td>
</tr>
<tr>
<td></td>
<td>Feedback from open sessions$^6$</td>
<td>Mockups</td>
<td>Teachers and graduate students</td>
<td>Notes</td>
<td>The design concept was demoed through mockups in order to obtain feedback about</td>
</tr>
</tbody>
</table>

$^4$ 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 Demo Day Festival (2014 and 2015).
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

<table>
<thead>
<tr>
<th>Product/Design</th>
<th>Methodology</th>
<th>Participants</th>
<th>Notes</th>
<th>The concept and the design artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Design</strong></td>
<td>Think-aloud interviews</td>
<td>Teachers and graduate students (n=5)</td>
<td>The intention was to identify major usability issues in the tool design.</td>
<td></td>
</tr>
<tr>
<td><strong>Prototype as Hypothesis</strong></td>
<td>Semi-structured interviews</td>
<td>Graduate students (n=6)</td>
<td>Notes, Audio recording</td>
<td>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.</td>
</tr>
<tr>
<td>Questionnaire</td>
<td>Graduate students taking part in the test sessions of the Feeler v.2.0 prototype (n=6)</td>
<td>Online form</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Semi-structured interviews</td>
<td>Functional prototype (v.1.0) test</td>
<td>Graduate students (n=6)</td>
<td>Notes, Audio recording</td>
<td>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.</td>
</tr>
<tr>
<td>Focus group</td>
<td>Graduate students (n=6)</td>
<td>Notes, Audio recording</td>
<td>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.</td>
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</table>
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
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).

![Image](https://example.com/feeler_prototype.jpg)

*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).

![Feeler software](image)

**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

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\(^8\) 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 Joaquin 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\textsuperscript{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\textsuperscript{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.](image)

\textsuperscript{13}http://www.neurosky.com/

\textsuperscript{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](image)

**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](image)

**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.](image)

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).
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 12.** A screenshot of the assessment questionnaire about the estimated relaxation levels that corresponded 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).

![Feeler](Image)

**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.
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 men-
tal 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). Follow-
ning this approach, Feeler aims to expand the cognitive strategies that learn-
ers’ use to regulate their behavior when performing independent study tasks. To
this end, the Feeler boxes guide learners to implement and test different strate-
gies that can help them regulate their attention and relaxation while performing
different activities (meditation, study, and play). Depending on learners’ judg-
ment, 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 inter-
act with a digital product and can be considered a language in themselves (Lö-
wgren, 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 inte-
grates 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
According to Löwgren, an important use quality is that “the interface is trans-
parent, such that the required operations can be carried out without distrac-
tions” (p.10). In both cases, Norman (1998) and Löwgren (2002) stress the im-
portance 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 pro-
vide 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 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 that was 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.
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 field-work 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 instantiations 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.

<table>
<thead>
<tr>
<th>Key Themes</th>
<th>Abstraction</th>
<th>Instantiation from the Feeler prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-knowledge</td>
<td>Free exploration</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access to the data collected by the monitoring tool: Feeler software allows learners access to their data in different formats.</td>
</tr>
<tr>
<td>Personal inquiry</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feedback to support hypothesis-testing: Feeler provides immediate feedback that helps learners test and evaluate their hypotheses.</td>
</tr>
<tr>
<td>Agency-oriented technology</td>
<td>Openness</td>
<td>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.</td>
</tr>
<tr>
<td>Control</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>Reflection</td>
<td>Parafunctionality</td>
<td>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.</td>
</tr>
<tr>
<td>Estrangement</td>
<td></td>
<td>Ambiguity as a strategy to trigger questions: The 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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>Self-awareness</td>
<td>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.</td>
</tr>
<tr>
<td>Self-control</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>


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 & Tirsch, 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 Bjögvinnsson, 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 Björgvinsson, 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; Sumson & 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 researchers, 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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Reflection and Self-Regulation Using Monitoring Tools in Learning

Critical Design Exploration on Self-Monitoring During Independent Study

Eva Durall Gazulla