Encounters with Sociotechnical Encapsulation: Exploring Diagnostic and Pedagogical Interventions for the study of Literacy Practices in DIY and Maker Initiatives

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy

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Abstract

Over the last few decades, scholars in various disciplines have raised concerns about notions of acquisition and delivery of technical skills. Rather than identifying specific skills or competencies, literacy practices entail heterogeneous phenomena in which the role of social, political, cultural, and technical dimensions needs to be carefully examined. What types of knowledge, skills, or expertise should count as literacy? How do we teach these skills and knowledge? How do we foster critical thinking and in-depth understanding of the relationships between society and technology?

The proliferation of Do-It-Yourself (DIY) and Maker initiatives is increasingly becoming a major focus for scholars identifying these practices as emerging forms of literacy. This dissertation entails a conceptual and an empirical examination of Do-It-Yourself and Maker initiatives as a setting in which to situate and explore questions about emerging forms of literacy; in particular, how the use of DIY electronics can create innovative forms of collecting, interpreting, sharing, and negotiating the meaning of information. This research focuses on understanding how these practices allow people to engage creatively and critically in the construction of new forms of evidence, collaboration, and re-negotiations of meaning in their everyday life.
The research method consists of iterative interventions engaging participants in the process of design and fabrication with DIY electronics. Throughout the case studies, I focused on the observation, documentation and assessment of the cognitive trajectories and inquiry practices afforded by the introduction of variations in levels of sociotechnical encapsulation and the progressive disclosure of the internal complexity of the electronic toolkits.

Key findings of the dissertation include understanding how the engagement with material fabrication of DIY electronics can act as cognitive scaffolds leading to a progressive definition of communities of learners and the transformation of learning practices. The studies provide evidence of the value of engaging school teachers in exploring DIY and Maker initiatives not only as a pedagogical resource but also as a catalyst for reflection of their own professional practice.
Acknowledgments

Acknowledging can be one of the most challenging tasks if you believe that theoretical and empirical explorations of cognition, meaning making, and ultimately, consciousness are inevitably situated and distributed. A project of this length in time and stubbornness would not have been possible without the support and guidance of many people. First of all, I want to thank to my supervisor Matt Ratto for believing in me, for his support and friendship throughout the process, and for teaching me how to complete a dissertation. Without his assistance and guidance I would never had competed this project. I want to thank my committee members Leslie Regan Shade and Costis Dallas for the generous comments and revisions, and my external readers Prof. Eric Paulos and Rhonda McEwen for accepting to review my dissertation. I would like to express my sincere gratitude to Heather L. McGregor and Agata Mergler for the endless hours we shared over the last few years, for your patience, and the sleepless nights you both in one way or another help me to go through. Finally, I thank my family for their encouragement and the unconditional support throughout these years. To my dad, thank you for teaching me to conclude always with yet another question and persist on my dreams and explorations.
# Table of Contents

**Chapter 1  Studying Literacy through Sociotechnical Encapsulation** .......... 1

1.1 The Challenges of Defining Literacy .................................................. 2
1.2 DIY and Maker Initiatives as a Setting for the Study of Literacy .......... 4
1.3 What is Sociotechnical Encapsulation? .............................................. 7
1.4 Research Approach and Questions ..................................................... 12
1.5 Overview of Chapters .......................................................................... 14

**Chapter 2 The Challenges of Defining Literacy** .................................. 17

2.1 Definitions of Literacy ......................................................................... 17
2.2 Literacy and the Information Society .................................................... 21
  2.2.1 Functional Literacy ...................................................................... 21
  2.2.2 Information Society Discourses ..................................................... 24
  2.2.3 Literacy as Social Practice: New Literacy Studies ......................... 28
  2.2.4 Multiliteracies .............................................................................. 31
2.3 Conclusion .............................................................................................. 38

**Chapter 3 Theories of the Sociotechnical** ......................................... 39

3.1 From Knowledge as Content to Learning as Practice ....................... 41
3.2 Cultural Historical Activity Theory (CHAT) ........................................ 42
  3.2.1 Internalization: The social Origins of Cognition ............................ 42
  3.2.2 Thinking with Instruments of Mediation ....................................... 44
3.3 Situated Learning .................................................................................... 49
3.4 Distributed Cognition ........................................................................... 51
3.5 Science and Technology Studies (STS) ................................................ 54
3.6 Actor-Network Theory (ANT): Knowledge as a “Network Effect” ...... 61
3.7 DIY and Maker initiatives as Sociotechnical Literacies ....................... 64
  3.7.1 Beyond Technological “Support” ................................................. 64
  3.7.2 New Trends is Human Computer Interaction ............................... 65
  3.7.3 Critical and Reflective ................................................................. 66
3.8 Conclusion .............................................................................................. 68

**Chapter 4 Methods** .............................................................................. 70

4.1 Conceptual Frameworks ....................................................................... 70
  4.1.1 Social Constructivist Lessons for the Study of Literacy ................. 70
  4.1.2 Encapsulation and Literacy Practices ............................................. 73
4.2 Research Aim: Diagnostic and Transformative ................................................................. 74
4.3 Research Approach ............................................................................................................. 75
  4.3.1 Multi-sited Ethnography .............................................................................................. 75
  4.3.2 Discourse Analysis (DA) ............................................................................................ 77
  4.3.3 Grounded Theory ....................................................................................................... 79
4.4 Conclusion: How to Study DIY and Maker initiatives .................................................... 80

Chapter 5 Encounters with Sociotechnical Encapsulation ................................................ 84

5.1 Part I - Designing Experiences with DIY Electronics .................................................... 85
  5.1.1 Critical Making: Connecting the Material and the Conceptual .................................... 86
  5.1.2 DIY and Maker Events: Learning through Participation .............................................. 87
  5.1.3 Encapsulating Input/output Connections .................................................................... 90
  5.1.4 Testing Encapsulation: Building DIY Prosthetics ..................................................... 94
  5.1.5 Citizen Science: Designing a DIY Water Quality Sensor ........................................... 97
  5.1.6 Conclusion: Encapsulation and Literacy Practices .................................................... 99

Part II – Case Studies: Exploring Sociotechnical Encapsulation .................................. 106

5.2 Overview of the Studies .................................................................................................... 107
  5.2.1 Research Site and Participants ................................................................................... 107
  5.2.2 Research Activities .................................................................................................... 108
  5.2.3 Data Sources and Strategies for Follow-up Interviews .............................................. 108
  5.2.4 Teachers’ Initial Perspectives .................................................................................... 109
5.3 Study 1: Exploring Autonomy Through DIY Toy Hacking .......................................... 112
  5.3.1 Type of Encapsulation and Structure of the Activity ................................................. 112
  5.3.2 Workshop Activities .................................................................................................. 114
  5.3.3 Findings ..................................................................................................................... 115
5.4 Study 2: Sensing for Acting with DIY Electronics ........................................................... 122
  5.4.1 Type of Encapsulation and Structure of the Activity ................................................. 124
  5.4.2 First Iteration: Discovering Input and Output Devices ............................................. 125
  5.4.3 Second Iteration: Opening the Black-Box ................................................................. 127
  5.4.4 Findings ..................................................................................................................... 129
5.5 Study 3: DIY Water Quality Sensing ............................................................................. 132
  5.5.1 Type of Encapsulation and Structure of the Activity ................................................. 133
  5.5.2 Workshop Activities .................................................................................................. 133
  5.5.3 Findings ..................................................................................................................... 138
5.6 Conclusion ....................................................................................................................... 147

Chapter 6 The Affordances of Sociotechnical Encapsulation ........................................ 148
### 6.1 The Notion of Affordance .......................................................... 148
### 6.2 The Co-construction of Tools and the Purpose of the Activity ............... 149
### 6.3 Encapsulation as an Evolving Instrument of Mediation .......................... 154
  - 6.3.1 Formalizing Two Types of Mediation ........................................ 158
  - 6.3.2 Progressive Definition of the Object of the Activity ....................... 159
### 6.4 Bringing DIY and Maker Initiatives into the Classrooms ...................... 161
  - 6.4.1 Not Teaching Universal Skills but Facilitating Processes of Becoming .... 162
  - 6.4.2 Starting with not well-defined Problems ..................................... 163
  - 6.4.3 Designing and Sustaining Educational Technologies ..................... 165
### 6.5 Conclusion .................................................................................. 166

**Chapter 7 Designing Tools For Interpretation and Critical Thinking** ........ 167

### 7.1 Reviewing of the Research Project ................................................. 168
### 7.2 Sociotechnical Encapsulation as a Research Approach ....................... 172
  - 7.2.1 DIY and Maker Initiatives as Practices for Innovation .................... 175
  - 7.2.2 Sociotechnical Encapsulation: Conceptual and Methodological Framework 176
  - 7.2.3 Designing Toolkits for DIY and Critical Making Experiences ........... 178
### 7.3 Limitations and Future Research .................................................... 178

**Appendices** ....................................................................................... 180

Appendix A – Form of Informed Consent ................................................. 180
Appendix B – DIY Prosthetics: Toolkit and Activities ................................... 182
Appendix D – Sensing for Acting Workshop: Script Activities ...................... 184
Appendix E – Sensing for Acting Workshop: Electronic Toolkit ........................ 186
Appendix F – Sensing for Acting Workshop: Wiring Diagram ......................... 187
Appendix G – DIY Water Quality Sensing: Electronic Toolkit ......................... 188

**References** ....................................................................................... 189
List of Tables

Table 1 - Three Domains of Literacy. Adapted from OECD (2000, p.x) .............................................23
Table 2 - Social Skills and Cultural Competencies. (Adapted from Jenkins et al., 2007: 4) ..........34
Table 3 - Participation in DIY and Maker Events .................................................................88
Table 4 – Social and Technical Dimensions ........................................................................103
Table 5 - Sociotechnical Matrix: Technical Encapsulation and Script Modality ..................105
Table 6 – DIY Water Quality Sensing: Workshop Activities ...............................................133
Table 7 - Sociotechnical Encapsulation and Literacy Practices .........................................153
List of Figures

Figure 1 - Mediated Action. Adapted from Vygotsky (1987/1930:86) .................................................................45
Figure 2 – Circuit Board Design ..........................................................................................................................92
Figure 3 – Creating Printed Circuit Board ...........................................................................................................92
Figure 4 – Soldering Shield Components ............................................................................................................92
Figure 5 – Completed Shield ..............................................................................................................................92
Figure 6 – DIY Water Quality Sensor (Sketch Diagram of Components) .............................................................98
Figure 7 - BrushBot Schematics .........................................................................................................................113
Figure 8 - Toy Hacking Workshop ....................................................................................................................115
Figure 9 – Exploring Input and Output devices ...............................................................................................126
Figure 10 – Creating a “Welcoming Classroom” ...............................................................................................128
Figure 11 - Building DIY Conductivity Probe ..................................................................................................137
Figure 12 – Analyzing Conductivity Data .........................................................................................................144
Figure 13 – DIY Controlled Environment for the Growth of Micro Organism .................................................147
Figure 14 - Model of an Activity System - Adapted from Engeström (1987, 2009) ............................................151
Chapter 1
Studying Literacy through Sociotechnical Encapsulation

A controversy has emerged in discussions of what mathematical skills need to be taught to schoolchildren. In the age of calculators, should they be required to demonstrate their skills at using an old cultural tool, or should we encourage them to become proficient at using a new cultural tool? (Wertsch, 1998:46)

If we seek to equip students to engage with the process by which knowledge is produced, by which ideas are represented, by which information is circulated and encoded, it will not be enough to continue to be concerned with representation. Educators will need to engage with the material by which representations are produced, with the ways in which hardware and software, the networks and biology of our modes of communication also serve to structure our possibilities for representation, modelling and comprehension. (Facer, 2011:71)

Pervasive technological change and the emergence of Do-It-Yourself (DIY) and Maker initiatives around the world are bringing renewed attention to questions about how technology influences the production and sharing of information and knowledge practices. The rhetoric of technological innovation has become habitual in collective imaginaries, not to say a norm in contemporary discourses about technological development and the impact of such development on social and economic change (Foray, 2006). We live in times when consumers and the tech industry itself greet the release of new gadgets with much enthusiasm, while the computational power available in tiny micro-computers increases exponentially. We are reminded of these trends often in cycles of weeks, through pervasive announcements about the next new computer, new cell phone, new tablet or a new cellphone application that will “radically” transform everyday life. However, this hype over awaiting for the new, paired with the sophistication available in current technology, does not come without concerns. Many students, parents, and especially teachers, are struggling with uncertainties over the implications and challenges of rapid technological change.
1.1 The Challenges of Defining Literacy

Evaluating the *impact* of technology in the production and sharing of information and knowledge requires addressing fundamental questions about the definition and the conceptualization of literacy. Whether literacy can be defined as a set of specific skills or competencies, profound debates exist regarding the definition of literacy and discussions about the effects of technology. Not only among policy makers and educators are questions about literacy predominant, but literacy and knowledge are also a major concern in the academic domains of Library and Information Science, Knowledge Organization, Knowledge Management (KM), Computer Supported Cooperative Work, and Computer Supported Collaborative Learning. Key concerns surrounding literacy include asking about what types of knowledge, skills, or expertise should count as literacy, and how we can effectively teach and foster these skills and knowledge.

Since the 1980s, various scholars have challenged publications from the United Nations Educational, Scientific and Cultural Organization (UNESCO; 1972, 2006) and the Organization for Economic Cooperation and Development (OECD, 2000) arguing that attempts to define literacy need to expand beyond simplistic notions of reading, writing, and mathematical thinking (Barton et al, 2000; Gee, 1996, 2000, 2001; Kress, 1997; Street, 1984, 1997, 2003). These scholars argue that it is imperative to examine perspectives that overemphasize definitions of literacy focusing exclusively on one-dimensional factors, which can often disregard the complex situated nature of literacy practices. The challenges in defining literacy also include concerns
about how a particular conceptualization of literacy can lead to simplistic views about their social and economic impact\(^1\).

Two fundamental challenges raised by scholars contesting simplistic definitions and taking into account literacy practices and technological change includes the following: (i) How do we understand the relationships between literacy and socio-cultural practices? (ii) How does technological change affect or transform these socio-cultural practices?

These questions entail both conceptual and methodological challenges. The most difficult issue is to define literacy, knowledge, and expertise. Depending on the conceptual frameworks that inform the researcher, definitions of literacy can vary significantly. This introduces uncertainties about methods, because the adoption of a particular definition brings about different points of view on how to provide strategies that guarantee acquisition or assure accurate assessment.

Defining literacy inevitably influences the perspectives and research interests emerging in DIY and Maker initiatives, in particular, as these initiatives are rapidly changing phenomena and are therefore an evolving and moving object of study.

A popular view among some economists, policy makers, and researchers in education and information studies is that rapid technological change makes even more prominent the need for identification and definition of specific skills (often technical) and knowledge, since these are seen as a requirement for participation in contemporary societies. Yet, unpacking the nature of participation also demands addressing questions about how access to information and knowledge

\(^1\) For a representative study, see for example the publication “The Social and Economic Impact of Illiteracy” (UNESCO, 2010).
\(^2\) In later sections I address some of the conceptual and methodological lessons introduced by STS scholars. In particular, I address some of difficulties implied in the notion of black box as an “inscription” and values in technology.
\(^3\) I need to thank here to my colleague Andy Keenan at the iSchool for pointing me to this master thesis on this
is—and could be—enabling not only creative, productive and efficient, but meaningful and responsible forms of participation in society (Jenkins et al., 2009; Ito et al., 2009; Facer, 2011; Jenkins et al., 2016)

Increased technological mediation in everyday life raises questions about the definition of literacy. Persuasive discourses such as the idea that we live in an “information age” and a “knowledge society/economy” introduce debates about the methods and strategies for the acquisition and delivery of skills and competences. Heated debates about what notions of literacy (New London Group, 1996) should inform agendas and literacy programs worldwide intensify anxieties among the public and also concerns amongst activists, artists, environmentalist grassroots and advocacy groups, which have historically examined technological innovation with critical eyes.

1.2 DIY and Maker Initiatives as a Setting for the Study of Literacy

Do-It-Yourself (DIY) and Maker initiatives have received significant attention by amateurs, hobbyists, and Maker communities, who are the major advocates and contributors. The current proliferation of after-school and extra-curricular programs for youth in schools, libraries, and community centres indicate how educators and parents are raising concerns as well as curiosity about the skills and knowledge that comes with rapid technology change.

The influence of contemporary DIY and Maker initiatives that aim to foster new and creative avenues for participation is also becoming an important focus of research. Trends in the fields of Human Computer Interaction (HCI), information studies, and design have started to show how DIY and Maker initiatives encompass complex and diverse practices demanding
multidisciplinary efforts. The emergence of new forms of use and appropriation of technology is significantly changing the focus on notions of efficiency and productivity, historically associated with the notion of “technological support”. What we are seeing is that DIY initiatives engaging in the use of microelectronics and sophisticated sensing devices are creating an entire new ecosystem of literacy practices moving towards innovative and unique re-appropriations of technology.

A growing number of researchers have started to look at DIY and Maker initiatives as examples of innovative knowledge practices, mediating the construction of personal identities and cultural production (Ito et al., 2008, 2009); exhibiting new forms of documentation and sharing practices emphasizing values of openness and collaboration (Kuznetsov & Paulos, 2010). Others characterize DIY and Maker initiatives as emerging forms of “critical technological fluency” (DiSalvo & Lukens, 2009; DiSalvo, 2012a), “Critical Making” (Ratto, 2011a), and “Hacking Literacies” (Santo, 2012). These initiatives are also seen as practices enabling new avenues for civic participation and resistance (Jenkins et al., 2009), and an appropriation of technology that cannot be assessed with conventional evaluation metrics, but rather demand new evaluation criteria such as “levels of engagement”, and “enjoyment of use” (Sengers & Gaver, 2005, 2009; Sengers et al., 2006; Boehner, 2006).

The DIY phenomena, however, brings to the front unresolved questions about how to study a diverse and heterogenous ecosystem of sociotechnical practices, as they involve a variety of settings, motivations, and fabrication materials and techniques (e.g. Buechley et al., 2007, 2008). DIY initiatives specifically experimenting with low-cost microelectronics and numerous devices for sensing and output, comprise loosely defined communities; from globally dispersed groups of hobbyists and experts experimenting with open software and hardware, to the use of several
online resources and social media platforms, such as Facebook, Flickr, and YouTube for documenting, distributing and sharing projects and experiences. Today, popular examples of online platforms specifically dedicated to document and teach others how to build or repair various types of artefacts include “Instrucables - DIY How To Make Instructions” (www.instructables.com) and “iFixit: The free repair manual” (www.ifixit.com). This ecosystem requires addressing some important questions; for example, what is the impact of these practices in the formation of new skills and knowledge, and what research strategies are better suited to understand and evaluate these practices?

Despite the increased attention to DIY and Maker initiatives, major research gaps remain insufficiently addressed. These initiatives can to be examined through the lenses of a long history of studies looking at the role of physical artefacts in the formation of complex cognitive activities (Vygotsky, 1978), traditions of craft and apprenticeship (e.g. Lave & Wenger, 1991; Lave, 2011), and the situated and distributed nature of cognition (Hutchins, 1995). However, understanding how these traditions have evolved with rapid technological change remains a major gap in the scholarly literature to date. One of the key preoccupations of this dissertation is to indicate how these emerging knowledge practices can be investigated by introducing these conceptual and methodological frameworks highlighting the fundamental role of communities of practice and the engagement in the fabrication of material artefacts.

A major challenge is the design of research strategies that can expand and contest perspectives focused exclusively on questions about the definition and acquisition of technical skills, often disregarding the constitutive role of social and cultural dimensions in the understanding of literacy. Additionally, research gaps persist in understanding the benefits and possibilities of adopting conceptualizations of literacy that contest simplistic notions of skill or competencies.
The scarcity of publications specifically engaged in empirical studies and the assessment of *literacies* in the context of DIY and Maker initiatives, increases a demand for research exploring conceptual frameworks as well as specific research instruments that take into account the heterogeneity of these practices.

In order to address these challenges, this dissertation attempts to bring conceptual and methodological clarity on how to study DIY and Maker initiatives and how to assess its cognitive and pedagogical value. In this dissertation I argue that DIY and Maker initiatives can be considered a valuable and innovative setting to situate questions about emerging literacy practices.

In later sections of this dissertation, I examine why the exclusive focus on “technical” or “informational” skills constitutes an oversimplification in the definition of literacy practices. For now, I will focus on providing some explanations about the overall rational that is provided in the title for this dissertation. When literacy is looked at through the lenses of theories revealing the co-constitution of social and technical dimensions, a focus on either side of this divide reveals a limitation, preventing deeper understanding of the richness of literacy practices (Street, 1984, 2003; Kress, 1997). In the following sections, I introduce the notion of *sociotechnical encapsulation* and highlight its relevance for the study of literacy practices.

### 1.3 What is Sociotechnical Encapsulation?

Encapsulation has multiple meanings and transverses multiple fields, including psychology, computer science, sociology, and philosophy, and this increases the need for clarification. In this section, I contrast some of the perspectives on encapsulation in order to clarify how this notion is defined in this dissertation.
Encapsulation is often used as a synonym for *black boxing*. In everyday use, we are familiar with expressions like “the black-box of a plane” referring to a device recording various types of information that can be accessed in the event of an accident. In this use of the word, a black box refers to a technical *artefact* archiving communications and many other types of information about the internal and external conditions of an aircraft. What is key in this use of the notion of *black box* is the idea of the reliability of the data inside the black box, regardless of the internal operations.

**Encapsulation in Psychology**

In psychology, encapsulation is associated with the notion of a behavioural *black box*. References to this idea date back to the Russian psychologist Ivan Pavlov (1902) and his studies on human and animal conditional reflexes. Pavlov’s studies in cognitive psychology, such as the conditioning of behavioural responses in laboratory animals exposed to persistent and often questionable stimuli, is perhaps one of the earliest manifestations of the notion of encapsulation as a metaphor, as well as a methodological strategy for the study of cognition. This idea has become a research paradigm later introduced by B. F. Skinner’s (1976) studies of cognition focusing strictly on behavioural responses attempting to address questions about the nature and functioning of human cognition.

**Encapsulation in Computer Science**

A slightly different idea of encapsulation (black box) is common in computer science and cybernetics, where the expression “black boxed” refers to a mechanism in a computer program that receives input information, and produces an expected output. In this context, the encapsulation (black box) metaphor is used to describe code examples implementing different levels of abstraction and different types of access to the components of a computer program. For
example, in object oriented programming languages (e.g. C++, C#, php, or Java), a well-known strategy used for the organization of complex algorithms is called *encapsulation* (Mitchell, 2003). In this context, a program is defined with a name, which is called a class and it represents a logical container. Inside this container, the programmer can include at least two types of components: a) variables, (such as name, last name, address, phone number, etc.) and b) functions or methods, which are subroutines or small pieces of code responsible of performing a single part of the operations of a program.

What is relevant to this notion of encapsulation is that technological artefacts, in particular electronic devices, operate under the premise of a careful assessment of elements that remain hidden to the users. Encapsulation is a simplification of the interactions with complex algorithms. The output is obtained without the need to understand how the results are actually computed or processed. Thus, encapsulation is key in allowing re-usability for different scenarios without the need to understand the operations inside every single part of the program. In short, encapsulation is a method for hiding complexity because this is a powerful method that allows for the use of complex interactions precisely because there is no need to know the internal operations of each and every single object or program.

**Encapsulation as Inscription of Values in Technology**

A different perspective about encapsulation and black boxing became popular in the 1980’s through studies in sociology and anthropology of science, today often grouped under the name of Science and Technology Studies (STS). Although there are important differences in these traditions that remain a topic of debate among STS scholars (Cf. Callon 1986b; Grint & Woolgar, 1997; Latour and Woolgar 1979; Law 2004, 2007; Winner, 1980, 1993), an important idea discussed by these scholars is that technology acts as a *black box* in which values and...
politics are inscribed, and as a result, the major task of the social scientist is seen as the need to *open* and examine these back boxes in order to reveal what types of social, cultural and political values have been inscribed in technological artefacts.\(^2\)

**Encapsulation as a Fundamental Cognitive Mechanism**

In various forms of cognitive activity and problem solving, encapsulation (black boxing) operates as an essential strategy for dealing with complexity when using and interacting with various resources, not only internal, but also resources that extend beyond the mind of a single individual. This idea has roots in early studies in social and cultural psychology (Vygotsky, 1930, 1978), suggesting that in order to understand the specificity of human cognition it is crucial to account for the *mediational* role of both physical and psychological tools.

Contemporary studies in cognitive science (Hutchins, 1995, 2011; Clark, 1997), education, and sociology have greatly advanced this idea indicating that literacy needs to be conceptualized as a social practice (Barton et al., 2000; Street, 1984, 1995), and therefore a situated and distributed phenomenon in which social as well as technical aspects play a fundamental role. The engagement in the fabrication of material artefacts has also been a major topic in constructionist approaches to education (Papert, 1980, Sørensen, 2009), which elaborate on ideas from developmental psychology in order to bring attention to the pedagogical value of material fabrication.

The emphasis on social and technical dimensions of cognition needs to look beyond traditional notions of literacy defined in terms of functional skills, and focused exclusively on how

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\(^2\) In later sections I address some of the conceptual and methodological lessons introduced by STS scholars. In particular, I address some of difficulties implied in the notion of black box as an “inscription” and values in technology.
individuals acquire knowledge about particular subject domains. Rather, literacy is understood as a collective and dynamic practice in which knowledge in any specific domain always entails networks of interaction among human and non-human actors (Latour, 2005). In this view, literacy entails not only the discussion of facts and evidence, but also the ability to negotiate uncertainty and disagreement through complex interactions with heterogeneous tools to mediation, including both technological/physical instruments and social/cultural interactions with others (Vygotsky, 1978). To know is to be able to participate in various communities of practice (Lave and Wenger, 1991) and to learn involves the ability to recruit diverse technological and social resources (Hutchins, 1995, 2011).

The key insight is that encapsulation entails not only the inscription of values and politics in technological artefacts, but it also entails a fundamental mechanism of complex human cognition (Hutchins, 1995; Cussins, 1992). The methodological implications for the study of literacy include (i) attention to the strategies used to deal with information overload; (ii) the role of both social and technical tools of mediation or scaffolds; and (iii) the emergent cognitive trajectories for inquiry and discovery.

In chapter 2, I will provide a more detailed overview of literacy and relevant concepts and theories associated with it, and in chapter 3, I will discuss in detail the conceptual frameworks that highlight the importance of understanding sociotechnical encapsulation as a fundamental mechanism in complex human cognition. For the moment, I move to the introduction of the research questions and core motivations that inform this dissertation.
1.4 Research Approach and Questions

My dissertation is an exploration investigating the pertinence of DIY and Maker initiatives to situate and expand our comprehension of contemporary literacy practices. A key motivation for this project is to better understand the types of practices that DIY and Maker initiatives are facilitating and how such practices may influence definitions of literacy. This also entails exploring both the pedagogical possibilities and the hybrid and perhaps non-traditional research methods that can better suit the study of these heterogeneous phenomena. Often, these take place in both formal and informal settings and interactions among multiple resources. Throughout the dissertation I discuss the challenges of studying DIY and Maker initiatives and how my studies attempted to address these issues. In particular, I analyze the methodological challenges of studying loosely defined practices and communities such as DIY workshops and Maker events.

Although these initiatives are receiving increased attention as they can be understood as emerging forms of literacy, information studies has only recently started to explore empirical methods for the study of these practices. A major area to which I expect my research project to contribute towards is in the design of methodological strategies encompassing both empirical diagnosis as well as pedagogical concerns. With my research I expect to contribute to the advancement of the design of specific pedagogical activities that introduce DIY and Maker initiatives in the context of formal education. Towards this end, I build upon orientations that bring attention to the pedagogical value of practices of material fabrication in fostering curiosity and engagement (Papert, 1980), but also with an emphasis on critical reflection fostered by these practices (Ratto, 2011a, 2011b).

I am particularly interested in better understanding (i) how the use of DIY microelectronics – for example in environmental and self-personal sensing – are increasingly emerging as innovative
practices for collecting, interpreting, and sharing information, and (ii) how these practices are allowing people to engage creatively and critically in the construction of new forms of evidence, collaboration, and re-negotiations of meaning in their everyday life.

My research is committed to explore how DIY initiatives constitute a unique and interesting setting within which to situate questions about literacy. I argue that it is through engagement with the fabrication of physical artefacts and reflection about their social and technical implications for our everyday life that we can create spaces, not only for discussion about current issues, but more importantly, spaces that can foster the imagination of better and alternative sociotechnical futures.

DIY and Maker initiatives should not be taken for granted as explanatory resources or homogeneous phenomena. It is with this aim that in my review of the literature, and further in the research design for the proposed studies, I dedicate great attention to examining how the conceptualization of literacy, learning, and cognition more broadly inform the selection of methods, data collection, and analysis, as well as the motivation of my research. The intuition which I hope to make visible throughout this dissertation is that the study of literacy practices requires the researcher to avoid simplistic reductionisms and ontological divides such as mind/body; utopian/dystopian; semiotic/material; social/natural; social/technical, but rather to engage in an investigation of the specific ways in which both technical and socio-cultural-political dimensions are articulated in the formation of complex and creative forms of literacy.
Research Questions

My primary research question is (Q1) what are the affordances of variable levels of sociotechnical encapsulation in fostering inquiry practices and cognitive trajectories? In order to address this question, there are other secondary questions that address specific aspects, including:

- (Q2): How do we better conceptualize and empirically study the various types of skill and knowledge practices emerging in DIY initiatives?

- (Q3): If the engagement with fabrication of physical artefacts can contribute to both diagnose literacy practices and foster critical and creative reflection, how then do we study these practices and the effects of sociotechnical encapsulation?

- (Q4): What are the affordances of variable levels of sociotechnical encapsulation in participants’ collaboration, motivation, and engagement?

- (Q5): What are the specific emerging knowledge practices fostered by DIY and Maker initiatives using microelectronics; for example, when used for environmental and self-personal sensing?

1.5 Overview of Chapters

In chapter 2, I start by considering the various challenges that emerge in defining literacy in terms of universal and technical skills and examine the contributions of New Literacy Studies (NLS) that advocates for a view of literacy as socio-cultural practice. In Chapter 3, I provide a particular view of cognitive practices: the sociotechnical perspective, by reviewing influential frameworks emerging from diverse fields such as developmental psychology, cultural anthropology and information studies. This allows me to establish the epistemological and
ontological lenses with which I look at DIY and Maker initiatives as emerging forms of
sociotechnical practice. In Chapter 4, I discuss the methodological approach used in this
dissertation, building upon the conceptualization of literacy practices developed in previous
chapters. This chapter focuses on addressing the challenges of studying a heterogeneous and
loosely define object such as DIY and Maker initiatives.

Chapter 5 comprises the core of my empirical approach to the study of DIY and Maker
initiatives. In the first part of the chapter, I describe some of the key explorations with DIY
electronics that led me to the notion of *sociotechnical encapsulation* as a research approach.
These include the fabrication of printed circuit boards and the creation of a DIY scientific
instrument capable of measuring the quality of water. In the second part, I describe in detail three
case studies engaging participants in the fabrication of DIY electronics. These studies included a
series of iterative workshops in which I investigated how different types of technical complexity
were hidden (encapsulated) from participants and two types of script modality. The studies were
complementary as each focused on different aspects of the interaction between social and
technical dimensions. Key findings of this research suggest that providing electronic toolkits that
are designed to expose participants to variable levels of social and technical complexity can lead
to significant outcomes, including: the re-appropriation and re-negotiation of technology design
and use; the ability to reflect on alternative adaptations of technological artefacts in the context
of formal education; the emergence of multiple and unexpected trajectories of inquiry and
learning; the fostering of interdisciplinary dialogs, as well as curiosity and motivation; and the
engagement and critical reflection about literacy practices as sociotechnical phenomena.

Chapter 6 analyzes these findings through the lenses of Activity Theory and distributed
cognition, in an attempt to formalize and evaluate key aspects of the methodological approach
articulated in this dissertation. It is argued that an important aspect of DIY and Maker initiatives is the co-construction of the electronic toolkits and the progressive definition of the object of the activity, as this is a mechanism allowing for the emergence of cognitive trajectories that are meaningful to participants’ interests and contexts. This chapter concludes with an analysis of the challenges, as well as the pertinence, of introducing DIY and Maker initiatives in the classrooms. The dissertation then concludes with a review of the research questions, a discussion of sociotechnical encapsulation as a research approach in education and information fields, and a brief discussion of the key contributions and limitations.
Chapter 2
The Challenges of Defining Literacy

Questions about literacy and how it relates to physical, social, and cultural practices transverse multiple disciplines and demand difficult discussions about the nature of cognition and knowledge. These questions also require addressing methodological debates pointing to how these phenomena should be studied. At the core of these discussions is a fundamental question: can literacy be understood as a set of universal skills, or rather, conceptualized as a process or practice, which is not easily separable from the specific contexts in which it is produced?

In this chapter, I present frameworks that contribute to define my research questions, and the conceptual resources that I believe can inform the study of DIY and Maker initiatives. The chapter focuses on key discussions that have followed the definition of “functional literacy” introduced by UNESCO (2006) in the late 1970s, in particular after the introduction of the notion of multi-literacies in the 1990s. I conclude with critical responses raised by researchers in New Literacy Studies (NLS), which comprises a group of scholars pointing to the ideological and political dimensions implied in the conceptualization and the strategies for the acquisition of literacy. A comprehensive reviews of the issues involved in defining literacy can be found in Street (1984, 1997, 2003), Gee (1996, 1999, 2000, 2004), Shapiro & Hughes (1996), the New London Group (1996), Jenkins (2007), and Ito et. al (2008, 2010).

2.1 Definitions of Literacy

Dictionary definitions refer to literacy as “the ability to read and write” (Oxford English Dictionary, 2015), or more broadly, “being educated”. This definition presents the ability to read and write in binary terms: someone has the ability or not; you either know how to interpret the
written symbols of a particular language or you do not. There are, however, various challenges
with this binary understanding of literacy. In this section, I introduce two issues that have been a
major concern for different conceptualizations of literacy. What are the relationships between
language and socio-cultural contexts? How does technology affect thinking and learning?

The first question points to the complex relationship between language (e.g. text, sound, image)
and specific socio-cultural contexts (Street, 1984, 1995, 1997; Gee, 1991). If the ability to
understand a written text, for instance, does not depend exclusively on being able to identify and
reproduce words and symbols, but also requires the dwelling and immersion into a particular
culture, binary definitions seem to obscure, rather than assist, a deeper understanding of the
richness of literacy (Kress, 1997). Various scholars addressing this issue indicate that defining
literacy always requires a conceptual foundation capable of articulating the relationships between
language and socio-cultural practices.

The second question introduces another important issue: the relationship between technology and
the human mind. One of the earliest examinations of this is found in the writings of the ancient
philosopher Plato, who in one of his dialogues inquires about the significant impact that writing
introduces in peoples’ ways of remembering. Plato argues against writing saying that the ability
to express thoughts in written form will lead people to become forgetful. As he eloquently puts
it:

[T]his invention [writing] will produce forgetfulness in the minds of those who learn to
use it, because they will not practice their memory. Their trust in writing, produced by
external characters which are no part of themselves, will discourage the use of their own
memory within them. You have invented an elixir not of memory, but of reminding; and
you offer your pupils the appearance of wisdom, not true wisdom, for they will read
many things without instruction and will therefore seem to know many things, when they
are for the most part ignorant and hard to get along with, since they are not wise, but only
appear wise. (Phaedrus: 140; Plato, 1925)
Plato’s contention about the implications of writing is certainly puzzling. On the one hand, Plato argues for a notion of literacy in which knowledge is seen as abstract, universal, and context-independent (Cf. Plato’s Republic; Plato, 1994). That is, the “world of ideas”, which needs to be sharply differentiated from the sensible and material world. On the other hand, Plato’s comments on the dangers of literacy for the education of citizens, introduces questions about whether higher forms of literacy are actually associated with the acquisition of writing.

Literacy scholars Walter Ong and Eric Havelock – and later greatly influenced by them, Marshall McLuhan (1965) – have looked at this intriguing relationship between technological artefacts and the evolution of forms of thinking, remembering, and representing. These scholars argue that writing, as well as later developments – such as the printing press and electronic technologies – introduced fundamental changes in the ways we represent the world. Ong (1982) explicitly refers to writing as a technology. His intuition is that writing does not simply act as a medium for communication. There is a fundamental co-constitution of tools and thinking. Ong’s major concern is to highlight the changes in education and the overall social and cultural practices that took place with the transition from oral to literate societies. Havelock’s (1963) historical analysis of the notions of knowledge – understood as abstract, universal, and context-independent – goes a step further. He hypothesizes that the origin of abstract thinking, and perhaps the origin of Western forms of thinking, required the invention, adoption, and evolution of writing. Although this idea may seem a simplification and it has been contested (Cf. Scribner & Cole, 1981), the core intuition remains significant: writing allows for the externalization of knowledge, and in so doing, it enables new forms of memorization, representation, and higher levels of abstraction. In a similar vein, McLuhan’s (1964) idea that technology extends human mental abilities, and the
expression “the medium is the message”, both point to the complex relationships between technology, society, and literacy.

Throughout the 20th century, questions about the potentially beneficial as well as detrimental implications of the technology of writing in the forms of remembering and communicating continue to be a contested issue. Numerous ethnographic studies of knowledge practices have brought attention to these complex relationships between language, socio-cultural contexts, and the cognitive role of physical objects. Van Dijk (1985) suggests that researchers in psychology, anthropology, sociology, linguistics, and literary studies were the first disciplines addressing these issues (see also, Gee, 2000).

Studies examining the definitions of literacy and questioning what it actually entails to be able to understand and produce language have often pointed to the seminal work of Lev Vygotsky (1978) and Mikhail Bakhtin (2004). At the very turn of the 19th century these scholars introduced key critical questions about the social origins of literacy and the role of both physical and psychological artefacts. The attention to the relationships between tools, mind, and society has been influential and explicitly addressed by extensive studies of cognition emphasizing the situated and distributed nature of cognition and learning (e.g. Hutchins, 1995; Lave & Wenger, 1991; Wertsch, 1998).

Since the early 1980s, questions about technology and literacy are an increasing concern in both policy and scholarly circles and they have evolved into entirely new research fields, such as Human Computer Interaction (HIC), Computer Supported Collaborative Work (CSCW), Computer Supported Collaborative Learning (CSCL), and Knowledge Management (KM), among others. Although each of these fields addresses the relationships between technology,
society, knowledge, and literacy differently, the persistent intuition is that technological innovation and social practices need to be carefully examined in order to better understand emerging forms of thought, representation, and expression. In Chapter 3, I address this shift as a move from understanding knowledge as content to learning as practice, while also showing how the findings of these fields encompass a significant body of conceptual and methodological frameworks with which to look at DIY and Maker initiatives. In order to better understand the relevance and context in which these perspectives have developed, the next section examines some of the influential definitions of literacy and critical reactions introduced by scholars in New Literacy Studies (NLS).

### 2.2 Literacy and the Information Society

#### 2.2.1 Functional Literacy

How to prepare children for the future is a significant concern among researchers, parents, teachers, and policymakers. It is often framed as a question about how technology changes traditional forms of access, production, and sharing of knowledge. Under the label of “information” or “computer” skills, various scholars and educational programs attempt to define these literacies and indicate how crucial they are for productive participation in society, as well as for addressing major global challenges in the decades to come.

This preoccupation has been addressed, explicitly, by adopting a “functional” definition of literacy, which is articulated in representative publications such as the National Academy of Sciences’ report on reading (Snow, Burns, & Griffin, 1998), UNESCO’s *Education for All Global Monitoring Report* (2006), and the OECD/Statistics Canada’s reports: *Literacy Skills for*
UNESCO’s 1978 report is one of the earliest attempts to establish a globally accepted definition of literacy. The report states that:

A person is functionally literate who can engage in all those activities in which literacy is required for effective functioning of his group and community and also for enabling him to continue to use reading, writing and calculation for his own and the community’s development. (UNESCO, 1978; cited in UNESCO, 2006:30) [Italics added]

The emphasis on literacy as a fundamental skill for participation is also stressed by the OECD’s definition, which describes literacy in the following terms:

[T]he ability to understand and employ printed information in daily activities, at home, at work and in the community – to achieve one’s goals, and to develop one’s knowledge and potential. (OECD, 2000)

Both definitions refer to literacy as a fundamental requirement for successful participation in society. While UNESCO’s definition indicates that literacy is required for “effective functioning”, OECD’s definition highlights the development of personal “knowledge and potential”. In both definitions, the expectations for personal and community development are linked to the ability to understand “printed” information and arithmetic abilities or “calculation”.

Although the recommendations provided by each of these reports vary, a tendency in the measurement of literacy is the focus on skills required to a) understand textual information (Prose literacy), b) locate and use information (Document literacy), and c) apply arithmetic operations (Quantitative literacy). The OECD’s 2000 report, Literacy in the Information Age illustrates this trend in the conceptualization of literacy as a response to the “information” and “knowledge” society.
Table 1 - Three Domains of Literacy. Adapted from OECD (2000, p.x)

<table>
<thead>
<tr>
<th>Prose Literacy</th>
<th>Document Literacy</th>
<th>Quantitative Literacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>The knowledge and skills needed to understand and use information from texts including editorials, news, stories, brochures and instruction materials</td>
<td>The knowledge and skills required to locate and use information contained in various formats, including job applications, payroll forms, transportation schedules, maps, tables and charts.</td>
<td>The knowledge and skills required to apply arithmetic operations, either alone or sequentially, to numbers embedded in print materials, such as balancing a chequebook, figuring out a tip, completing an order or determining the amount of interest on a loan from an advertisement</td>
</tr>
</tbody>
</table>

UNESCO’s and OECD’s definition introduce a particular framing of literacy. They advocate for the need of “embracing a holistic view of educational development that includes the building of literate societies” (UNESCO, 2006:27). Although these reports acknowledge that there are multiple definitions of literacy, “some of which are even contradictory”, the justification for a “functional” definition is grounded on studies that correlate higher levels of literacy with the decrease of poverty and the increase of self-esteem and, particularly, women’s empowerment (UNESCO, 2006:31). In the framing of the “literacy problem”, the reports also bring attention to the fact that several activities involving the achievement of literacy are occurring in informal rather than formal settings. Moreover, an important aspect of these definitions is that they explicitly indicate that information technologies have introduced fundamental structural changes in the economy, and from this premise it follows that these skills need to be provided in order to assure productive participation in society.

However, “functional” definitions of literacy and notions of the “information society” have been a topic of heated debates. Over the last few decades, various perspectives have emerged not only expanding what should be included or emphasized by these definitions (Cf. Jenkins et al, 2009; Ito et al. 2008, 2009), but also contesting the conceptualization of literacy in terms of universal
skills. The notion of *multi*-literacies introduced by scholars in New Literacy Studies is an exemplar of the critiques to “functional” definitions (Cf. Barton, 2004; Gee, 2000, 2001; Kress, 1997; Street, 1997). Before moving into a review of some of these perspectives, I briefly enunciate in the following section some of the key ideas of the discourse and rhetoric of information literacy *for* the information age.

### 2.2.2 Information Society Discourses

Such popular phrases like the “information age”, the “information society”, or “knowledge economy” have become so pervasive terms that they tend to be used in reports and scholarly publications as if they were an inevitable fact. Despite the issues that many scholars have raised about these expressions (Chakravarty & Sarikakis, 2008), one important issue is that these notions often – if not always – articulate characterizations of what it is to be a “literate” citizen. In doing so, they have also introduced persuasive claims about the *expectations* and *effects* of literacy in society. This idea is the subject of innumerable publications in library and information sciences, education, policy and management. However, from each of these fields extensive publications also have challenged such notions of “information age” and “knowledge society”; for example, Tsoukas (2005) in knowledge management and organization literature and Frohmann (1992) in Library and Information Science both provide a comprehensive review of simplistic conceptualization of knowledge practices.

For the purposes of this review, I discuss only how the notion of “information literacy” has raised important debates about the conceptualization of literacy in information studies and education. Various scholars in library and information studies have argued for the need to move beyond notions of literacy exclusively focused on technical computer *skills*, such as finding and using information.
One of these formulations, expanding beyond the notion of skills, is introduced by Webber & Johnston who define information literacy as “the adoption of appropriate information behaviour to obtain, through whatever channel or medium, information well fitted to information needs, together with critical awareness of the importance of wise and ethical use of information in society” (Johnston, & Webber, 2003: 336). Virkus (2003) describes this shift from an emphasis on delivering “information-related competencies” as a move towards a conceptualization of literacy encompassing also “critical awareness of the importance of wise and ethical use” of information. Similarly, Bruce (2004) highlights the evolution of the notion of “information literacy” as follows:

The idea of information literacy, emerging with the advent of information technologies in the early 1970s, has grown, taken shape and strengthened to become recognized as the critical literacy for the twenty-first century. Sometimes interpreted as one of a number of literacies, information literacy (IL) is also described as the overarching literacy essential for twenty-first century living. Today, IL is inextricably associated with information practices and critical thinking in the information and communication technology (ICT) environment (Bruce, 2004:1). [Italics added]

One of the earliest works attempting to expand the definitions of literacy is Shapiro and Hughes’ (1996), “Information Literacy as a Liberal Art”3. In this seminal paper, Shapiro and Hughes inaugurate a new perspective about literacy in which information technology appears as the most fundamental component in assuring competent and free participation in society. In the opening paragraph, they introduce the challenges of the “information society” as follows:

What does a person need to know today to be a full-fledged, competent and literate member of the information society? As we witness not only the saturation of our daily lives with information organized and transmitted via information technology, but the way in which public issues and social life increasingly are affected by information-technology issues - from intellectual property to privacy and the structure of work to entertainment,

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3 I need to thank here to my colleague Andy Keenan at the iSchool for pointing me to this master thesis on this subject: “The Discourse of the Information Age” (Keenan, 2009).
art and fantasy life - the issue of what it means to be information-literate becomes more acute for our whole society. (1996:1) [Italics added]

A crucial aspect in these opening statements is the explicit correlation between the imminence of the “information society” and the need for specific skills. Shapiro and Hughes’s view acknowledges the challenges that come with technological innovation; at it affects almost every aspect of everyday life (e.g. education, work, entertainment). However, their view is far more ambitious. They see information literacy as the indispensable ability that will lead to the construction of the “educated information-age citizen”. They argue that: “information and computer literacy, in the conventional sense, are functionally valuable technical skills” (Shapiro and Hughes, 1996:3). However, the emphasis on technical skills needs to be extended and conceived as a new “liberal art” needed for:

(...) critical reflection on the nature of information itself, its technical infrastructure, and its social, cultural and even philosophical context and impact - as essential to the mental framework of the educated information-age citizen as the trivium of basic liberal arts (grammar, logic and rhetoric) was to the educated person in medieval society. (Shapiro and Hughes, 1996:3) [Italics added]

It is worth noting how literacy is depicted “as essential to the mental framework of the educated information-age citizen”. This idea characterizes a particularly optimistic view about literacy, which has been influential in various studies in Library and information Studies and Education. In order to provide this “information literacy” Shapiro and Hughes put forward an ambitious “curriculum”, encompassing seven types of literacy: 1) Tool literacy, 2) Resource literacy, 3) Social-structural literacy, 4) Research literacy, 5) Publishing literacy, 6) Emerging technology literacy, and 7) Critical literacy. Literacies 1), 2), 4), and 5) are mostly associated with the use of information technologies, such as hardware and software, including for example, the understanding of network topologies and protocols. These literacies also point to the ability to understand how to use, retrieve, and publish information in digital repositories.
Literacies 3), 6) and 7) are significantly different. They emphasize the need to go beyond technical skills. “Socio-Structural literacy” is conceived as “knowing that and how information is socially situated”. This definition brings attention to the social practices and institutions that mediate the creation and use of information and knowledge. “Emerging Technology Literacy” is particularly noteworthy as it refers to “the ability to ongoingly adapt to, understand, evaluate, and make use of the continually emerging innovations in information technology”. Finally, “Critical Literacy” is perhaps the most challenging and ambitious in Shapiro and Hughes’ view for the formation of the citizen of the information age. This notion encompasses historical, philosophical, socio-political, and cultural perspectives. They describe this as follows:

Critical literacy, or the ability to evaluate critically the intellectual, human and social strengths and weaknesses, potentials and limits, benefits and costs of information technologies. This would need to include a historical perspective (e.g. the connection between algorithmic thinking, formalization in mathematics, and the development of Western science and rationality and their limits); a philosophical perspective (current debates in the philosophy of technology, the critique of instrumental reason, the possibility and nature of artificial intelligence); a sociopolitical perspective (e.g. the impact of information technology on work, public policy issues in the development of a global information infrastructure); and a cultural perspective (e.g. current discussions of the virtual body and of the definition of human being as an information-processing machine). (Ibid.) [Italics added]

Shapiro and Hughes add further in the closing remarks:

If the information society is to be a free and humane one - especially if we share the Enlightenment goals of abolishing unnecessary inequality and creating a society of liberty - then let us take up the challenge of Condorcet's vision. Let us contribute to liberty through advancing citizens' knowledge, through democratizing education. Let us design a comprehensive, multi-dimensional and thoughtful information literacy curriculum. (Ibid.) [Italics added]

It is worth noting that although this view on “Critical Literacy” sees the solution in an all-encompassing “curriculum”, the strategy seems to lack a discussion about how critical literacy will be actually achieved. The closing remarks are indicative of the need for a new multidimensional view of literacy. Yet, great challenges remain in terms of providing specific
methods with which to diagnose and foster not one universal “information age” citizen, but diverse, local, and evolving forms of civic participation.

In the following section, I review a contrasting perspective about literacy that has emerged in the New Literacy Studies.

### 2.2.3 Literacy as Social Practice: New Literacy Studies

The New Literacy Studies (NLS) encompass a group of scholars that over the last decades have engaged in critical examination of how literacy has been traditionally understood among policy and academic circles. Brian Street (2003) argues that what is “new” in New Literacy Studies is a fundamental shift in the conceptualization of literacy: from an emphasis on the acquisition of skills to a focus on the social practices that constitute, sustain, and influence reading and writing. The focus of New Literacy Studies is “not so much on acquisition of skills, as in dominant approaches, but rather on what it means to think of literacy as a social practice” (Street, 2003:77).

This approach brings attention to two important issues. First, the understanding of literacy cannot disregard historical change and the contexts in which “literacy practices” occur. Second, simplistic definitions of literacy (e.g. functional definitions) tend to prevent an understanding of the complexity and richness of social practices and more crucially, neglect issues about power and “dominance” (Cf. Gee, 1991, 1999; Street, 1984, 1997, 2003). Hence, a major methodological implication highlighted by The New Literacy Studies is the shift from “observing literacy events” to “conceptualizing literacy practices” (Street, 2003:79).

In *Literacy in Theory and Practice*, Street (1984) introduces an important distinction between two models of literacy: the “autonomous” and the “ideological” models. The differences between
these two models provide key conceptual as well as methodological insight for the study of literacy as social practice.

**Autonomous Models of Literacy**

A fundamental assumption in *The Autonomous Model* is that introducing literacy will have *specific effects* in society. As Street explains: the “assumption that literacy in itself—autonomously—will have effects on other social and cognitive practices” (Street, 2003). Scholars in New Literacy Studies emphatically contest this assumption. They argue that this view is inadequate for various reasons. At the foundation of the assumption described lays the idea that literacy can be seen as a *neutral, universal, and technical* skill. In his critique of the definition of “functional” literacy introduced by UNESCO, Street (1984) points out that the major issue with this view is that it underestimates – if not dismisses altogether, the social, political, and cultural dimensions that take part in any definition of literacy. Quoting radical writers Carol and Lars Berggren (1975), *The Literacy Process: A Practice in Domestication of Liberation*, Street indicates that: “Literacy is not neutral nor simply a technology: it contains the moral philosophy of a particular society and its education system. Thus, a ‘functional’ literacy disguises the relationship of a particular literacy programme to the underlying political and ideological framework.” Street highlights that in earlier initiatives, UNESCO’s “input was tied to a particular developmental and economistic ethos” (Street, 1985:184). Additionally, inspired by the work of Paulo Freire, *Pedagogy of the Oppressed*, Street cautions researchers about the implications of attempting sharp definitions of literacy, as there is always the risk of imposing the conception of literacy of a dominant culture. He describes this as follows:

> The autonomous approach is simply imposing western conceptions of literacy on to other cultures or within a country those of one class or cultural group onto others. (Street, 2003:77)
Introducing literacy to poor, "illiterate" people, villages, urban youth etc. will have the effect of enhancing their cognitive skills, improving their economic prospects, making them better citizens, regardless of the social and economic conditions that accounted for their "illiteracy" in the first place. (Street, 2003)

The key idea is that literacy does not have *autonomous* agency. Literacy does not have specific effects that can be clearly identified or predicted. It is unlikely that “introducing” some specific literacy skills will bring anticipated outcomes, such as economic growth, empowerment, “better citizens”, or cognitive development. As Street argues, “what the particular practices and concepts of reading and writing are for a given society depends upon the context; that they are already embedded in an ideology and cannot be isolated or treated as ‘neutral’ or merely ‘technical’” (Street, 1984:1). Street’s bold statement does not disregard the affordances of multiple information channels, but rather, he alerts policymakers and educators, and in particular researchers of knowledge practices, to the ideological connotation implied in any definition of literacy. Since literacy is a socio-cultural phenomenon, it involves a complex transformation of multiple variables that cannot be easily isolated or controlled. People bring with them stories and views about what literacy should be.

**Ideological Model of Literacy**

*The Ideological Model* of literacy differs from the Autonomous model by considering literacy not to be a technical skill, but rather a “social practice”. Such a distinction has key implications. Literacy practices change with social and cultural contexts. Literacy is not a universal skill that can be detached from specific social contexts. For scholars in New Literacy Studies, “literacy is a social practice, not simply a technical and neutral skill; that it is always embedded in socially constructed epistemological principles” (Street, 2003:77). A key aspect of literacy is that it “varies from one context to another and from one culture to another and so, therefore, do the effects of the different literacies in different conditions” (Street, 2003:77).
Similarly, Gee emphasizes the non-neutrality of literacy, saying that literacy is always placed in “specific social, cultural, institutional, and political practices.” and “these sociocultural practices always have inherent and value-laden, but often different, implications about what count as “acceptable” identities, actions, and ways of knowing. They are, in this sense, deeply “political” (Gee, 1999:356). Street defines a literacy event as “an occasion during which a person ‘attempts to comprehend graphic signs’” (2003:78). One of the issues with this characterization of literacy is that it tends to disregard the contexts in which the event occurs, and a variety of aspects such as interests, goals or political agendas. The key aspect emphasized by Street is that literacy is not restricted to single events, such as the reading of a book, or attending to a lecture. Literacy includes people’s previous knowledge and preferences as well as specific local social and cultural backgrounds. As he explains:

> We bring to literacy event concepts and social models regarding what the nature of the event is and makes it work, and give it meaning. *Literacy practices*, then, refer to the broader cultural conception of *particular ways of thinking about and doing reading and writing in cultural contexts*. (Street, 2003:79)

### 2.2.4 Multiliteracies

In 1996, scholars at The New London Group (1996) coined the term *Multiliteracies*. This notion was introduced as an alternative approach to literacy indicating the need to move beyond the conceptualization of literacy as a fixed and universal skill set. *Multiliteracies* have been discussed by scholars in different disciplines, including linguistics, education, and policy (Barton, 2000; Facer, 2010; Gee, 1991, 1999; Kress 1997; Street, 1984, 1997). While there are some differences about how each of these scholars address this notion, a central claim is that literacy needs to be understood as *multiple* due to the multiplicity of communication channels and socio-cultural contexts. The New London Group describes the motivations that led to the adoption of concept as follows:
Multiliteracies - a word we chose to describe two important arguments we might have with the emerging cultural, institutional, and global order: the *multiplicity of communication channels and media, and the increasing saliency of cultural and linguistic diversity* (1996: 63) [Italics added]

The perspective of *multiliteracies* addresses pedagogical challenges implied in the development of “teaching and learning relationship that creates the potential for building learning conditions leading to full and equitable social participation” (The New London Group, 1996:60). Moreover, the scholars at the New London Group start with the assumption that different communication channels have a profound impact in literacy practices. This idea resembles claims about “information literacy” which argue that different types of information modalities introduce the need for new types of skill. As Mills (2010) explains this idea:

> Contemporary forms of communication require working with multimodal texts, which combine visual, audio, gestural, spatial, or linguistic modes to enrich, modify, and enliven meaning. (Mills, 2010:250)

A fundamental critique, and perhaps the major purpose of the notion of multiliteracies, is to contest the idea that literacy can be reduced to a single technical skill set. The notion of *multiplicity* implies understanding that teaching and learning are not restricted to “formalized, monolinguat, monocultural, and rule-governed forms of language” (Ibid. p. 61). A multiple view of literacy needs “to account for the context of our culturally and linguistically diverse and increasingly globalized societies” (Ibid. p. 61). A key contribution is to indicate how literacy changes due to sociocultural diversity, in particular at the local level, and not only because of different information modalities.

The notion of multiliteracies has been significant in informing policies and national programs for literacy development. It has also received extensive discussion among educators addressing questions about participation and social change. Recent publications adopting this perspective
have looked at emerging forms of social interaction, including DIY and maker initiatives (Jenkins et. al, 2009; Ito et. al, 2007, 2009; Facer, 2011).

In *Confronting the Challenges of Participatory Culture: Media Education for the 21st Century*, Jenkins et al. argue that: “Participatory culture shifts the focus of literacy from one of individual expression to community involvement” (2007: 7). Two important ideas are involved in this shift from “individual expression” to “community involvement”. The first one is that the study of literacy cannot be confined to individual skills and knowledge. Rather, literacy is seen as a social activity, and this implies paying crucial attention to many other factors. Jenkins et al. (2007) highlight three of these: 1) *The Participation Gap*, associated with unequal access and opportunities; 2) *The Transparency Gap*, pointing to how new media affects people’s perceptions of the world; and 3) the *Ethics Gap*, which refers to questions about how technology transforms traditional forms of professional training and socialization.

The second implication is that our understanding of the impact of technology on literacy needs to move away from sharp divides, such as utopian and dystopian views of technological innovation. Jenkins et al. emphasize that technology can no longer be seen “as a magic black box with the potential to create a learning revolution”, nor it can be seen as a “black hole that consumes resources that might better be devoted to traditional classroom activities” (Ibid.). Jenkins et al. look at the exclusive focus on technological innovation with critical hesitation. They argue that discussions about new media often focus on defining the impact and role of information technologies. However, such an emphasis often leads to oversimplified views of society and the forms of participation that eventually emerge (as well as those that do not) from technological change. Moving away from simplistic divides also includes the well-known “digital divide”. Although Jenkins et al, stress the forms of unequal opportunities and exclusion, the digital divide
entails not only access to technology, but also demands critical questions about the conditions of participation. As they explain:

The new literacies almost all involve social skills developed through collaboration and networking. These skills build on the foundation of traditional literacy, research skills, technical skills, and critical analysis skills taught in the classroom. (Jenkins et al., 2007: 4) [Italics added]

In addition to research and technical skills, Jenkins et al. point out that the aim of literacy programs should be “to encourage youth to develop the skills, knowledge, ethical frameworks, and self-confidence needed to be full participants” (Jenkins et al., 2007: 8). An important point in this characterization of skills is that they are not exclusively technical; these are “social skills and cultural competencies” (2007: 4). From this perspective, the new skills proposed by Jenkins et al. encompass various forms of interaction emerging with new media. Some of which, the authors emphasize, are skills already taking place in contemporary societies. The following table summarizes key aspects of these skills described by Jenkins et al.

**Table 2 - Social Skills and Cultural Competencies. (Adapted from Jenkins et al., 2007: 4)**

<table>
<thead>
<tr>
<th>Skills</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Play</strong></td>
<td>The capacity to experiment with one’s surroundings as a form of problem-solving</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td>The ability to adopt alternative identities for the purpose of improvisation and discovery</td>
</tr>
<tr>
<td><strong>Simulation</strong></td>
<td>The ability to interpret and construct dynamic models of real-world processes</td>
</tr>
<tr>
<td>** Appropriation**</td>
<td>The ability to meaningfully sample and remix media content</td>
</tr>
<tr>
<td><strong>Multitasking</strong></td>
<td>The ability to scan one’s environment and shift focus as needed to salient details</td>
</tr>
<tr>
<td><strong>Distributed Cognition</strong></td>
<td>The ability to interact meaningfully with tools and expand mental capacities</td>
</tr>
<tr>
<td>Collective Intelligence</td>
<td>The ability to pool knowledge and compare notes with others toward a common goal</td>
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<tr>
<td>------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Judgment</strong></td>
<td>The ability to evaluate the reliability and credibility of different information sources</td>
</tr>
<tr>
<td><strong>Transmedia Navigation</strong></td>
<td>The ability to follow the flow of stories and information across multiple modalities</td>
</tr>
<tr>
<td><strong>Networking</strong></td>
<td>The ability to search for, synthesize, and disseminate information</td>
</tr>
<tr>
<td><strong>Negotiation</strong></td>
<td>The ability to travel across diverse communities, discerning and respecting multiple perspectives, and grasping and following alternative norms</td>
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Of major importance in the skills described by Jenkins et al. is that they move far beyond the definition of literacy as static and fixed skills. Rather, the abilities depicted in this classification indicate that literacy is a dynamic phenomenon demanding careful attention to the social and cultural practices.

Today, it is widely acknowledged that literacy practices are transformed by both the variety of digital technologies and specifically the social and cultural contexts. This idea has often led to debates about how the diversity of technology and media (e.g. text, sound, video, etc.) requires distinguishing unique forms of literacy. On the one hand, it has been argued that literacy is fundamentally “multiple” in the sense that literacy practices are always situated and transformed by specific social and cultural contexts. Additionally, literacy is also multiple as it entails interacting with various different types of media (e.g. Jenkins et al., 2007). On the other hand, however, the notion of multiliteracies can also be misleading. It can lead to a view that stabilizes and reduces literacy by directly correlating each specific media or modality with a unique and isolated form of literacy. Scholars in New Literacy Studies have addressed this issue by pointing
to the difficulties and dangers of attributing unique forms of literacy to either a type of media/modality or to a particular culture.

Street contends that the notion of plurality of literacies “creates a new reification in which each literacy appears a fixed and essential thing” (1997:48). A key point is that the notion of multiliteracies can be restrictive, if it presents different forms of literacy as essential and static abilities. The unexpected and dynamic contexts in which literacy practices take place imply that there is never a final or completed form of literacy. In this regard, Street argues that an additional risk implied in the notion of multiliteracies is that “there is a danger of associating a literacy with a culture where current anthropological perspectives suggest fragmentation and hybridity” (Ibid.)

Paul J. Gee has also brought attention to this issue by arguing that literacy is “multiple” in the sense that reading and writing practices become multiple as they are shaped by different sociocultural practices. Defining how New Literacy Studies approaches literacy, Gee argues that:

The New Literacy Studies approach literacy as part and parcel of, and inextricable from, specific social, cultural, institutional, and political practices. Thus, literacy is, in a sense, "multiple": literacy becomes different "literacies," as reading and writing are differently and distinctively shaped and transformed inside different sociocultural practices. (Gee, 1999) [Italics added]

Gunther Kress (1997) has raised an important point about the notion of “plurality” of literacies arguing that it is “paradoxical” and there might not be a need for it at all because it seems to put forward a view of language that simply underestimates the “the dynamic and culturally varied quality of literacy ”. As he explains,

This paradox only exists if in the first place we assume that language is autonomous, unaffected by the social, and therefore stable. If we assume that language is dynamic because it is constantly being remade by its users in response to the demands of their social environments, we do not then have a need to invent a plurality of literacies: it is a normal and absolutely fundamental characteristic of language and of literacy to be constantly remade in relation to the needs of the moment; it is neither autonomous or
Street agrees with Kress on the fact that there might not be a need for a notion of “plurality” of literacies, if we recognize that the fundamental aspect of language is to be dynamic and multiple. In fact, as Kress emphasizes, language and literacy are “constantly remade in relation to the needs of the moment” (Kress, 1997:115). However, Street highlights an additional point: the notion of multiliteracy has been particularly valuable in advocating for different views about language and literacy, in particular, in the context of policy and literacy programs. He argues that the use of such terms as “multiple” and “plural” has led to rethinking and expanding notions of literacy as independent and transferable skills. As he explains:

I have found, particularly in development circles, where agencies present literacy as the panacea to social ills and the key ingredient in modernisation, the dominant assumption has been of a single autonomous literacy that is the same everywhere and simply needs transplanting to new environments. (Street, 1997b: 49)

One of the crucial implications of understanding literacy as dynamic practices encompassing social, cultural, and technological aspects, is that this perspective provides ways to expand and challenge well-established views reducing literacy to universal technical skills. Arguments about the unproblematic transferability of literacy across different sociocultural contexts, as well as the simplistic correlations between information modalities and specific forms of literacy, reveal how inadequate and restrictive they are. As Street, Kress, Gee and others have argued, understanding literacy entails asking fundamental questions about the nature of language and the formation of meaning. It also entails careful attention to the specific practices and varied artefacts that mediate and extend our forms of communication far beyond traditional written and spoken language. In short, the major insight of understanding literacy as a social practice is that it points the researcher to look at the complex co-constitution of social and technical.
influential literacy report, Gee states that, without such a view, “by placing into the background these social, institutional, and political realities - by decontextualizing reading from them - the report cannot tell the truth about the world in which it seeks to intervene. (Gee, 1999)

2.3 Conclusion

In this chapter, I have addressed key issues in the conceptualization of literacy and some responses to these issues from contemporary scholars in New Literacy Studies. The key insight was that every definition indicates a particular methodological strategy for the acquisition of literacy. I also examined how New Literacy Studies have provided evidence to support the need to move away from simplistic notions of skill towards an understanding of literacy as a social practice. This thus enables the researcher to formulate new questions about issues that perhaps were not visible before, such as the socio-cultural diversity of literacy in local contexts; the simultaneous operation of multimodal information channels in fostering complex forms of understanding and new forms participation, and the formation of identities. With the aim of deepening the understanding of the theories and methods that have inspired these radical shifts in the understanding of literacy, in the next chapter I look into various theories of socio-technical practice, which will reveal key lessons for the studies of DIY and Maker initiatives presented in later chapters of this dissertation.
In this chapter I review the contributions in the conceptualization of cognition and literacy provided by research in Cultural-Historical Activity Theory (CHAT), Situated Learning, Distributed Cognition, Science and Technology Studies (STS), and Actor Network Theory (ANT). I highlight how these theories provide conceptual and methodological insights about the co-constitution of physical objects and complex forms of thinking. The chapter concludes with a review of emerging initiatives in Human Computer Interaction (HCI), art, and design such Speculative Design, Reflective Design, and Critical Making, which have started to engaged in the study of DIY and Maker initiatives by placing an emphasis on material fabrication. The review of this body of literature focuses on new trends and orientations in the design of information artefacts that move beyond traditional notions of “support”, “efficiency” and “productivity”. These approaches highlight specific empirical studies that indicate not only the pertinence of emerging knowledge practices in DIY and maker initiatives, but also the need for further studies specifically designed to explore the co-constitution of social and technical dimensions. I indicate the theoretical and methodological pertinence of understanding literacy as encompassing both physical objects and social practices.

In order to advance in the articulation of the frameworks with which I will examine emerging forms of literacy in DIY and maker initiatives, I focus on key theories and methodological

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4 The idea that human cognition involves a complex interaction between physical tools and socio-cultural practices has been for decades a subject of debate. Later in this review, I introduce some of the major commitments of these socio constructivist theories. (Cf. Vygotsky, 1978; Lave & Wenger, 1991; Hutchins, 1995, Gee, 1999; Wertsch, 1998)
insights from a group of scholars that have specifically addressed the sociotechnical dimensions in the conceptualization of knowledge practices.

I start by introducing three foundational constructivist commitments for the understanding of cognitive activity and its relationship with the social, cultural, and historical context that have influenced multiple scholars in education, information studies, and organizational studies. The first idea is that higher mental functions are primarily dependent on communication among people, and therefore of social and cultural origin (internalization). The second is that human cognition can be described as a mediated activity, in which both physical and psychological tools act as cognitive scaffolds (Engeström, 1999; Vygotsky, 1978, 1986, Wertsch, 1998). And, the third refers to the Zone of Proximal Development (ZPD), which indicates that the development of literacy practices develops through cognitive scaffolds, including tools of mediation and interactions with more advanced peers.

In the following section, I present some of the key findings of research explicitly inspired by Activity Theory and ethnographic methods addressing the interactions between social and technical dimensions: Situated Learning (Lave & Wenger, 1991; Lave, 2011) and Distributed Cognition (Clark, 1996; Hutchins, 1995). I conclude with a review of some of the main issues introduced by scholars in Science and Technology Studies (STS) and Actor Network Theory (ANT) in conceptualizing the production of scientific knowledge. As I explain further in this chapter, STS, and ANT in particular, advance the conceptualization sociotechnical literacies by providing not only conceptual and methodological strategies, but also a vocabulary that I use to adapt the notion of sociotechnical encapsulation for the study of literacy practices emerging in DIY and Maker initiatives.
3.1 From Knowledge as Content to Learning as Practice

A traditional (rationalistic) perspective of learning and literacy considers knowledge as mental representation. This paradigm conceptualizes knowledge as an abstract generalization, usually as content that lives in individuals’ heads. This notion has led to a characterization of literacy as an individualistic task of “acquisition”, “assimilation” or “transfer” of information, strictly classified in knowledge domains (Engeström, 2001; Lave and Wenger, 1991; Scardamalia & Bereiter, 1993, 2006). However, this notion of knowledge – the accumulated abstract generalization and thus, the characterization of learning as acquisition or transfer – has been at the center of heated contemporary debates, not only in psychology and education, but also in sociology and cognitive sciences. Numerous researchers have contested this view. They advocate for a fundamental shift in the understanding of literacy, knowledge, and human cognitive activity more broadly. Key references include the work of Bruner (1990) in social and developmental psychology; Scribner and Cole (1989) in the psychology of literacy and comparative human cognition; research on “embodied” (Varela et. al, 1991), “distributed” (Clark, 1991; Hutchins, 1995), and “situated” cognition (Lave & Wenger, 1991; Suchman, 1987, 2007); and, developments in Science and Technology Studies explicitly conceptualizing literacy as a sociotechnical phenomena.

This fundamental shift resulted from understanding that cultural and historical factors, as well as a variety of supporting artefacts, play significant roles in cognitive activity. Although there are different perspectives amongst researchers, there are key aspects that characterize constructivist views about learning, teaching, and literacy. These include: (1) Knowledge cannot not be reduced to explicit content, which can be easily transferred from one individual to the other; (2)
Knowledge is fundamentally a construction: it is produced, and more importantly, it is sustained by specific socio-cultural practices situated also within particular contexts.

3.2 Cultural Historical Activity Theory (CHAT)

What is unique about us as species is that we not only adapt to the natural and social worlds through appropriate actions, but we also create theories and stories to help us understand and even explain the world and our actions in it (Bruner, 1997:122).

What in general does it mean to be a ‘means’ of thought or of memory? Psychologists who so enjoy using these fuzzy expressions furnish us with no answer to these questions (Vygotsky, 1978).

Activity Theory (AT) is one of the earliest attempts to think about the meditational role of artefacts and the role of social and cultural practices in the achievement of higher forms of cognitive activity. In the following section, I discuss the ideas initially formulated by Lev Vygotsky (1978, 1986).

3.2.1 Internalization: The social Origins of Cognition

One of the most influential formulations of Vygotsky’s approach to the study of knowledge and literacy practices is the idea of internalization. This intuition is looking at two difficult questions: Does society and culture affect cognition? If so, how do they do it?

Vygotsky’s idea suggests a relationship between communication practices and cognition and attempts a methodological strategy for studying the social and technical dimensions in human

5 It is important to note that in contemporary philosophy of mind debates exist regarding the idea of internalization, broadly understood as the assimilation of culture into the individual’s mind. For instance, in certain domains of Artificial Intelligence and neuroscience the use of such notions as social or cultural are almost prohibited. The idea of internalization has been questioned as being too general or lacking physiological evidence, which in some extreme extrapolations such as memes (Cf. Dawkins, 1892; Dennett 1991) had led to oversimplified notions of social Darwinism. I do not attempt to engage in these discussions here. My purpose is to introduce key issues about the need to account for social and cultural aspects when conceptualizing of literacy practices.
cognition. Vygotsky formulates the dependence thinking on forms of communication and social practices as a “law of cultural development”. He explains:

We can formulate the general law of cultural development as follows: every function in the cultural development of the child appears on the stage twice, in two planes, first, the social, then the psychological, first between people as an intermental category, then within the child as an intramental category. This pertains equally to voluntary attention, to logical memory, to the formation of concepts, and to the development of the will. (Vygotsky, 1987: Vol. 4, p. 106) [italics added]

Before exploring the meaning of intermental and intramental, it is crucial to note that “higher mental functions” include “voluntary attention” (consciousness), logical memory, and the “formation of concepts”. The theory of internalization is directed to explore the genetic origin of these higher mental functions, by studying how humans communicate and learn to use language. For Vygotsky, the genetic origin is the study of the genesis, in other words, the process of development by which these functions originate and evolve during the lifespan of a person (ontogenesis) (Cf. Vygotsky, 1978, Wertsch, 1985).

The pertinence of Vygotsky’s “law of cultural development” to explain the role performed by the social and cultural environment cannot be oversimplified. The main challenge in hypothesis is precisely to understand what is implied that a higher mental function originates from the social – first between people (intermental), and then within the individual (intramental).

The key intuition of the genetic law is that higher functions originate in social relations among people. However, the law of cultural development does not pretend to have a fixed definition of the higher mental functions. The meaning of this intuition cannot be stated as a maxim.

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6 Whether this relationship is causal is a subject of debate; in particular, in certain fields such as neuroscience. What is key to note here is that Vygotsky does not talk about causation of the mental nor does he refer to literacy as a fixed skill set. Rather, his intuition is to point to the crucial role of communication practices (culture) influencing the development of language.
disregarding the constraints imposed by the genetic approach. Instead, this general law describes a developmental history in which particular stages are differentiated: for example, the indicative gestures of early infants, speech acquisition, the use of tools, and later the formation of conceptual and abstract forms of mental activity.

As Wertsch (1998) indicates, the notion of internalization should not assume an essential opposition between *internal* and *external*. As he explains:

This term can be quite misleading. For starters, it encourages us to engage in the search for internal concepts, rules, and other such mental entities that are quite suspect in the eyes of philosophers such as Wittgenstein (1972) and cognitive scientists such as Clark (1993, 1997). The construct of ‘internalization’ also entails a kind of opposition, between external and internal processes, that all too easily leads to the kind of mind-body dualism that has plagued philosophy and psychology for centuries (Wertsch, 1998:48).

In short, cognition has a social origin because meaning is a functional attribution that occurs among people. Children learn from others how to attribute meaning; first to their own actions, but after to signs and words. Hence, a theory of meaning (as a mediated activity) operates as the explanatory principle of higher mental functions.

### 3.2.2 Thinking with Instruments of Mediation

Must we think of thinking or memory as analogous to external activity or do devices play a certain role as a fulcrum giving support and help to the mental processes? What does this support consist of? What, in general, does it mean to be a means of thinking or memory? (Vygotsky, 1987:61)

The second influential idea introduced by Vygotsky is that higher mental functions involve the interaction with both physical and psychological instruments of mediation. A consequence of the internalization of social relations is the ability to attribute meaning to different kinds of auxiliary means. Higher mental functions, such as the use of signs and words to coordinate behaviour and
solve multiple cognitive tasks, are built upon this meaningful attribution. The *mediated activity* is for Vygotsky the formal presentation of this explanatory principle. As he describes this process:

In natural memory a direct associative (conditional reflex) connection A-B is established between two stimuli A and B. In artificial, mnemotechnic memory of the same impression, by means of psychological tool X (a knot in a handkerchief, a mnemonic scheme) instead of the direct connection A-B, two new ones are established: A-X, and X-B. Just like the connection A-B, each of them is a natural conditional reflex process, determined by the properties of the brain tissue. What is new, artificial, and instrumental is the fact of the replacement of one connection A-B by two connections: A-X and X-B. They lead to the same result, but by a different path. What is new is the artificial direction which the instrument gives to the natural process of establishing a conditional connection, i.e., the active utilization of the natural properties of the brain tissue. (Vygotsky, 1997/1930:86)

![Diagram of Mediated Action](image)

Figure 1 - Mediated Action. Adapted from Vygotsky (1987/1930:86)

The key aspect of the mediated activity is that the structure of mental functions is transformed by introducing artificial means. This particular example describing the mechanism of assisted memory is one of the multiple examples operating under the mediated principle. For centuries, humans have used external devices to enhance their memory: from the complex knot-systems and scratched pieces of wood used by primitive cultures to register events, to sophisticated maps, diagrams, and the use of devices to perform computations, such as the abacus, among many others. The meaningful action is extended to all lower mental functions (memory, perception,

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7 An interesting resemblance of Vygotsky’s instrumental approach can be found in Daniel Dennett’s (1991, 1995) analysis of cultural factors in cognition; Richard Dawkins “Extended Phenotype” (1982). Although Dennett and Dawkins universe of memes populating the brain and selfishly assuming the control of mental functions is not present in Vygotsky’s perspective, the meme metaphor resembles the commitment to culture as the key-factor in the evolution of human forms of adaptation.
attention), and the profound transformation of these basic forms takes place when a new stimulus is introduced (the X in the previous scheme). This functional attribution, in the form of new artificial connections, becomes the distinctive structural characteristic of all higher mental functions.

This explanatory principle suggests that the characteristic feature of the higher mental functions can be understood by the creation and use of instrument of mediation. A structural change occurs when instruments are incorporated into problem-solving tasks. These changes, however, cannot be explained sufficiently by the stimulus-response (S-R) scheme. It follows from this *meditational* approach that the classical S-R scheme is insufficient because it is unable to explain the role of signs in human cognition. Indeed, humans are different from animals at least in one respect: the complexity of the active adaptation to their environments due to the *simple* structural change of their cognitive tasks by introducing auxiliary means. Finally, mediated activity expresses a logical form of the *scaffolding process* introduced by the internalization of meaningful actions. Mediation constitutes the mechanism by which cognition extends its powers: (i) by communicating with others, behaviour *becomes* meaningful, and (ii) by introducing instruments of mediation, lower mental functions\(^8\) are structurally transformed. As Jerome Bruner has eloquently expressed:

> Culture became the major factor in giving form to the minds of those living under its sway. A product of history rather than of nature, culture now became the world to which we had to adapt and the tool kit for doing so. (Bruner, 1990:11-12)

\(^8\) In Vygotsky’s terminology, “lower” mental functions refer to biological and physiological characteristics of the brain.
Scaffolding Thinking Through Culture

The “Zone of Proximal Development” (ZPD) constitutes a succinct and insightful formulation of the ontological and epistemological implications of Vygotsky’s approach. The ZPD is defined as:

\[ \text{The distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers. (Vygotsky, 1978: 86)} \]

The ZPD does not describe a geographical zone at all. This evocative concept introduces a model of human cognition in which more experienced peers introduce profound changes to their own cognitive abilities as well as to the abilities of their peers. The ZPD describes a potential level of development. Furthermore, though not all cognitive functions are present at a particular stage of development, a child can achieve those functions by collaborating with peers, or by receiving instruction from more experienced peer. The ZPD points to a constitute relation between the higher mental functions and the agents that lead to further levels of cognitive development. The introduction of instruments of mediation and the intervention of experienced peers, for instance, can lead to the resolution of cognitive tasks that were not possible before. Cole (1985) describes this cognitive mechanism in a succinct and persuasive form: “Culture and cognition create each other” (Cole, 1985:158-159)”

Instruments of mediation are part of a complex system of activity composed by the body, social relationships, and multiple cultural artefacts. From this configuration, cognition is defined as an open-ended phenomenon in which cognitive skills and abilities are extended by instruments of mediation including both physical artefacts and collaboration with more experienced peers.
Words do more than communicating thoughts

Language is not a vehicle of thought, or at least, this does not seem to be its primary function\(^9\). Words used in writing or speech cannot express mental content nor represent an object if those words and utterances are not situated in socio cultural contexts. The interaction between thought and language is better understood as a complex system of activity, and this implies that questions about the role of language (and the definition of literacy) should be asked differently. Language is a vehicle as much as it is a cognitive tool. Hence, formulating this relationship in terms of the primary role that language is not necessarily false, but inadequate. Both possibilities can be demonstrated. Language conveys thoughts as much as it acts as a cognitive scaffold. The key point is that presenting the question in the form of a primary role of language separated from the complex system of which it is a part, is not only a methodological mistake, it can prevent the study of emerging forms of language, and thus literacy practices.

Vygotsky’s approach is radically different. Language does not perform a single role, but several different roles along an internalization process. Language is an artefact introducing profound changes in the structures of the mind. As Vygotsky suggests in the following passage:

\[
\text{[T]hought and word are not cut from a single mold. In a certain sense, one can say that we find more opposition than agreement between them. The structure of speech is not a simple mirror image of the structure of thought. It cannot, therefore, be placed on thought like clothes off a rack. Speech does not merely serve as the expression of developed thought. Thought is restructured as it is transformed into speech. It is not expressed but completed in the word. Therefore, precisely because of their contrasting directions of movement, the development of the internal and external aspects of speech form a true unity. (Vygotsky, 1962)}
\]

\(^9\) This is a crucial point of discussion in literacy studies, and more recently in researchers advocating for discourse analysis as a conceptual and methodological approach to the study of knowledge practices and the interpretation of text. (Cf. in cognitive linguistics, the work of Lakoff and Johnson (1980) and more recent research in discourse analysis (Gee, 1992, 1996, 1999).
3.3 Situated Learning

[...] Given a relational understanding of person, world, and activity, participation, at the core of our theory of learning, can be neither fully internalized as knowledge structures, nor fully externalized as instrumental or overarching activity structures. Participation is always based on situated negotiation and renegotiation of meaning in the world. (Lave and Wenger, 1991:51)

The idea that learning is “situated” has been widely acknowledged in a variety of disciplines, and it is often seamlessly argued that learning is situated in various different contexts. However, ethnographic studies have shown that this situatedness should not be taken lightly as “in situ” nor confused with notions of “learning by doing” (Lave & Wenger, 1991:29). Influenced by Vygotskian ideas of internalization and the Zone of Proximal development (discussed earlier), Lave and Wenger (1991) suggest that: “learning is an integral part of generative social practice in the lived-in world” (Ibid. p. 35). A key aspect of this “generative” practice is that it requires the development of a sense of belonging and membership. From this perspective, literacy is seen as process of identity formation or “becoming full participant in a sociocultural practice” (Ibid. p. 29).

Lave and Wenger provide an analytical construct to describe this practice: “legitimate peripheral participation” (1991:29). This concept suggests that learning involves a progressive (gradual) move from the “periphery” – understood as disconnection/distance from a community – towards a “center”, ideally denoting the immersion into the community. The term “legitimate” refers to a progressive understanding of the language rules, codes, and practices that are appropriate, accepted, and relevant for one particular community. The ethnographic studies conducted by Lave and Wenger included cases of apprenticeship including the practices of midwives, tailors, quartermasters, butchers, and nondrinking alcoholics (Ibid. p. 61). In these cases the move from
periphery to center means that newcomer apprentices followed a progressive immersion into the community from an initial stage of “peripherally” (being outsiders to the community).

However, as they emphasize, the move from the “periphery” to the “center” should not be taken as a linear process of skill acquisition of knowledge. Rather, they argue that participation is complex and diverse; it involves different types and intensities, and an “ambiguity” that is constitutive of peripheral participation. It would be reductive to assume that every newcomer to a community follows the same trajectory or achieves the same goals during the process of becoming a “legitimate participant”. One of the difficulties of understanding the meaning of legitimate peripheral participation is this “composite character”. Lave and Wenger argue that it can be misleading to decompose this concept into three analytical divides, such as (i) legitimate vs. illegitimate, (ii) peripheral vs. central, and (iii) participation vs. nonparticipation (Ibid. p. 35). The issue with these divides is that they frame the process of becoming a participant in a binary, and thus in reductive terms. As they emphasize: “there may very well be no such things as ‘illegitimate peripheral participant’” (Ibid. p. 35) nor should we think of “full” or “complete” participation. Participation in a community is, precisely, followed by diverse and evolving forms of establishing and renegotiating distance/proximity. As the authors indicate, “legitimate peripherality” is a complex concept, as it refers to changing and evolving relations of power among participants. More or less intensive participation leads to various forms of empowerment. The key point in their argument is that “Peripheral participation is about being located in the social world. Changing locations and perspectives are part of actors’ learning trajectories, developing identities, and forms of membership” (Ibid. p. 36).
Implications for the conceptualization of literacy practices

Learning is not merely a process of acquiring knowledge: it entails much more than the access, transfer or processing of information. Rather, learning should be seen as a process of becoming a “legitimate” participant in specific and often overlapping communities of practice. Key aspects of the conceptualization of literacy as “Situated” can be summarized as follows:

- Success as well as failure to learn is associated with the ability to participate in a community.
- Literacy is not a precondition for participation: Literacy is the outcome of becoming a participant.
- Situated means: “relational character of knowledge and learning” and “negotiated character of meaning” (Ibid. p.33)

3.4 Distributed Cognition

Contemporary perspectives in cognitive science have highlighted the requirement of considering the role of environmental factors and multiple types of external supports as part of a comprehensive and naturalistic explanation of human mental activity. For instance, Dennett (1991, 1995), Clark (1997, 1998), Hutchins (1995, 2011), Cussins (1992), and Carruthers (1998, 2008) seem to agree at least on a basic intuition: material objects and the collective practices that coordinate their production and use must be taken into consideration when characterizing the complex cognitive phenomena. Asking about the relationship between the human mind and the environment, and assessing the role of many kinds of artefacts, has proved to demand a multidisciplinary perspective; including approaches from developmental psychology, evolutionary biology, developmental psychology, neurosciences, and information sciences.
Distributed cognition is one of these perspectives that sees the mind, the world, and language to be part of a complex phenomenon requiring explanatory principles that go beyond simplistic rationalist views, which since the philosopher Renee Descartes (Brandhorst, 2010), have tended to assume that human cognition can be conceptualized as a rational or mental substance separated from the physical world.

In this section, I discuss some of the key contributions of this body of research in the conceptualization of literacy, as well as methodological insights for the study of the cognitive role of social practices and physical objects.

This extended notion of cognition is also addressed by philosopher and cognitive scientist, Andy Clark (1997), who seems to go even further than Vygotsky’s “Zone of Proximal Development”. He describes the inseparable and co-constitution of mind, world, and language as follows:

[T]he sheer intimacy of the relations between human thought and the tools of public language bequeaths an interesting puzzle. For in this case, especially, it is a delicate matter to determine where the user ends and the tool begins! (Clark, 1997: 194) [Italics added]

Mental processes are “extended processes”. As Clark suggests, cognition cannot be restricted to the limits of the body and the skull because the mind and all its surprising powers would be poorly explained if humans are considered isolated beings. For a proper understanding of cognition, Clark demands also a perspective in which the mind would be better understood as a phenomenon that extends throughout the mediating resources, including the enormous body of tools acting as cognitive aids, and other supports in which computational tasks are externalized and distributed. Cognition occurs somehow in the brain. There is no discussion about this fact: without the brain (and certainly, all the body-system), there would be no mental phenomena.
Nevertheless, as Hutchins (1995, 2011) indicates, the main issue demanding further explanation is the complexity of the in-out feedback loop between the mind and the environment.

Grounded in a thorough ethnographic investigation, Hutchins (1995) shows that complex cognitive activity cannot be explained by merely referring to the skills of a single individual. Hutchins argues that solving complex cognitive tasks demand a coordinated integration of all the members of the crew. His key finding is that cognitive processes will be barely characterized considering isolated individuals. As he explains:

[T]he effects of group-level cognitive properties are not produced solely by structure internal to the individuals. Rather, the cognitive properties of the groups are produced by interaction between structures internal to individuals and structures external to individuals. (Hutchins, 1995:262)

The complex interactions between internal and external structures taking place in warship navigation, extensively documented by Hutchins, resemble Vygotsky’s “Zone of Proximal Development”. Cognition extends its potential through social practices. Not only is the use of tools required in solving complex tasks, but engagement in coordinated practice becomes indispensable for recruiting cognitive resources. Hutchins describes the characteristics of distributed cognition as follows:

All human societies face cognitive tasks that are beyond the capabilities of any individual member. Even the simplest culture contains more information than could be learned by any individual in a lifetime (…), so the tasks of learning, remembering, and transmitting cultural knowledge are inevitably distributed. (Hutchins, 1995:262) [Italics added]

Two important methodological insights need to be highlighted for the study of knowledge practices. First, the observation and diagnosis of cognition requires examining the role performed

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10 Hutchins (1995) studies the (knowledge) practices taking place in a war vessel in which the crewmembers and equipment take part, simultaneously, in the resolution of complex operations such as navigating the warship, and monitoring its position.
by instruments of mediation transforming the structure of the cognitive task. Second, social practices, including not only the use of natural languages, but also signs and gestures are constitutive of complex problem solving as it is only through these practices that crucial cognitive resources become available.

3.5 Science and Technology Studies (STS)

Over the last four decades, the study of socio-technical phenomena has seen extensive contributions, both conceptual and methodological. A major shift in the study of social, cultural, political implications as well as ethical ramifications of technology design and use has emerged from Science and Technology Studies (STS). In this section, I outline key points about the profound implications STS research has had on the conceptualization and study of literacy practices. I briefly introduce the context in which STS research emerged pointing to the distinction between social and natural sciences. I then review some of the reactions to technological determinism present in STS literature, and discuss the challenges implied in the notion of black boxing/encapsulation referring to the inscription of values in technology. Finally, I outline methodological lessons for the study of knowledge practices indicating that sociotechnical phenomena should be conceptualized as an effect of networks composed of human and non-humans.

Origins

Science and Technology Studies (STS) encompass a diverse group of researchers, which since the 1970s, started to react to deterministic views about science and technology. One of the major efforts of STS scholars is to indicate that the social cannot be disregarded when asking questions about the nature of scientific knowledge or the design and use of technology.
An important insight of Bijker et al.’s (1987), *The Social Construction of Technological Systems*, was that most of the “science studies” which emerged during the 1980s can be seen as initiatives moving towards social constructivism in order to challenge long standing ideas about the neutrality and objectivity of scientific knowledge and technological innovation. Whether these reactions can or should be “unified” in an all encompassing social constructivist view – as attempted by Bijker et al. – a common theme in STS research remains the invitation to examine the intricate ways in which particular knowledge claims are produced and sustained (Latour & Woolgar, 1979).

STS comprise an explicit attempt to adopt socio-constructivist orientations to look at scientific knowledge and technology with conceptual and methodological sensibilities developed by sociological and anthropological studies. Some of these perspectives, which Grint and Woolgar (1997) characterize with the generic label of “the social shaping approach”, include different views such as “Sociology of Scientific Knowledge” (SSK) (e.g. Bloor, 1999a,1999b; Collins, 1985; Latour & Woolgar, 1986). Similar views include notions of the “social construction of technology” (SCOT) (Bijker et al. 1987), the “social shaping of technology” (MacKenzie et al., 1985), and Actor Network Theory or sociology of translation (Biker and Law, 1992, Callon, 1986a, 1986b, Latour, 1987, 1999, Law, 1999).

**Social vs. Natural Sciences**

A significant aspect of STS is that they demand a review of a long-standing distinction in research orientations: the opposition between social and natural sciences, which is predicated under the assumption that the social and the natural are two separate realms. This idea is present (and still common) in numerous publications addressing the relationship between technology and society. This distinction has been historically formulated in terms of subjective vs. objective,
social vs. technical, material vs. semiotic (Cf. Grint & Woolgar, 1997; Latour, 1993, 2005). At the core of these dualistic views is the belief that we can draw a sharp ontological distinction between the (i) subjective/social and (ii) the objective/natural/technical. The former refers to what is essentially human, such as the ability of having values, desires, emotions, beliefs, and intentions. The latter refers precisely to the opposite: the inability to have intention or belief, and thus, to be regarded as objective and physical – such as the world outside or simply nature, a material product or object.

Questions about how these realms affect each other entail centuries-long discussions. Researchers in STS indicate that this discussion needs to be situated in the context of the modernist Enlightenment tradition, which has looked at technological innovation as an evolution of reason itself. In this tradition, the objective/natural/technical realm is “traditionally” regarded as neutral as it seems to exist without need to account for values, interests, intentions, etc. However, for various reasons the socio-technical divide is problematic, obscuring rather than contributing to deep understanding of knowledge practices and literacy (Cf. Callon, 1986a; Latour 2005).

**Technological Determinism: Extending Nature’s Neutrality to Technology**

A crucial task for STS researchers is to challenge how the ontological distinction between society and nature leads to deterministic orientations in research – in particular, to technological determinisms. As Grint and Woolgar point out: “technological determinism portrays technology as an exogenous and autonomous development which coerces and determines social and

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11 One of the most provocative formulations of this idea is found in Bruno Latour’s *We have never been modern* (1993).
economic organizations and relationships” (Grint and Woolgar, 1997:11). The core idea is that society is seen as helplessly determined by the dictates of technological change.

However, STS scholars have provided varied and emphatic reactions to technological determinism, arguing that such a view is simplistic and inadequate, as it disregards the complex ways in which the so-called realm of the social/subjective interferes with both the production of knowledge and the design and use of technology. This intuition is present in notions of “social construction” (Pinch & Bijker, 1987) and “social shaping” (MacKenzie & Wajcman, 1985), which are perspectives with an explicit statement about the “effects” and “impact” of society in the formation of science and technology. The key idea is that the distinction between object/subject and social/technical tends to assume that technological innovation follows from a natural and inevitable progress, often resembling the idea of Darwinian evolution (Grint & Woolgar).

A common aspect in almost every STS approach is the attempt to give back agency to the social, which had been historically dismissed. As Grint & Woolgar argue: “The ‘social shaping’ approach is a generic label for those accounts which suggest that the capacity of the technology is equivalent to the political circumstances of its production” (Grint & Woolgar: 19). [Italics added]

**Symmetry: Explaining Society with Nature or Nature with Society**

An important reaction to claims about the objectivity and neutrality of scientific knowledge has been articulated by David Bloor’s symmetry principle. The core idea of symmetry is to point to the inadequacy of an old assumption about scientific knowledge: “that true (or rational) beliefs are to be explained by reference to reality, while false (or irrational) beliefs are explained by
reference to the distorting influence of society” (Bloor, 1999a: 84). Challenging this assumption has profound implications for the conceptualization of knowledge. The “turn” to social constructivism, in Bloor’s terms, implies that knowledge (scientific), either true or false, needs to be explained and accounted for with the same explanatory resources; this, the meaning of “symmetry”. Accomplishing such a task is what Bloor understands as the goal of the Sociology of Scientific Knowledge (SSK)\(^\text{12}\). SSK scholars argue that knowledge is not simply discovered by looking at nature, but it is constructed by and through practices of negotiation and simplification, which are also influenced by beliefs, intentions, and interests – in short, by the social. Perhaps the most well known of these reactions is the idea of black boxing inscribing values in technology.

**Black boxing: Inscribing Values in Technology**

One of most influential ideas introduced by STS and SSK is that technology acts as a black box in which values and politics are inscribed, and therefore the major task of the social scientist is to open these boxes and reveal what is inside (Winner, 1980, 1999a, Grint & Woolgar, 1997; Latour 2005). As Winner points out, the notion of black box constitutes a fundamental concern to social constructivist perspectives:

The plea frequently voiced by the social constructivists is that we open ‘the black box’ of historical and contemporary technology to see what is there. The term black box in both technical and social science parlance is a device or system that, for convenience, is described solely in terms of inputs and outputs. One need not understand anything about what goes on inside such black boxes. One simply brackets them as functions that perform certain valuable functions. (Winner, 1993:365)

\(^{12}\) The heated debate between Bruno Latour and David Bloor regarding the notion of symmetry is presented in a special issue of *Studies in History and Philosophy of Science*. Cf. Latour (1999) and Bloor (1999).
In his famous article “Do Artefacts Have Politics?” Winner (1980) argues that among the heated controversies about technology and society “there is no idea more provocative than the notion that technical things have political qualities.” (p. 121). Winner points out that the idea of ascribing beliefs and values to physical things can seem “at first glance, completely mistaken” (1999a: 12). What makes this idea seem counter intuitive (and mistaken) is that we often believe that people and not things can hold values and politics. A common reaction from STS scholars is to respond to this with the following “maxim”: “what matters is not technology itself, but the social or economic systems in which it is embedded.” (Ibid.) This idea has been crucial in defining the aim of STS. As Winner argues, by pointing to the social contexts in which technology is produced, designed, deployed, and used, the social scientist is capable of refuting the technological determinists – the idea that technology is neutral and follows a natural evolutionary progress.

Similarly, Grint and Woolgar argue that STS approaches “share the view that technological artefacts do not possess capacities by virtue of extrapolation from previous technical state of affairs, but rather that the nature, form and capacity of a technology is the upshot of various antecedent circumstances involved in its development (mainly, taken to include design, manufacture and production)” (Woolgar and Grint, 1997:97). This idea is also present in Latour’s famous paper “Technology is society made durable” (1991) in which he argues that non-human actors are crucial for the understanding of power relations in various forms of domination.

**Issues with the inscription Metaphor**

Various scholars have raised critical questions about this idea that values and politics are *inscribed* in technology. Woolgar and Grint (1997) ask: “what is ‘it’ into which politics are being
inscribed” (p. 98) and “what is exactly being built in” (1997: 99). Their critical point is to examine whether technology can be seen as a type of container in which values can be inscribed. They argue that this “metaphor” tends to underestimate the complex practices that need to be in place in order to sustain such values, beliefs, and political interests. An important methodological lesson pointed out by Woolgar and Grint is that the “embodiment metaphor often presupposes the unproblematic character of what exactly is being built in” (Ibid.). Worth noting in this critique, is that such things like political values and interests are not readily available to the researcher examining technological artefacts. They argue that values are not to be considered as objective “antecedent circumstances”, easily accessible. Rather, an “active interpretative work” is needed from the researcher or the user of technology in order to instantiate values and interests. Thus, an important warning is that “social shaping” does not occur at one given point, for instance, at early stages of design, as it is often believed.

Similarly, in the context of human computer interaction, Lucy Suchman provides evidence of the intricate ways in which plans associated with the expected functionality and behaviours of computer programs cannot be defined only by revealing the intentions of its designers. Values and politics are enacted at each stage; from design to use technology entails a “situated action” (2007). A key point in her studies is to reveal that technology cannot be simply taken as a container in which values are inscribed. If we take seriously Suchman’s notion of “situated action”, it is precisely through the re-enactment and permanent re-negotiations of intended plans inscribed by designers and the actual forms of use after design how computer interfaces achieve their agency.

Finally, an additional methodological implication pointed out by Winner (1993) is that through careful ethnographic research, the social scientist abandons the ambition for an all-encompassing
view about the causal relationships between society and technology, and for that matter, the assumptions about direct “effects” or “causes” of technological innovation in knowledge practice. As he explains:

An important aim of the social constructivist mode of inquiry is to look carefully at the inner workings of real technologies and their histories to see what is actually taking place. It recommends that rather than employ such broad-gauged notion as technological determinism or technological imperatives, scholars need to talk more precisely about the dynamics of technological change. Rather than try to explain things through such loosely conceived notions as the trajectory of a technical field or technical momentum, we need to look very closely at the artefacts and varieties of technical knowledge in question and at the social actors whose activities affect their development (Winner, 1993: 364-365) [Italics added]

3.6 Actor-Network Theory (ANT): Knowledge as a “Network Effect”

Actor Network Theory (ANT) is an eye-opening perspective to examine sociotechnical phenomena. ANT encompasses a heterogeneous body of empirical and conceptual work. Since its initial formulation about five decades ago, ANT has evolved through additions and revisions, as well as its application in various disciplines. Whether ANT should be regarded as a unified theory rather than a multiplicity of theories is a subject of contentious debate, with numerous publications addressing the evolution of ANT (e.g. Law, 1992; Law & Hassard, 1999).

ANT is an ontological and epistemological position aiming to deal with complexity and messiness and avoid simplistic reductionisms (Fenwick & Edwards, 2011). ANT’s major commitment is to challenge macro theories about society, nature, and technology, and for this reason, as John Law explains, any attempt to naturalize or reduce ANT to a single “theory” constitutes a betrayal to its origins (1999:8).

Scholars in education, management, medicine and other disciplines have explicitly adopted ANT as a research method, in particular, ANT’s anti-essentialist flat-ontology for the study of
sociotechnical phenomena, which looks at questions about knowledge, power, and organizations as “network effects” or *assemblages* emerging from the interaction among both human and non-humans.

In this section, I outline ANT’s ontological *sensibilities* and commitments and indicate how these provide a valuable *framework*\(^\text{13}\) for the conceptualization and the study of literacy practices.

A crucial aspect of ANT is to treat *social relations, knowledge, or power* as “network effects”. This idea originates from views in sociology of science emphasizing that because the processes by which scientific knowledge is established should not be taken lightly, it does not follow a linear process of *discovery*. Knowledge should be seen as a result or *effect*. As John Law describes this view about knowledge:

\[
\text{[K]nowledge is a } \textit{social product} \text{ rather than something generated through the operation of a privileged scientific method. And, in particular, they [the sociologists of knowledge] argued that "knowledge" (but they generalize from knowledge to agents, social institutions, machines, and organizations) may be seen as a product or an effect of a network of heterogeneous materials. (Law, 1992:381) [Italics in original]}
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For ANT, the *social* on its own cannot simply *explain* other phenomena, for example, in such cases in which it is said that the social “causes” something or that it has certain “effects”. The social also needs to be explained. It is in this context that the principle of Generalized Symmetry is introduced to account for the tension that has been common in sociology of scientific knowledge (see discussion about David Bloor’s notion of symmetry in section 3.3.5 “Science and Technology Studies (STS)”).

\(^{13}\) The word “framework” is used here loosely. As it will become evident in later sections, one of the issues that ANT is dealing with is precisely the notion of conceptual framework.
One of the exemplars of this approach is Bruno Latour and Steve Woolgar’ *Laboratory Life* (1979). By looking at the practices of scientists collecting soil samples in order to determine the transformation of forest and savannah ecosystems, they, literally, “follow the actors” looking at the various translations that took place from the collection and classification of samples, throughout the process of data analysis and dissemination in academic journals. In this process, the sociologists discovered that knowledge “appears in the form of skills embodied in the scientists and technicians” (Law, 1992:381), and then, that knowledge “is embodied in a variety of material forms” (Ibid.). An important aspect of this view is that what gets to be established as “knowledge” implies a complex process of negotiations, inscriptions and simplifications, rather that a smooth and linear process of discovery.

With this fundamental commitment ANT starts as a methodological strategy for examining how such things like society, power, and knowledge have come to be what they are. And, in pursuing such questions, ANT develops a vocabulary to describe the emergence and stabilization of these “network effects”. Two of the key concepts in terminology are the notions of ordering and patterning. As Law explains: “the crucial analytical move made by actor-network writers: the suggestion that the social is nothing other than patterned networks of heterogeneous materials”

This is the actor-network diagnosis of science: that it is a process of "heterogeneous engineering" in which bits and pieces from the social, the technical, the conceptual, and the textual are fitted together, and so converted (or "translated") into a set of equally heterogeneous scientific products. (Law, 1992:381)

ANT’s commitment to the study of the patterning of heterogeneous materials (networks of human and non-humans) assumes that in the process constructing knowledge involves “translations” in which inevitably some resistances have been overcome.
3.7 DIY and Maker initiatives as Sociotechnical Literacies

In the process of refining my research project and looking for conceptual and methodological strategies to address them, I have provided a foundation for the study of knowledge practices in current DIY initiatives and maker initiatives. My research questions and methodological strategy have been grounded in New Literacy Studies, Science and Technology Studies, Activity Theory, as well as theories of situated learning and distributed cognition. I conclude this chapter with a review of recent studies in Human Computer Interaction (HCI) and various perspectives in design that I see not only as emerging studies specifically adopting some of the conceptual and methodological frameworks that I provided, but also, and more importantly, because these are the fields to which I expect my dissertation can provide a valuable contribution.

3.7.1 Beyond Technological “Support”

Since the foundation of research fields studying the various ways in which technology can assist work and educational settings, such as Computer Supported Cooperative Work (CSCW), Computer Supported Collaborative Learning (CSCL), and Human Computer Interaction (HCI), the definition of technological support and mediation has been open to extensive discussion. In organization, management and information studies the notion of “computer supported” or “computer assisted” has often been correlated with an increase in productivity, efficiency, and management.

One of the key issues with these formulations of technological “support” is that they tend to see literacy and knowledge practices only through the assumption of clearly specified skills and outcomes, and as a result, technology is not understood as a fundamental component of cognition but merely as something that “supports” work of learning practices.
Major shifts in the orientation of design of information artefacts has taken place after at least four decades of research in sociology of knowledge, Science and Technology Studies, and Actor Network Theory (e.g. Latour, 2005; Bijker & Law, 1992; Grint & Woolgar, 1997). Today it is widely acknowledged that enhancing working or learning environments by means of the implementation of information technologies is not straightforward. In fact, researchers in these fields contend that the very notion of technological support, enhancement, or assistance does not depend exclusively, and perhaps often not primarily on technical knowledge or skill (e.g. the use of information systems), but more importantly, on users’ abilities to filter, interpret and critically assess information, as well as the ability to engage and enact collective practices among peer workers and learners.

Ethnographic studies of information and knowledge practices reveal that creative and innovative forms of knowledge are always situated within specific socio-technical contexts (Bowker and Star, 1999; Latour, 2005, Suchman, 2007) and communities of practice (Lave & Wenger, 1991; Cook & Brown, 1999; Duguid, 2008; Lave, 2011) that make possible and sustain such practices.

3.7.2 New Trends is Human Computer Interaction

Increasingly, the focus of research on emerging forms of sociotechnical practice is moving far beyond notions of enhancement, efficiency or productivity. Recent orientations in HCI informed by STS and ANT frameworks as well as design and art point to research emphasizing how the definition of the purpose and expected forms of use of technology are expanding towards new creative and often unexpected ways. Bill Gaver (2009) reminds us that there has

14 This move “Beyond efficiency and productivity” is extensively discussed by Andrew Feenberg (1999)’ “Questioning Technology”. One of his key arguments is that these predominant values in the conceptualization of technology tend to disregard normative and political dimensions.
been a “real revolution”: “computing is leaving the confines of task-oriented, focused, rational work, and joining us in our homes, on the street, at parties […]” (Gaver, 2009:164). Yet, and despite the increasing publications indicating these trends, a significant number of researchers looking at knowledge practices and the design of information systems “have been slow to appreciate the implications of technology’s incursion into our everyday lives.” (Ibid.)

Researchers looking at this “revolution”, indicated by Gaver, include for example, scholars studying information artefacts designed for non-conventional purposes, “evocative” interpretations, as well as various “levels of engagement”, and “enjoyment of use” (Boehner & Sengers, 2005; Sengers and Gaver, 1996; Boehner, 2006); others indicate the need for methods and intervention strategies fostering critical thinking about the social, ethical, and political ramifications of technology (Ratto, 2011a), and deep understanding of the co-construction of technological and social forces (Lukens & DiSalvo, 2012: 33). Similarly, scholars looking at DIY initiatives and Maker movements emphasize the need for a better understanding of emerging values in technology design such as hack-ability and re-purpose-ability (Galloway, 2004), which constitute a radically different orientation in design as they are aimed at openness and enable users to adapt and transform information systems according to diverse needs and interests.

### 3.7.3 Critical and Reflective

Critical perspectives to the design of the sociotechnical include an emerging body of research focused on exploring the process of material fabrication as means for critical reflection. Ratto (2011a), for example, argues that an important motivation of Critical Making (CM) is to address a predominant tendency in current research: the “deeper disconnect between conceptual understandings of technological objects and our material experiences with them” (p. 253)”
(Ratto, 2001a). CM can be described as a perspective engaged in the exploration of new materials and technologies assisting the fabrication of physical objects. However, CM is also a method committed to examine, elicit, and challenge the co-constitution of materiality and the social, cultural, as well as political ramifications. Ratto explains the key motivation of CM research as follows:

[T]he issue I want to understand is the seeming disconnect between deterministic, conceptual understandings of the role of technology in social life, and the more material and nuanced understanding of how one relates to them. (2011a: 253)

The emphasis on a “nuanced understanding” of sociotechnical practices has also been an emerging trend in current research in Human Computer Interaction. Boehner et al. (2005) suggest that current DIY and Maker initiatives constitute vivid examples of resistance to traditional values that had informed the design and use of technology (e.g. efficiency or productivity). Some of these emerging values or “metrics” include for example “levels of engagement, enjoyment of use, integration with everyday experiences, the variability of use or capacity for re-appropriation” as well as “critical reflection, emotional experience, interpretive flexibility” (Boehner & Sengers, 2005).

The idea that information systems are “Interpretatively flexible” (Pinch & Bijker, 1995) has been well-known by researchers in STS and HCI. Suchman (2007) for example emphasizes this with her notion of “human-machine reconfigurations”, which indicates how the interaction with information artefacts (e.g. graphic user interfaces) always implies a re-negotiation with the “final” users and re-adaptation to specific contexts of use. Similarly, Grint and Woolgar (1997) describe the interpretative flexibility of technology by exploring the diverse negotiations and interpretations that users have when they are asked to follow the instructions in user manuals.
Of chief importance in emerging critical perspectives is the deliberate attempt to design information systems fostering critical reflection. In “Designing for Interpretation”, Sengers and Gaver (2005) describe this initiative in design as “providing software that encourage[s] people to reflect on their activities and aspirations” (2005). Similarly, Boehner et al. (2005) stress that systems can “embody cultural critique”, and thus “may be designed, not to do what users want, but to introduce users to new, critically-informed ways of looking at the world around them.”

The shift towards critical reflection as a guiding principle in the design of information systems has also important methodological implications. The method of study should not be seen as a conventional “intervention”. As Boehner explains: “reflective design is characterized not as an intervention but as a practice of participative inquiry” “[b]ecause of its focus on both designers and participants in the design process” (Boehner, 2006:368). Furthermore, the focus on co-design between participants and designer leads to an important methodological insight. “User appropriation of systems” becomes a valuable evaluation metric (Sengers & Gaver, 2005). Although these non-conventional metrics are yet under-researched, and there is a need for exploring new alternatives, a key insight in these initiatives is that they reframe the aim of the research from efficiency and productivity to advancing social sciences theories for understanding literacy and meaning making in everyday practice.

3.8 Conclusion

In this chapter I have examined influential theories that have contributed to shift the understanding of literacy practices, and cognition more broadly, as a complex interaction of social and technical dimensions that cannot be merely reduced to a set of skills. These theories have provided a conceptual and methodological framework that allows re-defining the “literacy
problem”, which I have called the theories of the sociotechnical. The key idea of this approach to is to recognize the role physical and social dimensions operating as tools of mediation. Finally, the sociotechnical approach to literacy reveals a situated phenomenon of co-construction of identity, cognition, and participation. For these reasons it points to the inadequacy of sharply separating formal/informal settings, as learning is a process better characterized as a process of developing identities through participation in diverse communities of practice. In Chapter 4, I discuss the methodological implications that arise when a researchers is informed by a sociotechnical approach to literacy practices and in Chapter 5 I outline the research strategy used in to conduct my studies.
Chapter 4
Methods

In this dissertation, I aim to better understand the literacy practices that take place through the engagement in the design and fabrication of prototypes using DIY microelectronics. The overarching research question motivating my project is: what are the affordances of variable levels of sociotechnical encapsulation in fostering inquiry practices and cognitive trajectories?

In order to address this question, I used a mixed-methods approach and a triangulation of data sources in order to collect sufficient and rich data to increase the reliability of my findings. While the research approach adopted elements from ethnographic research, discourse analysis, research in New Literacy Studies, and Science and Technology Studies, I was mainly informed by the ontological and epistemological sensibilities initiated by Actor Network Theory.

In this chapter, I discuss the conceptual frameworks that inform my research design and provide a rationale for the case studies presented in the following chapter.

4.1 Conceptual Frameworks
4.1.1 Social Constructivist Lessons for the Study of Literacy

In order to address the importance of conceptual frameworks in the design of a research strategy, Crotty (1998) suggests that a research design needs to start by asking three fundamental questions: “1. What knowledge claims are being made by the researcher (including a theoretical perspective)? 2. What strategies of inquiry will inform the procedures? 3. What methods of data collection and analysis will be used?” (Crotty, 1998 cited in Creswell, 2008:5).
These questions imply that every methodological approach is grounded in particular views ("knowledge claims") about what the object of study is (ontology), how it can and will be studied (epistemology), and what specific instruments and procedures will be used when collecting and analysing the data (methodology). As Creswell points out, designing a methodological strategy and identifying a theoretical perspective “means that researchers start a project with certain assumptions about how they will learn and what they will learn during their inquiry” (2008:6).

My research questions and research design are informed by the ontological and epistemological insights discussed by scholars in New Literacy Studies (NLS), Science and Technology Studies (STS), and Actor Network Theory (ANT). Although there are important differences in how these fields define their purpose and select their research strategies, it can be argued that these approaches are examples of qualitative research adopting a social constructivist orientation in the definition of its object of study. NLS, STS, and ANT incorporate theories and methods from anthropology, sociology, and psychology, and as is indicative of qualitative research, they focus on “discovering and understanding the experiences, perspectives, and thoughts of participants” (Harwell, 2011:148).

Differently, and in some cases explicitly against quantitative controlled studies informed by positivist views and attempting to “maximize objectivity, replicability, and generalizibility of findings” (Ibid), social constructivist research starts with the assumption that “individuals seek understanding of the world in which they live and work” (Creswell, 2008). The main ontological commitment is that that people “develop subjective meanings of their experiences-meanings directed toward certain objects or things. These meanings are varied and multiple, leading the researcher to look for the complexity of views rather than narrowing meanings into a few categories or ideas” (Creswell, 2008). Hence, adopting a constructivist framework has important
methodological implications. The researcher needs to “rely as much as possible on the participants views”. The researcher “listens carefully to what people say or do in their life setting” and the “discussions or interactions with other persons” (Creswell, 2008:9).

Throughout my review of the literature, I introduced some of the key conceptual and epistemological claims that scholars in NLS, situated and distributed cognition, STS and ANT provide for understanding and studying literacy practices. From these perspectives about literacy, and human cognition more broadly, we learn that in order to understand literacy practices we need to address complex interactions; mainly, the co-constitution of social, cultural, political, and technical dimensions. Reviewing the limitations of a functional definition (literacy as a universal technical skill), we discovered that literacy is a dynamic social practice (Gee, 1991, 1999; Street, 1984, 1997, 2003); it requires the ability to reflect on our own knowledge practices (Barton, 2000); and it entails the ability to engage in complex forms of thinking and discovering a “variety of orders” (Law & Mol, 2002:7). Moreover, one of the crucial claims informing my research is that literacy practices can be understood as “network effects” (Law, 2002). This implies that in order to understand how knowledge is constructed, the researcher needs to carefully examine the processes of translation, stabilization, and encapsulation taking place in any claim made about facts or evidence (Latour & Woolgar, 1979).

This idea introduced by researchers in STS and ANT has been crucial, not only in the definition of my research questions, but also in informing how I studied the impact of sociotechnical encapsulation in literacy practices. The construction of knowledge entails a process of progressive (yet not necessarily linear) moments of openness and closure of “black boxes”.

72
In the following section, I discuss why this notion of encapsulation (black-boxing) is crucial for studying literacy practices, and highlight its methodological implications.

4.1.2 Encapsulation and Literacy Practices

A traditional view of encapsulation tells us that black-boxing entails the inscription of values and politics in technological artefacts (e.g. Bijker et al., 1987), leading to various forms of exclusion (Law & Mol, 2002), or preventing customization and re-purpose. Yet, a different view describes encapsulation as a fundamental mechanism in achieving cognitive success; for example, in mastering expert practices (Lave & Wenger, 1991; Polanyi, 1966; Vygotsky 1978), managing cognitive and perceptual overload (Sweller et al., 2007), or achieving higher levels of abstraction (Cussins, 1992; Latour & Woolgar, 1979).

These two views are not mutually exclusive but complementary. Opening a black box does not necessarily lead to overcoming forms of exclusion or fostering new forms of participation or literacy (Cf. Winner, 2003). Nor should the opening of technological black boxes be seen as leading to an increase of knowledge, literacy, or empowerment, necessarily; at least not autonomously, as Street and other scholars in NLS argue against this model of literacy (see Chapter 2, section 2.2.3). The idea of absolute “transparency” (as opposed to black boxed) fails to recognize that complex problem solving, and more broadly, meaning making, operates always within a tacit context or background. Recognizing the cognitive role of encapsulation leads the researcher to look at the practices by which the social and the technical can be re-arranged, re-stabilized, and re-encapsulated, so that they may eventually afford different understandings, as well as new forms of interaction.
An important methodological implication is that understanding encapsulation as a cognitive mechanism brings attention to how social and technical aspects mediate and co-construct literacy practices. This view entreats the researcher to look at the processes of openness and closure. Thus, the primary methodological strategy articulated by ANT: “follow the actors” (Latour, 2005). This strategy suggests that in order to understand how actor-networks are formed, the researcher must examine how the trajectories of (sociotechnical) encapsulations enable (or prevent) specific types of knowledge (literacy practices) within specific contexts.

The key idea is that if we understand literacy as the ability to enact, perform and engage in coordinated practices that recruit both social and technical resources (Lave & Wenger, 1991; Hutchins, 1995), sociotechnical encapsulation reveals itself as a fundamental characteristic of literacy.

4.2 Research Aim: Diagnostic and Transformative

With my research, I am seeking both diagnostic and transformative outcomes. The aim is diagnostic as my goal was to observe and document participants’ cognitive trajectories through the design and fabrication of DIY microelectronics. I studied these practices by gathering information about how different levels of encapsulation in the electronic toolkits and instructions provided to participants could lead to different interactions among their peers, emerging forms of talk and improvisation, as well as influencing the level of engagement and motivation. The case studies presented in the next chapter were designed to better understand participant’s uncertainties and expectations about the role of technology, not only in their everyday lives, but also about participants’ insights about possible applications of DIY initiatives in the classrooms.
The aim of my research was also *transformative*. I expected to enhance participants’ understanding of the complex interactions between social and technical dimensions, and raise awareness of the potential and empowering roles of DIY and maker initiatives as examples for creative and responsible participation in society. Finally, a chief motivation of my overall project was to advance both pedagogical strategies and the design of DIY microelectronic toolkits created to encourage participant’s discussion and reflection about the forms of use that have been inscribed by designers in several of the technologies we interact with today. In this regard, the case studies aimed to explore how the engagement with variable levels of encapsulation could also provided participants the possibility of re-negotiating and re-imagining their relationships with technology. In particular, I expected to better understand how the DIY microelectronic toolkits could allow participants to explore customization and adaptability, as they engaged in discovery and experimentation throughout the interventions.

### 4.3 Research Approach

In previous sections I discussed how New Literacy Studies (NLS), Science and Technology Studies (STS), and Actor-Network Theory (ANT) conceptualize literacy practices and why sociotechnical encapsulation is a fundamental mechanism in complex forms of human cognition. In this section, I move to an examination of the specific research methods that I used to investigate the cognitive trajectories that emerge in the design and fabrication of DIY microelectronics.

#### 4.3.1 Multi-sited Ethnography

Marcus (1995) suggests that “multi-sited” ethnography has become an influential trend in interdisciplinary approaches, such as in media studies, science and technology studies, and
cultural studies more broadly. The notion of multi-sited implies a shift from “traditional” ethnographic studies, in which the researcher is expected to engage with a single site for a long period of time. Creswell describes this traditional approach in conducting ethnographies as follows:

(…) the researcher studies an intact cultural group in a natural setting over a prolonged period of time by collecting, primarily, observational data (…). The research process is flexible and typically evolves contextually in response to the lived realities encountered in the field setting (Lecompte and Schensul, 1999). (Creswell, 2008:16) [Italics added]

Major difficulties have been found in this view of ethnographic research. Over the last few decades, one of the key discussions in anthropological research is precisely to contest the notions of “intact culture”, “natural setting”, and the very idea that the ethnographer is merely a neutral observer (Cf. Marcus, 1995, 2008; Hess, 2001; Gallagher & Freeman, 2011).

The shift towards multi-site ethnographic research has been led primarily by the need to account for socio-cultural practices that are not homogenous in time and space. As Marcus (1995) explains:

[...] ethnographic research self-consciously embedded in a world system, now often associated with the wave of intellectual capital labelled postmodern, moves out from the single sites and local situations of conventional ethnographic research designs to examine the circulation of cultural meanings, objects, and identities in diffuse time-space. (Marcus, 1995:96)

Multi-sited ethnography is directed to the study of an object “that cannot be accounted for ethnographically by remaining focused on a single site of intensive investigation” (Marcus, 1995:96). Multi-site ethnographic research implies, then, a “mobile ethnography” or the idea that the ethnographer is a “circumstantial activist”. An important methodological implication is that moving across research sites, the “identity of the ethnographer requires renegotiation” (Marcus, 1995:112). This negotiation of the researcher’s identity implies the adaptation to the specific
characteristics of the research settings. Although this could be seen as detrimental to the
objectivity and the impartiality of the researchers, for example in cases when the researcher
needs to play different roles (e.g. consultant, participant, or informant), Marcus argues against
this view by indicating how ethnographic work cannot assume the position of a “detached”
scholar. Rather, the adaptation of the researcher, its mobility, is in some cases strategic and
desirable. As he explains:

In conducting multi-sited research, one finds oneself with all sorts of cross-cutting and
contradictory personal commitments. These conflicts are resolved, perhaps ambivalently,
not by refuge in being a detached anthropological scholar, but in being a sort of
ethnographer—activist, renegotiating identities in different sites as one learns more about
a slice of the world system (Marcus, 1995:113)

4.3.2 Discourse Analysis (DA)

Discourse Analysis is not a unified body of theory or a unique methodology with straightforward
recipes to be followed. The study of language and literacy practices, as it is presented in multiple
forms of text such as oral, written, or signed languages, entails enormous challenges: from the
identification of multiple genres of language to the selection of assessment criteria. As Gee et al.
(1992) suggest: “The term “discourse analysis” covers many dissimilar enterprises and analytic
purposes, including ethnomethodological studies of conversation (Sacks, 1974; Sacks, Schegloff,
and Jefferson, 1977; Schenkein, 1978); analyses of speech events (Hymes, 1962; Gumperz,
1982; Ochs and Schieffelin, 1983), as well as other forms of microanalysis of discourse (Gee et

Despite the diversity of approaches, a key intuition in discourse analysis is that “micro”
structures and specific uses of language can reveal crucial aspects about how people perceive,
experience, and value. As Gee explains, “discourse analysis is a theory and a method for
studying how the details of language get recruited, ‘on site’, to ‘pull off’ specific social activities
and social identities” (1999:1)

This idea highlights some underlying principles; particularly, the social and organizational discourses that shape these practices. Gee et al. (1992) point out that discourse is “produced by speakers who are ineluctably situated in a sociohistorical matrix whose cultural, political, economic, social, and personal realities shape the discourse.” Further, “discourse itself constitutes or embodies important aspects of experience and, at the same time, constitutes important parts of that sociohistorical matrix.” (Gee et al., 1992: 228)

For the purposes of my research, this fundamental aspect of discourse analysis is particularly relevant: text is socially situated and the use of language is inherently dialogic. This perspective is grounded in the works of Bakhtin, Vygotsky, and Wittgenstein who emphasize that even forms of discourse considered “private” are often dependent on common agreements and categories; they only occur as co-constructed understandings. As Gee writes, “When a monk meditates alone in the desert, when one reads or writes privately, it is still a culturally grounded, social activity.” (Gee et al., 1992: 235)

In order to study the wide range of discursive practices, a key methodological strategy is to examine how things are “talked about”; how participants develop their own language to think and talk about a particular phenomenon. As Finlay (1987) explains in the following definition of discourse analysis:

[D]iscourse analysis is the study of the way in which an object or idea, any object or idea, is taken up by various institutions and epistemological positions, and of the way in which those institutions and positions treat it. Discourse analysis studies the way in which objects or ideas are spoken about. (Finlay, 1987:2, cited in Frohmann, 1992: 367)

In Chapter 5, I will describe in detail how the case studies provide activities in which participants were able to engage in developing their own of “talk” through the process of fabricating and
exploring with DIY microelectronics. For the moment, it is crucial mentioning that discourse analysis informed my research strategy by leading me to explore the design of intervention activities through which participants had the opportunity to develop a language to “talk about” their interactions and expectations with DIY electronics, and technology in their everyday life more broadly. The key aspect of discourse analysis as a methodological strategy is to emphasize the limitation of asking participants what they think, especially if the object of analysis is unknown or they have had little experience with it. Instead, discourse analysis invites the researcher to find ways to study what participants think and believe by observing the various ways in which they talk about a particular object or idea, as well as facilitating scenarios and discussions through which participants can form opinions and understandings.

### 4.3.3 Grounded Theory

Grounded theory is a methodology that seeks to construct theory about issues of importance in people’s lives (Glaser, 1978; Glaser & Strauss, 1967; Strauss & Corbin, 1998). It does this through a process of data collection that is often described as inductive in nature (Morse, 2001), in that the researcher has no preconceived ideas to prove or disprove. Rather, *issues of importance to participants emerge from the stories that they tell about an area of interest that they have in common with the researcher.* (Mills et al., 2006:26-27) [Italics added]

My research strategy adopted a general idea in Grounded Theory research: the search for emergent themes from collected data focuses on eliciting issues of importance rather than proving or disproving hypothesis (Mills et al., 2006). However, my approach cannot be considered exclusively a Grounded Theory research. I started with specific theoretical foundations provided by New Literacy Studies (NLS), Science and Technology Studies (STS), and particularly, the notion of *cognitive trajectories* (Hutchins, 1995, 2011; Cussins, 1992) discussed earlier in Chapters 2 and 3. These foundations provided a working hypothesis that my studies attempted to validate and explore in the context of DIY microelectronics: mainly, the
intuition that modifying the levels of sociotechnical encapsulation can lead to emerging forms of literacy practices.

However, the data collected throughout my studies, including empirical observation, analysis of discursive and material fabrication practices, as well as multiple complementary interviews and notes from informal conversations, were intended go beyond proving or disproving one single hypothesis about the role of sociotechnical encapsulation in affording cognitive trajectories. In fact, the research design was the result of a deliberate attempt not only to understand participant’s views and expectations, but also more crucially, to provide a research setting in which both participants and the researcher could explore and discuss aspects of sociotechnical encapsulation in the formation of emerging literacy practices and its relevance and potential application to the classroom settings.

4.4 Conclusion: How to Study DIY and Maker initiatives

DIY and Maker initiatives encompass diverse and often loose communities and practices. In many cases they are not well-established communities that can be studied by traditional “single” site ethnography. Differently, these initiatives encompass a variety of settings and motivations, as well as fabrication materials and techniques (Buechley et al. 2007, 2008). These initiatives include diverse communities: from hobbyists and amateurs to expert computer programmers and engineers working with open software and hardware solutions. DIY and Maker initiatives encompass as well the participation in multiple social media platforms such as Facebook, Flickr, and YouTube for the distribution and sharing of documentation about how to build specific artefacts. Two prominent examples include the websites “iFixit: The free repair manual”
and “Instructables - DIY How To Make Instructions”
(www.instructables.com), which illustrate a diverse spectrum of DIY and Maker projects.

Given the heterogeneous composition of DIY and Maker communities, I have been cautious in arguing that my research approach is strictly ethnographic. If we agree with Marcus (1995) and others (cf. Hess, 2001) that the new generation of STS and ANT research needs to examine how the limitations of the traditional one-site ethnographic approach prevents the understanding of certain emerging practices, then it becomes key to engage in a multi-sited ethnographic strategy for the study of DIY initiatives. The interventions that I present in the following chapter constitute a methodological exploration in this direction, in the sense that I adopted data collection procedures common to ethnographic studies such as interviews, participant observation, and a researcher diary, but in order to increase the reliability of my findings, I also collected comparative data across multiple research sites that allowed me to iteratively refine the research design.

Although researchers of DIY communities often do not frame their studies as multi-sited ethnographies, a common aspect for instance in Jenson et al. (2011) examining virtual communities and video games, Galloway (2004, 2008, 2013) looking at urban computing and locative media, and Buechley et al. (2008, 2009) specifically studying the fabrication of DIY wearable microelectronics, is that they all engage in the study of multiple sites and diverse groups of participants in order to explore a specific research focus and increase the reliability of their findings.

Actor-Network Theory (ANT) suggests to “follow the actors” (Latour, 2005). In order to understand knowledge practices the researcher needs to look at the processes of translation and
stabilization (black-boxing/encapsulation) taking place amongst a particular group of actors in contexts. However, since DIY and Maker initiatives encompass such a variety of practices it revealed itself to be difficult to point to a distinct group of actors to be “followed”. Attempting to “follow the actors” may be impossible, if not inadequate for the study of DIY and Maker initiatives. Attempting an ethnographic study of these communities reveals inevitably fragmentary since they are distributed across multiple sites and used multiple online platforms. It could be argued that due to the diversity of practices and actors involved in DIY and Maker initiatives there may not be representative actors to be followed.

Throughout my own process of immersion into DIY and Maker initiatives and the review of inspirational work such as Ratto (2011a), DiSalvo (2012a), Buechley et al (2009), Sengers and Gaver (2005), Sengers et al (2005), Boehner (2006), Jeremijenko (2014), among others, I started to identify unique aspects in these initiatives that indicate emerging knowledge practices associated with the production and use of information systems and resources, such as specific learning trajectories that involved the engagement with the fabrication of electronic artefacts or innovative forms for documentation and sharing experiences. As I progressed in my immersion into DIY and Maker initiatives, these cognitive trajectories gradually became the focus of my attention, as I discovered similarities as well as differences, depending on the type of tools and the structure activities involved.

The more I learnt about DIY and Maker initiatives through my own explorations and becoming familiar with the emerging literature, I realized that there was not a unified strategy for studying these initiatives. I discovered that DIY and Maker practices encompass a variety of communities and for this reason, in order to design a research strategy, I had to first immerse myself into the
design of specific DIY projects and learn about the diversity of materials, technologies, and resources used by these communities.

In this process, I discovered that DIY and Maker initiatives are heterogeneous phenomena and this implies that they should not be understood as a distinct practice or community, but rather that they need to be considered as emerging forms of sociotechnical practice demanding the exploration of new research strategies. As these initiatives constitute a rapidly changing object of study, one of the major challenges includes a constant review of conceptual frameworks that can better assist the researcher in selecting a particular focus, and at the same time, the need for rigorous empirical observation and direct engagement in the fabrication of DIY artefacts and Maker projects.

In the next chapter, I move to the presentation of the case studies that I conducted, informed by these conceptual and methodological directions. I will describe the evolution of my interventions that started with my own explorations designing DIY and Maker toolkits and experiences, and then the results of studying specific variations in sociotechnical encapsulation with a community of high school teachers.
Chapter 5
Encounters with Sociotechnical Encapsulation

Scholars suggest that the selection of particular frameworks for the study of literacy practices has fundamental implications in defining the purpose of a study, as well as specific methodological decisions about how the studies can and should be conducted. So far, I have presented an analytical approach pointing to the diversity of DIY and Maker initiatives and how they entail heterogeneous communities of interests, materials, and resources. I have highlighted that when attempting a formalization of DIY and Maker initiatives as an object of study, the researcher must learn to be cautious in order to avoid overgeneralization, which may result in simplifications of the complexity of these practices. This is to avoid betraying the values of openness and exploration inspiring DIY and Maker initiatives.

In this chapter I present the trajectory that I followed to design intervention strategies informed by frameworks and orientations in the conceptualization of literacy practices such as New Literacy Studies (Street, 1995, 1997b; New London Group, 1996; Gee, 2000, 2004), as well as the notions of Situated Learning (Lave and Wenger, 1991) and Distributed Cognition (Hutchins, 1995, 2012).

My research strategy did not follow a linear trajectory; it was the result of my own explorations and inspiration from other researchers currently addressing DIY initiatives and Maker movements in a variety of disciplines. The results presented in this chapter entailed long process. The first stage was a period of exploration and testing with DIY artefacts and participation in various DIY and Maker events. The second entailed the design and refinement of the DIY experiences, including the design of workshops activities and electronic toolkits that could assist
me in the examination of sociotechnical dimensions and its pertinence for the study of literacy practices.

The first part of this chapter describes the activities and projects that I conducted in order to deepen my understanding of DIY and Maker initiatives. I introduce the pilot studies that helped me to become myself an avid DIY Maker and the projects I engaged in as a preparation for a more systematic approach presented in the second part of the chapter. I highlight how these preliminary activities led me to discover and articulate the notion of sociotechnical encapsulation and its pertinence for the study of literacy practices emerging in DIY and Maker initiatives. In the second part of the chapter, I present the core case studies conducted, in which I introduced variations in the level and type of sociotechnical encapsulation in order to observe and document emerging cognitive trajectories. The chapter concludes with a summary of the findings and the overarching themes that emerged throughout the studies. These themes will be further analyzed in more detail in the following chapter.

5.1 Part I - Designing Experiences with DIY Electronics

Currently, most of the microelectronics used in mobile devices such as cell phones, tablets, and laptops, are designed as closed-systems, which often prevent adaptation or the use of these devices for purposes not intended by its designers. This issue has been well documented by researchers in Human Computer Interaction, pointing not only to the advantages of open hardware and software, but also to the challenges entailed in attempting to define all the possible affordances of a technological artefact at early stages of the design process (Suchman, 2007; Grint & and Woolgar, 1997). The forms of use expected by the designers are always defined and
transformed when the artefacts reach the final users. The idea of exploring the affordances of open and flexible technologies was greatly inspired by these initiatives in HCI.

In this section, I present some of the projects that contributed to my own exploration with the notion of sociotechnical encapsulation. The projects described here constituted an engagement in the process of fabrication of DIY electronic toolkits that could specifically address some of the challenges I identified attending to DIY and Maker events, as well as the issues encountered when conducting my own workshops directed to introduce participants to DIY electronics.

5.1.1 Critical Making: Connecting the Material and the Conceptual

In order to become familiar with DIY and Maker initiatives, it is crucial to immerse oneself into the processes of making, testing, and experimenting with different materials, and artefacts. My first introduction to DIY and Maker initiatives involving the use of open hardware and software was at the Critical Making class at the Faculty of Information, taught by Professor Matt Ratto in 2008. Through this class I learnt about various conceptual frameworks used in Science and Technology Studies (STS) and engaged in the fabrication of devices deliberately designed to provoke and engage people in critical thinking. One of the challenges we explored was the design of artefacts that could lead to reflection on issues such as privacy and surveillance, agency, and embodiment by engaging in the process of fabrication and re-purposing of technology.

During this time, I had the opportunity to explore and contribute to different projects that allowed me to discover the possibilities and complexities involved in DIY and Maker initiatives. In collaboration with other master’s students at that time we developed various projects that allowed us to discover how off-the-shelf technologies, such as TV remote controls or wireless
video consoles like the Nintendo Wii, could be repurposed and hacked. These explorations were significant as we learnt that existing technologies could be used for various different purposes and transformed to create evocative artefacts engaging people in other types of interactions reflective of sociotechnical issues. Through these explorations, I became particularly interested both in how these DIY artefacts could create interactive spaces connecting physical and digital worlds and how they could be a valuable setting for the study of emerging literacy practices or use as pedagogical resources.

One of the key findings at these early stages of my research was the idea of inscription of values in technology. As we explored this idea through the reading of STS scholars and the re-design and repurposing of existing technologies, Critical Making revealed itself not only as a practice for opening the black boxes of technology and examining the values and purposes initially intended by its designers, but also as a critical practice by the inscription or encapsulation of different values, such that artefacts could lead to new interactions and ultimately, to reflections about the complex relationships between technology and society.

5.1.2 DIY and Maker Events: Learning through Participation

Since 2008, I have participated and organized numerous events and workshops on DIY electronics. In these experiences with DIY and Maker projects and communities I assumed different roles, from being a curious observer in DIY and Maker events to being a mentor and organizer. The table below outlines some of the events and activities that allowed me not only to gain direct access to DIY and Maker culture and communities, but also contributed to my own learning process about the challenges and possibilities of DIY microelectronics.
### Table 3 - Participation in DIY and Maker Events

<table>
<thead>
<tr>
<th>Event</th>
<th>Location/ Date</th>
<th>Type</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Children's Own Media Museum</td>
<td>Harbourfront Centre, Toronto. May 2013</td>
<td>Arduino workshop</td>
<td>Mentor</td>
</tr>
<tr>
<td>DIY Prosthetics Workshop</td>
<td>Manizles, Colombia. April, 2013</td>
<td>Arduino workshop</td>
<td>Mentor/Organizer</td>
</tr>
<tr>
<td>CHI2014 Workshop/Hackathon,</td>
<td>CHI2014 Conference. Toronto. April, 2014</td>
<td>Hackathon/Arduino Workshop</td>
<td>Developer/Mentor</td>
</tr>
<tr>
<td>Maker Faire at Toronto Public Library</td>
<td>Toronto. September, 2013</td>
<td>Maker Fair</td>
<td>Participant</td>
</tr>
<tr>
<td>Get-YourBot-On – Hackathon Introduction to Arduino Workshop</td>
<td>Toronto Science Centre November, 2014</td>
<td>Hackathon, Arduino workshop</td>
<td>Mentor/Participant</td>
</tr>
<tr>
<td>DIY Water Quality Sensing at Subtle Technologies Festival</td>
<td>Toronto. May 2014</td>
<td>Arduino Workshop</td>
<td>Mentor/Organizer</td>
</tr>
</tbody>
</table>

**Learning on the Spot: Short Time and Unclear Targets**

When acting as a participant at these events, I started to become particularly interested in the open-ended and loosely structured dynamic of these activities. A Hackathon or a Maker Faire encompass a particular type of activity, in which participants engage in tasks of making and learning a particular topic. The duration of these events ranges from a few hours to sessions that can last a few days, or even weeks. The audience attending these events can be quite diverse, often ranging from curious beginners expecting to learn about new gadgets or emerging
technologies, to expert hobbyists, and mentors attending to showcase their own projects, provide assistance, and share their knowledge.

One of the key aspects that captured my attention at these events was that the informal tone and the loose structure of activities seemed to foster motivation and collaboration among participants. Hackathons, in particular, are framed as a contest that brings together diverse audiences, skills, and resources often leading to different types of interactions and negotiations towards the definition of the goal and purpose of artefacts. In other cases, participants are given a pre-defined target or challenge, but in more open-ended and experimental events, participants have to explore and learn first about what is possible through the process of designing, making, and engaging in discussions with other peers and mentors.

**Technical Complexity: Finding a Balance between Showing and Hiding**

When acting as a mentor and organizer of DIY workshops, I discovered that the preparations for these activities required careful assessment of the complexity and level of skill to be required from participants. Participants can often be intimidated, frustrated or even disappointed if they encounter tasks that are beyond their current abilities or skill. For this reason, I started to realize that on some occasions hiding certain technical details could motivate participants by allowing them to engage in the task and create functional artefacts, which they would not have been able to build otherwise. This observation was influential in discovering the importance of encapsulation for the study of literacy practices emerging in DIY and Maker initiatives, as it indicated the need to assess the appropriate level of skill and knowledge that will be required for the fabrication of DIY electronics.
In Chapter 3, I introduced Vygotsky’s notion of “Zone of Proximal Development” ZPD (1978), which suggests that engaging in tasks that are beyond the current level of skill and knowledge can have a significant role in the development of new cognitive skills and knowledge. What is key for understanding the pertinence of DIY initiatives as a setting in which to study and eventually foster literacy is that the complexity of the instruction given for the fabrication of a DIY artefact needs to be attuned to the level of the skill and knowledge of the participants, but it can also act as a cognitive scaffold leading participants to explore new cognitive trajectories.

One of the early challenges that I had to face during the design of my workshops was the need to reduce the level of complexity in the tasks and the electronic toolkit. In the cases in which participants had no previous experience, it seemed pertinent not to reveal some of the more technical details of the artefact, and rather, hide this complexity in order to facilitate not only the fabrication of functional artefacts in the short periods time, but more crucially, to foster curiosity and encourage participants to continue with their own explorations.

In the following section I present my experimentations investigating how different types of encapsulation could assist in the design of DIY activities and toolkits deliberately intended to engage participants without any prior knowledge or experience with electronics. These explorations resulted in three iterative pilot projects, which led me to the definition of the types of sociotechnical encapsulation that I used in the studies discussed later in this chapter.

5.1.3 Encapsulating Input/output Connections

The first project exploring variations in encapsulation was a personal study conducted at the Critical Making Lab at the Faculty of Information for a period of two months in the fall of 2013. During this period I explored how different types of circuits could be encapsulated (hide)
through the construction of a printed circuit board (PCB), so that participants using this pre-assembled circuit would not have to learn the internal complexity of the wiring connections. The focus of this project was limited to experimentation with the construction of a PCB that could be easily attached to inexpensive and widely available micro controllers, such as the Arduino Mini-Pro (See images bellow). These type of extensions to existing circuit boards are known as shields – which are electronic circuits that can be attached in order to simplify its use or extend its capabilities. For example, shields may include standardized connectors that prevent users from making mistakes connecting the wires or radio frequency antennas allowing a DIY project to connect wirelessly to other devices. Shields can also add the ability to interact with conventional home appliances devices, among many other types of extensions\textsuperscript{15}.

**Designing a Printed Circuit Board (PCB)**

The design process of a PCB entailed a number of unexpected challenges, including a need to expand my understanding of complex and highly technical details in the use of software and equipment, as well as constraints imposed by the size and type of the conductive materials. The following images present the process of designing a printed circuit board for an Arduino board.

\\textsuperscript{15} The website \url{http://shieldlist.org/} documents several of the available shields.
Figure 2 – Circuit Board Design

Figure 3 – Creating Printed Circuit Board

Figure 2 illustrates the design of the circuit board using the application *Eagle*, an open source PCB editor that allows the creation of PCB prototypes that can be printed in copper sheets using a computer numerical control (CNC) milling machine (as shown in Figure 3).

Figure 4 – Soldering Shield Components

Figure 5 – Completed Shield

Once the PCB board is completed, all connectors are permanently attached to the shield using a soldering iron (Figure 4). Figure 4 presents both sides of the completed shield, which can be attached to the Arduino board.

**The Power of Extensions: “Shields” are important**

Shields can be thought of as specific encapsulations of hardware and software. They are a selection of components that simplify the use of complex devices by hiding internal operations.
In most cases, shields are designed for very specific purposes, and the key aspect is that they allow non-experts to use complex circuits, precisely, because they act as a black box where there is no need to know about its internal operations.

The idea of hiding complexity became an important discovery when assessing what activities and electronic toolkits could lead to participants through multiple and diverse cognitive trajectories. I discovered that shields can hide some aspects, but if they are designed differently, they can also be used to show. In other words, a pre-built circuit can either help or prevent participants to learn about electronics. For example, if a circuit highlights how components should be connected or shows the path of the electric current, this will be valuable for a novice user. However, engineers often do not think about these pedagogical challenges or affordances. Some of the motivating questions that led me to experiment with printed circuit boards included: how can the design of an electronic device help reduce the visual clutter that often occurs due to the complexity of the wiring? Can the design of an electronic circuit be a pedagogical tool on its own, for example, by encouraging participants to inquire further about the internal operations? And finally, what could be the pedagogical affordances of either hiding or showing the connections in an electronic artefact?

In an attempt to address these questions I realized that I had to immerse myself into the design of various prototypes that could be later tested in a real setting. The following section presents some of the key findings in this process.

**The input-black box-output mechanism**

The *input-black box-output* mechanism is a fundamental characteristic of probably any microelectronic device that uses sensors and actuators. At the most abstract level, an electronic
artefact of this type performs three functions. 1) collect a signal, 2) process the signal, and 3) do something with the collected data. This principle or mechanism is one of the first things someone learning about DIY microelectronics needs to understand. Although this general principle seems straightforward, the actual fabrication of DIY electronics always becomes much more complex and challenging. My previous experiences, both in building my own artefacts and teaching others how to build DIY electronics, led me to discover that when making the actual wiring (and that means the connections of the wires that make a circuit functional), participants tend to struggle and often lose their motivation given the visual complexity of the circuits.

One of the key aspects that led me to experiment with the design of PCB shields (extension circuits) for existing pre-manufactured boards was to explore how the design of an electronic toolkit itself could foster motivation and curiosity, while encouraging participants to learn about DIY electronics. I focused on simplifying the connections required to work with devices such as LED lights, motors and speakers, since during my previous experiences, I had realized that such aspects like the complexity created by a large number of the connections (wires) coming in and out of an artefact, could easily overwhelm participants with no previous knowledge or experience. Engaging in the design of a printed circuit board was then a learning process towards the design of circuits that could be used to assist participants in discovering how such complexity could be reduced, and hence allowing them to easily create functional prototypes by following wiring diagrams and instructions.

5.1.4 Testing Encapsulation: Building DIY Prosthetics

Previous explorations with printed circuit boards led me to imagine a new iteration of an electronic toolkit that could be used to explore the role of variable levels of sociotechnical encapsulation in fostering knowledge and inquiry practices (cognitive trajectories). In this
iteration, the key challenge was to create a toolkit capable of allowing participants with no previous knowledge about computer programming or microelectronics to explore with the fabrication of DIY prosthetics. With this challenge in mind, and extending the focus on encapsulation at the level of connections (as described in the previous section), I envisioned a toolkit including a pre-programmed microcontroller to which participants could attach various types of sensors and actuators without the need to understand the internal operations of the code. With this toolkit, participants could obtain immediate responses from the sensors by following instructions and wiring diagrams. The toolkit included three sensors: light, potentiometer, and push button; and four actuators: DC motor, vibrating motor, servomotor, LEDs, and speaker. When testing pre-programmed microcontrollers in order to provide high levels of encapsulation, I predefined the possibilities in which the circuits could be connected. This preparatory work encompassed setting correlations between each sensor (input) and actuator (output) included in the toolkit 16.

The initial tests of this prototype were influential in the refinement of my research questions, as the preliminary findings suggested that highly encapsulated devices – at the hardware and software levels – could have a significant impact in participants’ reactions, motivations, and the quality of their analyses and prototypes. Although this initial toolkit had a limited functionality, it provided the ability to create functional electronic prosthetics, while fostering discussion about technological augmentation among participants that had no previous experience with DIY electronics.

16 Achieving such correlation between sensors and actuators is not a trivial task. It involves computational normalization of sensors’ readings and determining thresholds for each sensor. It is beyond the scope of this presentation to describe in detail how such encapsulation was actually accomplished.
During this workshop, I provided a pre-programmed microcontroller, a few numbers of input and output devices, as well as step-by-step instructions on how to wire all the connections. Participants did not have to know anything about the internal operations of the artefact. It is worth noting that the purpose was not to teach computer-programming skills, but rather, the workshop was designed to foster curiosity about DIY prosthetics by allowing participants to build relatively simple electronic artefacts, such as a blinking light (LED), the movement of a motor, or a sound pattern as part of a prosthetic artefact. During these activities, I observed that following highly structured instructions seemed to be an effective strategy when introducing electronics to novice users. However, after participants were familiarized with the toolkit provided, and discovered its limitations, it became evident that in order to motivate them to learn more about DIY prosthetics it was better to have a flexible script of the activity and allow them to discover through experimentation what they wanted to build. For example, some of the participants explained that they wanted to explore on their own and try to figure things out without assistance. In these cases, an over-scripted activity seemed to fail in fostering motivation and engagement.

A major finding in this process was that the level of encapsulation (complexity that is hidden or disclosed) in hardware and software, as well as the scripting of the activity, could either encourage or prevent participants from engaging in the task. A major challenge that became evident after the workshop was that over-scripting the activity could prevent exploration and discovery, while the absence of any guidance and structure could also cause disappointment and frustration. One of the key discoveries was that attempting to conduct workshops with DIY electronics seemed to require careful assessment of two main aspects. First, open-ended prototyping, where participants do not know what to build from the beginning, and rather
develop an idea through the experimentation and fabrication process; second, the level of encapsulation, which refers to the complexity in both software and hardware that is disclosed to the participants.

In the next section, I present a third iteration of the electronic toolkit introducing a script in the activity directed to the fabrication of a DIY scientific instrument.

5.1.5 Citizen Science: Designing a DIY Water Quality Sensor

Citizen Science is an emerging and growing body of DIY and Maker initiatives experimenting with the fabrication and use of scientific instruments encouraging people around the globe in the collection and analysis of various types of environmental data. One of the projects that I became particularly interested in was “The Smart Citizen Kit: Crowdsourced Environmental Monitoring”, a project started at the Fab Lab Barcelona. Since 2013, this team has been developing an electronic toolkit that collects various types of environmental data and making it available to the public through the online platform Smartcitizen.me. Like Smartcitizen, there are many other online resources dedicated to promote DIY Science such as the popular websites Instructables.com and Envirodiy.org.

Following my own interest on water pollution and my explorations with the use of DIY electronics for environmental sensing, the DIY Water Quality Sensor and inspiration from DIY Science initiatives, I engaged in several tests using the electrical conductivity as a measurement indicating some aspect of the quality of water. In contemporary standards for water quality, the electrical conductivity is used to determine if a water sample can be considered acceptable drinking water. The growing interest of DIY Science initiatives in the conductivity of water is justified as this measurement is directly correlated with the amount of certain types of salt such
as sodium, potassium, and calcium, which can be harmful for human health even if they are present in very low concentrations (Health Canada, 2015).

This project started by replicating the experiments of other researchers and DIY enthusiasts exploring how to build a probe capable of measuring the electrical conductivity of water using cheap materials and electronic components that become widely available (e.g. Arduino Board). The image below illustrates the components included in the DIY Water Quality Sensor.

![Image of DIY Water Quality Sensor](image.png)

**Figure 6 – DIY Water Quality Sensor (Sketch Diagram of Components)**

For over a six months period (Fall-Spring 2014), I conducted several iterations in the design of conductivity probes and tested numerous water samples collected from different locations in Toronto and Bogota. These experimentations included testing the conductivity and reliability of different conductive materials such as copper, steel, nickel and chromium. These experimentations revealed that the use of different metals in addition to environmental conditions such as temperature and humidity could influence the readings and therefore they had to be accounted for during the measurements.
**Encapsulating Reliability with 3D Printed Scaffolds**

The initial experimentations with a DIY conductivity probes revealed that in order to obtain consistent and accurate measurements, many different factors had to be carefully controlled, including the size of the electrodes, the distance between them, as well as ambient variables such as the temperature and humidity. The idea of using 3D printing technologies to create a customized scaffold for the DIY conductivity probe emerged as an attempt to encapsulate the complexity and hence, prevent the potential inaccuracies occurred by differences in the size and distance between electrodes. The design of 3D printing scaffolds for the DIY Conductivity Probe was conducted with the assistance of my colleague Daniel Southwick at the Critical Making Lab, and the guidance of professors and graduate students at the Chemistry Department at the University of Toronto (for details about the process of designing, building, and testing with conductivity probes see Appendix C).

**5.1.6 Conclusion: Encapsulation and Literacy Practices**

Encapsulation can be a crucial factor facilitating as well as preventing the emergence of learning trajectories. How much technical complexity is hidden and to what extent the activity is designed to encourage participants to uncover designers’ assumptions is a contested and unresolved issue (Cf. Kapur, 2010). Through my own engagement in various DIY and Maker events and explorations with the fabrication of printed circuit boards and the creation of the DIY Conductivity Probe, I discovered that hiding technical complexity in electronic toolkits and varying the structure of the workshop were significant factors for the design of DIY experiences.

Although my explorations were not explicitly focused on teaching participants about computer programming, in my own preparations and design experiments I discovered that understanding basic principles about electronics was imperative. In my early projects, I assumed that the ease of
access and extensive online documentation on how to build DIY electronics would be straightforward, and participants would “just” go and find those resources and solve specific problems they had encountered. However, learning those “basic principles” was not straightforward. Solving quite specific problems, such as identifying the open-source library required to collect data from a sensor, and then trying to build more advanced projects and move beyond a “demo” project, required many other “skills” and a great amount of time for trial and error.

Throughout my own process learning the “skills” required to make DIY electronics and repurposing other people’s instructions and projects, I discovered several additional challenges. I had to learn more than key concepts about computer programming. There were many other not abstract or explicit aspects, such as understanding how to deal with the sensitivity and accuracy of sensor devices or addressing questions like why the stability of the circuits varied depending on the length of the wiring connections. For example, soldering the wires instead of using a breadboard or changing the length of the cables, was crucial in reducing the noise produced by electrical static and improving the reliability of the data collected from analog and digital sensors. I encountered many other “skills” that were not described in tutorials; problems that appeared only when I tried to increase the complexity of the artefacts or adding other devices (e.g. sensors and actuators) that started to conflict with each other.

These explorations helped me realize why some participants often feel intimidated when they are asked to build relatively “simple” circuits, even though they have assistance from diagrams and wiring instructions. In most of the workshops that I conducted, participants’ backgrounds and experiences with technology were quite different, ranging from undergraduate students in design and architecture to schoolteachers, some of which had never worked with DIY electronics.
before. The diversity of participants, a characteristic of DIY and Maker initiatives, revealed that there was not a unique way of defining a “simple circuit”.

In order to account for this diversity of skills and knowledge, the electronic toolkit and the activities of the workshops had to be flexible and open. Being able to replicate a circuit does not assure understanding or the ability to change or customize it, at least not without extensive hours of testing and, progressively, learning about fundamental concepts of computer programming and principles of electricity. Additionally, not everyone needed or wanted to engage in the low level details of programming a microcontroller. Encapsulating technical complexity and allowing only a few possible options in the toolkit proved to be valuable, in particular, when working with participants with no previous experience.

The intuition that emerged from these explorations was that introducing variations in the level of encapsulation facilitates multiple and not expected learning trajectories. For example, in the DIY Prosthetics workshop, hiding complexity and preventing access to the underlying code, proved crucial in encouraging participants to continue their own explorations and learning about DIY electronics. Introducing variations in the activity, such as using a pre-programmed microcontroller instead of asking participants to learn how to program it (microcontroller), or clearly defining the goal of the activity instead of presenting it as open-ended had important implications. One, it allowed participants to focus on the design of their prototypes; (2) to spend more time in prototyping; (3) to engage in critical discussions that were not necessarily concerned with technical details of difficulties; and, (4) to spend additional time reflecting on the selection of sensors and actuators, and vocalizing their concerns amongst peers.
In other cases, however, removing access to the internal programing was also problematic and discouraging for more advanced users, as they quickly realized that the limited possibilities of the toolkit would not allow them to built the artefacts they prototyped; for example, attempting to control more than one actuator (a DC motor and servo motor) with the same sensor (a photo resistor) was not possible given the constraints that I introduced into the electronic toolkit.

For the design of the next iterations of my workshops, I decided to work with users that had plenty of experience with teaching in school settings but without or minimal experience with the design or fabrication of DIY microelectronics. My intuition was that I could recreate, at least to some extent, the cognitive trajectories that I experienced and observed in other participants during the process of learning about DIY and Maker initiatives and the design of my own DIY electronics and toolkits. The key idea was that engaging with the process of fabrication and experiencing different levels of technical complexity could be stimulating for participants and help me to understand the challenges and the potential benefits of bringing DIY activities to the classrooms.

In the following sections I describe some of the key findings emerged during the early projects and design explorations.

**Dealing with Code Complexity**

Novice users are often overwhelmed by the complexity of “coding”. This is a major issue that has been raised by researchers exploring visual tools assisting the creation of computer algorithms (See for example visual programming tools such as Scratch, developed by Resnick et. al (2013) at his team at MIT MediaLab, or Steamlabs.ca, an online platform for creating DIY electronics. In my own explorations, I decided to address code complexity by designing a toolkit
that allowed a progressive exploration and disclosure of the internal components and complexity, while at the same time making it possible for the novice participants to start building functional prototypes without the need to understand all technical details.

**Operationalizing Sociotechnical Encapsulation**

Below I outline the key dimensions of sociotechnical encapsulation that proved to be relevant for the study as well as the design of interventions/workshops with DIY electronics.

**Table 4 – Social and Technical Dimensions**

<table>
<thead>
<tr>
<th>Social/Cognitive Dimensions</th>
<th>Technical Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants’ interests, expectations, and concerns about technology in their everyday life.</td>
<td><em>Hardware</em>: Pre-assembled vs. non-assembled microelectronics; the number and complexity of sensors used; the role of shields, connectors, and wiring.</td>
</tr>
<tr>
<td>Participants’ previous knowledge about microelectronics.</td>
<td><em>Software</em>: The ability to reuse code, use of external libraries. Ability to change the code.</td>
</tr>
<tr>
<td>Levels of scripting of the activity (e.g. open ended prototyping vs. strict definition of goals and sequence of the activity).</td>
<td><em>Instruction Materials</em>: Step by step instructions; circuit boards diagrams.</td>
</tr>
</tbody>
</table>

In an attempt to integrate the technical and social/cognitive dimensions described above into a systematic model, sociotechnical encapsulation was operationalized at the level of complexity in the physical arrangement and level of disclosure of the logic underlying the operations of the microelectronic components. I defined three levels, *Low*, *Medium*, and *High* encapsulation.

It is crucial to note that both the Levels of Encapsulation and the Script Modalities are imprecise, and do not attempt to map the level of encapsulation to a numerical scale. Within each of these levels there could be numerous levels or subtypes. Rather, these scales need to be understood as “ideal types”, which describe representative cases where the complexity of the internal
operations is hidden from the participant and a particular type of the definition of the task is provided. I use the type “medium” to represent an average of one of the most common formats of DIY electronics workshops that I encountered (e.g. uploading sample code to a microcontroller following instructions). The strategy for envisioning alternative variations in the format of DIY workshops was to introduce changes in these two dimensions: (1) Level of Technical Encapsulation and (2) Script Modality. Table 4 depicts six possible variations for this operationalization of sociotechnical encapsulation and provides a classification of the exploratory DIY projects described earlier and the case studies that will be introduced in the Part II of this Chapter.
### Table 5 - Sociotechnical Matrix: Technical Encapsulation and Script Modality

<table>
<thead>
<tr>
<th>Technical Encapsulation</th>
<th>Script Modality</th>
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<tbody>
<tr>
<td></td>
<td><strong>Open-ended</strong></td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>S1</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
<td></td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>P2, S2A</td>
</tr>
</tbody>
</table>

#### Pilot Projects
- **P1** - Pilot 1: Arduino Workshops
- **P2** - Pilot 2: DIY Prosthetics Workshop
- **P3** - Pilot 3: Designing a DIY Scientific Instrument

#### Case Studies
- **S1** - Study 1: DIY Toy Hacking
- **S2A**: Sensing for Acting (Iteration 2 – Pre-programed Arduino)
- **S2B**: Sensing for Acting (Iteration 3 – Programming Arduino from Scratch)
- **S3** - Study 3: Building a DIY Water Quality Sensor

#### Technical Complexity
- **[Low]** – “On your own”: No computer, microcontroller, no sensors, only a few actuators (such as motors or LEDs) are provided to the participants. No step-by-step instructions or wiring diagrams.
- **[Medium]** – “Typical DIY Electronics Workshop”: In addition to an electronic toolkit, the participants need a computer in order to program the microcontroller. Participants are asked to upload sample code and assemble the circuits following wiring diagrams.
- **[High]** – “Hiding All internal Code”: All the programming logic is hidden from the participants. A pre-programmed microcontroller defines an array of possibilities for connecting input and output devices. Wiring diagrams are often provided.

#### Script Modalities
- **[Open-ended]**: The workshop does not define a specific objective or target of the activity; it includes open-prototyping, and it is intended to allow progressive exploration of the goal and purpose of the artefact.
- **[Directed to a specific object/goal]**: The workshop activity defines a specific objective; the function and purpose of the artefacts is defined prior to the activity.
Part II – Case Studies: Exploring Sociotechnical Encapsulation

The studies presented in this section were designed to learn about the knowledge practices and teachers’ reflections about literacy emerging from encounters with various types of sociotechnical encapsulation. The main goal was to develop an in-depth understanding of participants’ reflections and insights emerging through the fabrication and experimentation with DIY electronics. The methodological strategy introduced variations in the complexity of the electronic toolkit and the script of the activity according to the Sociotechnical Matrix. In all the iterations, the focus was to observe, document, and follow-up with participants about their experiences, as they progressively discovered details about the internal complexity and operation of the electronic toolkits provided.

The main hypothesis that emerged during the pilot projects presented in the previous section, was that variations in the script (structure) of the workshop activity and the technical level (complexity of the electronic toolkit) could have a significant impact in the type of literacy practices (cognitive trajectories) that participants engaged with during the interventions. This hypothesis was informed by the review of the literature on literacy practices. In Chapter 2, I introduced key aspects emphasizing how through the lenses of Activity Theory (Vygotsky, 1978), Situated Learning (Lave and Wenger, 1991) and Distributed Cognition (Clark, 1991; Hutchins, 1995), physical tools and interactions among peers need to be considered as fundamental scaffolds in complex human cognitive activity.
5.2 Overview of the Studies

5.2.1 Research Site and Participants

The workshops described in this second part of the Chapter were conducted at a private high school in Bogota, Colombia. This school was selected due to the following circumstances and criteria. First of all, I had worked at this institution in the past as humanities and history teacher, as well as a consultant for the development and implementation of information technologies in education. This pre-existing relation with the institution allowed me to personally contact the Principal and present my research interest in the pedagogical value of DIY and Maker initiatives. After the Principal manifested interest in my research project, I was invited to give a lecture at the beginning of the school year and given authorization to contact and recruit participants. The recruitment process involved both informal conversations with the teachers and a Form of Informed Consent (Appendix A) translated in Spanish.

One important criterion for the selection of this school was my familiarity with the pedagogical orientations and commitments of the institution. The school has a strong commitment with traditions such as Active Learning (Bean, 2011), which place a strong emphasis on the arts and engagement in the fabrication of crafts as a key component of learning. Finally, I was also aware that most of the school teachers did not have a previous experience working with DIY electronics, and this constituted an unique opportunity to work with novice users, which had become a major target during my previous explorations with DIY and Maker initiatives.

The research activities took place between December 2014 and April 2015. During this period, I conducted a total of three iterations of the DIY workshops and participated in other academic activities at the institution that allowed me engage with the participants in the context of their work and collect data from several informal conversations. The workshops took place at the
beginning of the school year, a moment when teachers are designing and planning their activities for the year. This was not planned but in some way accidental, in the sense that this was the most suitable time for the teachers. A total of 25 teachers agreed to participate in the activities.

5.2.2 Research Activities

As stated in my main research question, the aim of my research was to understand how the variations in sociotechnical encapsulation could influence literacy practices. In order to study these phenomena I conducted a series of iterative workshops in which I observed and documented the process of design and fabrication of DIY microelectronics.

All the workshops consisted of a semi-scripted activity in which participants were asked to design a prototype or an artefact that could be a toy, or a device for sensing some aspect of the environment, in order to produce a response chosen by the participant. Participants were provided with an electronic toolkit including different types of input and output devices (See Appendix G for details of the sensors, materials and guiding instructions provided during the workshops).

5.2.3 Data Sources and Strategies for Follow-up Interviews

The data collected during the studies included several sources: notes from pre-intervention focus groups, video and audio recordings of the workshops, photographs of participant interactions and prototypes, semi-structured interviews, as well as numerous notes from informal conversations. The range of data types allowed for data triangulation; for example, verification of research findings through the comparison of the different data sources. Open Coding was used for the workshop field notes and transcripts of semi-structured interviews.
All follow-up interviews started with questions about the participants’ professional background and their experience using information technologies in everyday life, and specifically, familiarity with DIY and Maker initiatives. The purpose of probing and follow-up questions was to set the stage and allow me to prepare the direction of the interview. During the workshops, follow up questions also provided an opportunity for participants to express in their own words what they were doing, and vocalize decisions made during the design process. Probing and background questions allowed for the identification of the language and context of use familiar to each participant. In particular, becoming familiar with the participants’ background and expertise assisted in selecting adequate language to introduce questions that could trigger participant’s reactions and comments about the potential role and impact of DIY microelectronics in the classroom.

5.2.4 Teachers’ Initial Perspectives

As indicated earlier, my research project was presented to elementary and high school teachers at an introductory lecture where I described the objectives of my research and showcased multiple examples of DIY and maker projects. It is important to note that this lecture was introduced in the context of other activities for teacher’s “Pedagogical sessions”, which are training activities held every year prior to the initialization of classes. This context was important because it seemed to influence the way participants perceived, at least initially, the purpose and scope, as well as the potential benefits of participating in the workshops.

During the Q&A session after my lecture, it became evident that most of the teachers perceived the purpose of my research as a question about emerging technologies and its applicability to the classroom activities. It seemed they were expecting to learn specific contents and teaching methodologies. However, this perception of prescription was progressively transformed
throughout the workshops and in the follow-up interviews, when teachers started to realize different ways of relating DIY electronics with the content and challenges they had faced in their own classes. In the following sections of this chapter, I present in more detail these reactions and changes to initial perceptions. For the moment, I introduce some of the questions and comments raised during the Q&A session, when some of the teachers manifested some concerns and valuable questions about the idea of introducing DIY initiatives into the classrooms. The following excerpt of the discussion indicates the varied array of teachers’ initial reactions the my research project:

Is the “Do-It-Yourself” a methodology? Or a source, a way of putting into play what we call learning when we talk about literacy? For example children in first [grade], they are already acquiring their alphabetic code, they are already formalizing certain things and we can say that everyone has already acquired a certain level of literacy. And that “Do-It-Yourself” in this case could already be said to be a source for learning certain things. Learning to give them a personal code is a resource to get there through instruments ... through many things, then is “Do-It-Yourself” a source that makes it possible to put that literacy into play towards creativity, towards exploration, to create new things?

[First Grade Teacher, December 9, 2014]

I really like your question because the idea of thinking [about] “do-it-yourself” as a prescription [in the sense of] we all now have to become “do-it-yourself” requires a critical view. No, but what you say is that “do-it-yourself” is also a pedagogical resource. A resource of exploration on critical doing, but it is also like making strips or making looms. I believe “do-it-yourself” is a form of doing. It is a doing that can be thoughtful or not. But the interesting thing is that, with or without electronic devices, it invites to play many language games between the biological and the physical, between the daily life and the academy. I think these are very interesting “toys” and can facilitate those projects. But hey, let's see, I'm here to test with explorations in that sense.

[Researcher, December 9, 2014]

Current [advanced] technologies can be seen in these artefacts, but the elements we use in the classroom, let's say, that the purpose of “Do-it-Yourself” may refer to [the
use of] paper and pencil too. That is there and people already do it. So it's not just that technology has led to that at the moment. That [“Do-it-Yourself”] can be many things.

[Biology Teacher, December 9, 2014]

I would like to say that also sometimes we feel that all this technology and ICTs [Information and Communication Technologies] come to us as something that one “must do!” [As a] thing that needs to be adopted! And, am I of the position that “you have to do”? No. I feel that also within the processes that we [currently] do in the classroom we are encouraging that the children can then approach it [new technologies] without fear. For example, we have been working on technology, and the importance being able to ask themselves [students] a question that will allow them to sit in front of a computer and wonder, “how I can get my plant to tell me when I have to water it.” Yes? I generate some curiosities in some things not always ... my comment is that we are not so far from what is happening. We may not be skilled with technology, we may not be using it all the time inside the classroom, but critical reading exercises, cultural projects, and questions about the meaningful practices are driving them into this exercise of questioning and feeling capable of doing things for themselves. This is ultimately the issue of autonomy and critical thinking that we have as mission of the school.

[Math Teacher, December 9, 2014]

It is worth noting that the questions and comments suggested encompass mixed reactions to the DIY projects and artefacts showcased during my introductory lecture. These comments reveal that most of the teachers were not familiar with the technologies or even seemed to look at them as if they were sophisticated and cutting edge technologies that they would never know how to use or build by themselves. The idea of Do-It-Yourself in relation to technology and its relevance to thinking about literacy was also an important topic in the discussions. One of the most interesting questions, raised by a First Grade teacher, was whether DIY initiatives should be considered as a didactic resource or a pedagogical approach to literacy, teaching and learning.

Another reaction to the idea of using DIY electronics in the classrooms was the perception of prescription. As a Math teacher expressed, new information and communications technologies
are often perceived as something that needs to be adopted simply because they are sophisticated. This is a long standing issue in the assessment of educational technologies and I was happily surprised that the teachers were well aware of the challenges that come with the implementation of any new technology in the classroom, as they bring fundamental pedagogical questions about why and how these technologies should, or should not, be implemented.

In this section I have briefly introduced the research site and some of the initial perceptions and reactions that participants had prior to the workshops. In the following sections, I describe and discuss the workshops conducted, highlighting how the interventions seemed to have changed some of these initial perceptions by fostering reflections about literacy and teachers’ own cognitive trajectories that emerged through the engagement in the fabrication of DIY electronics.

5.3 Study 1: Exploring Autonomy Through DIY Toy Hacking

The first iteration of the DIY workshops was the DIY Toy Hacking. This workshop took place on December 2014; it was offered to a total of seventeen participants including teachers from kindergarten and grades one to five. The workshop consisted of one session that lasted two hours-and-a-half. The teachers were recruited after the introductory lecture in which I presented the purpose of my research and displayed some DIY projects. All participants were provided with a copy of the Informed Consent Form (See Appendix A) that was translated in Spanish.

5.3.1 Type of Encapsulation and Structure of the Activity

In conversations with kindergarten and elementary school teachers prior to the workshop, some of them expressed hesitation about whether they had the necessary technical abilities and knowledge to participate in the workshop. Although I had explicitly stated that no technical
knowledge or prior experience with electronics was required to participate, the projects that I presented in my introductory lecture, which included the use of various types of sensors (e.g. humidity, temperature, and movement) and actuators (e.g. servo motors, speakers, LEDs, and push buttons) were perceived as “too” advanced and inevitably seemed to overwhelm some of the participants. After these conversations, I decided to adapt the script of the workshop and simplify the activity in order to address participants’ concerns regarding their lack of experience working with DIY electronics. The solution I envisioned was to remove the Arduino microcontroller altogether, and rather engage in a much simpler activity.

In this workshop, I explored a low level of encapsulation – understood as technical complexity – in combination with an open-ended activity in which the objective was loosely defined as the creation of an autonomous robot. As mentioned earlier, in this workshop I did not use a pre-programmed microcontroller and removed all sensing devices. Participants were asked to create a type of BrushBot17 (a robot made of a brush), which is an artefact capable of exhibiting autonomous movements that occur due to friction and vibration and can be built using a few components such as a coin battery, a motor, and the head of a toothbrush.

![BrushBot Schematics](http://makezine.com/projects/building-brushbot-kits/)

**Figure 7 - BrushBot Schematics**

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The *BrushBot* was one of the projects I had seen at various DIY and Maker events and it was certainly an inspiration for the adaptation of the activity and the exploration of a low-level encapsulation. I decided to introduce this activity also because I wanted teachers to feel more comfortable and capable of relating the workshop to their experience working with crafts in their classrooms. It is worth noting that since participants were all teachers working with children between ages five to eight, creating an autonomous toy seemed to me an activity that would allow them to relate to their work and an activity that children would find appealing and engaging.

### 5.3.2 Workshop Activities

**Making and Exploring with Materials**

The workshop started with a brief presentation of the components and a demonstration of a small automata showing how we could build an artefact that moves through a surface mimicking an autonomous behaviour. During this presentation, I advised participants that the goal of the workshop was to create an autonomous toy and they could use any other additional materials that they had available, such as paper, scotch tape, cardboard, etc. The teachers formed groups of four to five and worked on their projects for about two-and-a-half hours. After the workshop, I conducted follow up interviews with three of the participants.

Figure 8 illustrates the activities, showing the diversity of materials and group dynamics (A: Working Groups; B: Material Introduced by Participants; C: “Paper Clip Worm”; D: Fabrication Process; E: “Butterfly”; F: “Skater with Fans”; G: Projects showcase).
During the workshop, I walked around the tables taking photographs, video recording, asking questions about what the participants were doing, observing how they interacted with the materials and their peers, and whether any challenges were encountered. Approximately 45 minutes before the completion of the workshop, I asked participants to think about a name for the artefact/toy they were building, and I informed them that at the end of the activity they would be asked to share their experiences and present the final projects to the other groups.

In the following sections I discussed some of the key findings, emerging themes and discussions.

5.3.3 Findings

Co-construction of Functional and Aesthetic Dimensions

Throughout the activity the notion of purpose and aesthetic appearance of the artefacts was important in fostering a sense of excitement and authorship, as well as curiosity about exploring with various types of materials. During my observations of the design process and later during the follow-up interviews, I discovered that participants attempted to control the random behaviour, resulted from the use of vibrating motors, in order to give a distinctive personality to their artefacts. The stories and explanations that emerged from this activity were certainly
unexpected. It was surprising to hear how explanations about the function and the purpose of the artefacts were entangled with aesthetical aspects and descriptions about how the materials themselves had defined certain patterns of movement, and ultimately the “personality” of their toys. Expressions like “active”, “dancing”, “stubborn”, or “hesitant” were often used to explain the personalities of the artefacts.

The aesthetic aspect was an important consideration throughout the activity. Participants dedicated a great deal of time and effort enhancing and transforming the appearance of their artefacts. What was interesting in this exploration of both “function” and “beauty”, according to participants expectations, was that often the addition of too many aesthetic components (e.g. legs, arms, heads, feathers, and even flowers) progressively transformed the physical properties, modifying the weight and the volume, and as a result the patterns of movement exhibit by the artefacts. Participants discovered that each addition or change in the artefacts’ shape or weight necessarily transformed the autonomous movement, leading to a permanent need of renegotiation and evaluation.

**Excitement and the Need to be Resourceful**

Two recurrent themes were present during the activity and the follow-up interviews. The excitement of building an artefact that displays an autonomous behaviour and participant’s improvisation and resourcefulness occurred during experimentation with different materials. The need to be “resourceful” meant an attitude towards finding a solution to a problem with the few resources provided and the need to repurpose the materials to accommodate participants’ expectations. The following excerpt from the follow-up interviews indicates some of these reactions:
It seemed to me that the [the workshop] was very surprising, that with so few elements one could do a little thing that moves on its own. This is absolutely amazing, and this can happen to the children too. And it was really easy. The thing is to understand that if you join two little wires with a small motor … a very funny autonomous movement starts to happen. […] I think it can become more complex, and even the kids can do it more complex so they would find other [type of] toys. Just the fact that you build this with your hands, this is something they [students] really connect with. It’s something that creates an impact on them. It’s creative. And for us, it was the discovery that we were joining two cables and the thing [the toy] just moves. […] My guess is that there are a lot more discoveries that have to do with the elements [materials, components] you add, such as the weight, the movement, or the volume. These are the elements that we could work and research about. In relation with what we did in the workshop, this is very appealing to me.

[3rd grade teacher]

It is worth noting some of the findings and self-evaluation present in this participant’s comments above. The participant points out that the activity was “surprising” and “amazing” because it entailed a process of discovering and learning about what each of the component could eventually do. Moreover, the participant situates herself as a student and brings attention to how “build[ing] this with your hands” is a key element not only in creating a sense of ownership, but also in fostering engagement and curiosity for further explorations. The participant also highlights that the activity can be modified and “become more complex”, and this indicates how she realized that these types of activities could be changed and progressively introduce more complex components, and in doing so open new avenues for other type of discoveries. Of key importance is the idea that engaging in the fabrication of artefacts requires also engaging in the analysis of physical properties such as weight and volume and how these directly affect the movement of the artefact.

**Dealing with Frustration and Reflections about Learning**

Another important theme emerging during the workshop was the need to deal with frustration when the components didn’t work as expected. One important question to ask is to what extent
the participants felt intimidated by initial frustration and whether they attributed this to their lack of understanding or previous experience. In other words, what role does this initial frustration play in fostering curiosity and engagement, willingness to continue further explorations, and when to request for assistance from their peers?

One important point about the encounters with frustration due to technical issues is that regardless of how simple an artefact seems to work, there are always contingencies and breakdowns that can prevent the continuation of the activity. For example, during this workshop, some of the batteries provided did not work, but participants were hesitant to request my assistance. I observed that they felt more comfortable asking help from their peers or borrowing their batteries and testing them on their own artefacts. Only after they had discovered that it was an issue with their batteries, did they approach me and request new batteries.

This may seem trivial and obvious. However, during the follow-up interviews, when I asked participants to describe any challenges they encountered, this topic of understanding how participants deal with frustration and technical breakdown became salient. The open structure of the activity seemed to invite participants to try to solve the difficulties or technical issues on their own, encouraging them to take the task as a personal challenge; they struggled and attempted to make things work on their own before asking for assistance.

The following extract from a follow-up interview illustrates how some participants dealt with frustration and technical issues and how these led to further explorations:

Was that other motor [the vibrating motor] strange to you?

[Researcher, Interview, February 18, 2015]

no, no! What I wanted to know was how each of them [the motors] worked and for what they could serve in what we were trying to do. After we saw what they could be
used for... because I think we started the work thinking in [building] a bird, I don’t remember, but for me, I learnt how each of the motors could do.

[P3, Interview, February 18, 2015]

Yes, we had two different parts [motors].

[Researcher, Interview, February 18, 2015]

Yes, we had two parts that did not work the same. So, I had to know how they both work. That was the first [challenge]. The second was the batteries that didn’t work the first time, so we were frustrated when we saw that it didn’t move, but in the end it [the motor] did work.

[P2, Interview, February 18, 2015]

An important outcome of the workshop was that the low level of encapsulation and the open-ended structure of the activity seemed to allow participants, initially intimidated or uncomfortable with the use of electronic devices, to move towards a different attitude and open up to discover new opportunities for exploration and learning. Engaging in the fabrication of a physical object led to significant reflections about teachers’ own learning process, about the components and the materials used, as well as to the brainstorming and prototypes for future activities that could foster student engagement and curiosity in the context of their own class projects.

**After the Workshop: Continuing Conversations**

After the workshops, almost all of the participants suggested that they wanted to keep the artefacts they had created. In fact, they requested me not to take them apart and instead wanted to keep them in order to continue further design and exploration with the components. These reactions were indicative of a positive impact of the workshop in fostering teacher’s interest and curiosity about DIY electronics and a sense of authorship, as they felt they had been able to learn about electronic circuits previously unknown to them, and more importantly, they seem to see
the artefacts as a physical proof of such accomplishments. Some of them even suggested that they wanted to show the artefacts to family members and other teachers at the school and discuss ideas for the school year.

In the weeks that followed this workshop, and while I was conducting other studies and interviews, some teachers from the school approached me to provide comments on how inspiring the artefacts were. I was at the same time surprised and grateful to hear from them how the initial workshops had fostered curiosity and interest among the teachers’ community.

The Toy Hacking Workshop provided subsequent discussions, and even the development of prototypes that teachers started to envision during the follow-up interviews and several informal conversations. In particular, Third Grade teachers specifically requested to have a brainstorming session in order to continue the conversation about what type of electronic artefacts could be used to explore a project that they had planned for the academic year focused on the environment and introduction to science.

The analysis of all these follow-up discussions and prototyping is certainty beyond the scope of this study. However, it is crucial to summarize some of the key topics that emerged during these activities, as they provide not only indications about the methodological challenges entailed in using workshops as a research method for the study of DIY and Maker initiatives, but also because they can serve as reference for future ideas directed to bring these initiatives into classrooms.

Below I briefly summarize the findings that emerged in conversation with Third Grade teachers when assessing the pedagogical challenges of introducing DIY electronics into the classrooms.
Material Exploration of Scientific Concepts

The fabrication of DIY artefacts using sensing devices and actuators provided a hands-on experience significantly relevant for students moving from Third Grade up to Fifth Grade because these initiatives can constitute a material exploration of scientific concepts such as volume, weight, temperature, and humidity. The process of fabrication can also confront participants with the need to make hypotheses about why the artefacts are working (or not) in a particular way, thus exploring avenues for changing their behaviour by modifying the physical properties of the artefacts.

Emergence of Real and Meaningful Problems

Introducing a sophisticated electronic device for the measurement of some aspect about the environment such as temperature or humidity can be problematic, in particular, when working with children in elementary school. Young students have not fully developed these concepts, and for this reason, a measurement such as “25 degrees Celsius” or “60% of humidity” may not be meaningful for them. One of the Third Grade teachers suggested that one of the major challenges of introducing a sensing device requires finding strategies to make the need for a specific measurement to become a problem for the children in their own terms and according to their interests. As she explained: “What we have to think about is how the group [of students] move in order to have the necessity to think about something [such as a sensing device] that helps us to know [for example] how much humidity this plant has in comparison with this one other, which is located in a different location.” In short, the introduction of DIY electronics needs to face a major challenge, which is to find pedagogical strategies in which the need for using a particular sensor of electronic device emerges organically from a student’s interests and understanding.
5.4 Study 2: Sensing for Acting with DIY Electronics

The second study, “Sensing for Acting with DIY Electronics”, took place between December 2014 and February 2015. This variation of the intervention encompassed two sessions. The first one was conducted with two groups. Group A: five Music teachers; Group B: seven Art teachers (ceramics, knitting, theatre, carpentry, painting, design, and photography). All of the teachers participating in these workshops were recruited during a focus-group discussion that took place after the introductory lecture in which I presented the purpose of my research and displayed some DIY projects. All participants were provided with a copy of the Informed Consent Form (See Appendix A) that was translated in Spanish.

Right after my introductory lecture, Art teachers had a meeting in order to plan the activities for their up-coming year. They asked me to attend this meeting and further discuss my research and learn about their own class projects. During this meeting the discussions were quite informal and I spent most of the time listening to the teachers’ projects, stories about their own experiences in art and crafts, as well as ideas and challenges they envisioned if they were to introduce DIY electronics into their classes. Some of the teachers manifested some hesitation when I deliberately asked if they had specific ideas or projects they would like to create or explore during the workshops with DIY electronics. As the conversations unfolded, I talked about some projects that I had created in my own explorations, some of which I have seen at DIY and Maker events, as I thought these ideas could be inspiring for the design of their own projects for the up-coming year.

In order to provide an accurate description of the activities conducted in this study, it is crucial to start with clarifications about the data sources, the duration of the study, and follow-up activities. The activities initially were intended not only as an attempt to respond to participants’
expectations, but also to serve as an introduction and an opportunity to engage in more nuanced and detailed conversations that were only possible after the first session. The data collected for this study included the observation of participants’ interactions with the electronic toolkit; the prototypes and discussions taking place during and after the workshops; and follow-up interviews. The data sources expanded to include several informal conversations and discussions that continued for a couple of weeks after the workshops. During this additional period, I discussed ideas developed after the workshop and provided assistance in building functional prototypes that teachers were not able to complete during the workshop. It is worth recalling that during the same period teachers were attending to other pedagogical sessions and their time availability was limited. For this reason, in some cases these informal conversations were the only opportunity to conclude the follow-up interviews, while responding to teachers’ request for feedback to projects that they had already started to envision for the academic year. A few weeks after the workshops, students were back to classes and some of the teachers continued requesting my assistance in the implementation of electronic artefacts that they were planning to use in their own classes. For two months after the completion of the studies, I continued my affiliation with the school. This was a time when I started the codification and analysis of the data, but I continued supporting their own projects remotely.

All these circumstances made it quite difficult to decide when to finish the data collection process and selecting what to include in this dissertation. It is important mentioning that the discussions, prototypes, and ideas that developed long after the workshops had concluded, provided enormous value to the analysis of findings and the evaluation of the research design explored in this intervention.
In the following section I describe the type of sociotechnical encapsulation and the structure of the activity used in this study, as this introduces important variations in comparison to the DIY Toy Hacking Workshop.

5.4.1 Type of Encapsulation and Structure of the Activity

In this workshop, the type of sociotechnical encapsulation and the structure of the activity varied in some important aspects in relation to the previous study. The use of an electronic toolkit (See Appendix E) increased the level of encapsulation by providing an array of pre-programmed possibilities hidden behind the scenes – coded into the Arduino microcontroller. Although the activity was much more structured, as participants were provided with diagrams and instructions describing the possible combinations between sensors and actuators (See Appendix F), the high-level goal or definition of the objective was rather open-ended and it was not as clear as in the previous intervention, the DIY Toy Hacking workshop, where the goal was presented as the creation of an artefact exhibiting autonomous behaviour.

The idea of “Sensing for Acting” was a metaphor used to orient the objective of the activity, while at the same time not strictly defining the purpose or function of the artefacts. Participants were asked to experiment with the electronic toolkit and select at least one sensor (e.g. movement, distance, light) and then select an actuator (e.g. motor, light, sound, vibration) that would respond to the sensor producing reaction that was meaningful for them, such as the use of a movement or sound sensor to create an action: turning on a light, producing a sound, or triggering the movement of a physical object.

The workshop was intended to explore the following questions: (1) what are participants’ reactions to the encapsulation and script modality, for example, in their motivation, engagement,
and prototyping activities? (2) what are participants’ suggestions, justifications, or narratives emerged throughout the design process? (3) how does the electronic toolkit assist in the progressive exploration of the function and purpose of the artefacts?

5.4.2 First Iteration: Discovering Input and Output Devices

The first interaction of the workshop focused on discovering the electronic toolkit. The activity started with a brief presentation of the names and function of the sensors and actuators available in the toolkit (Appendix E). The purpose of the workshop was presented as an activity in which teachers would learn about basic concepts of input and output devices as an attempt to inspire them to think about the potential pedagogical value of introducing DIY electronics in the classrooms.

The images below illustrate the process of exploration with the electronic toolkit as participants discovered how to connect sensors and actuators. During this process the teachers created initial prototypes following wiring diagrams (Appendix F), engaged in discussion about the purpose of the component progressively discovered the various possibilities of the toolkit. It is worth noting how the process of design included the construction additional drawings and interactions with other teachers as crucial resources for understanding how different sensors could be used to control the actuators.
Figure 9 – Exploring Input and Output devices
5.4.3 Second Iteration: Opening the Black-Box

After the first iteration of the “Sensing for Acting” workshop, some of the Art teachers manifested a major challenge: how to change the limitations of the pre-programmed toolkit and continue the development of DIY electronics on their own. This motivation to continue the exploration with the electronic toolkit created an opportunity for the design of a follow-up intervention, in which participants could be exposed to the internal complexity of the code by opening the complexities previously hidden in the electronic toolkit. The teachers suggested to organize an additional workshop in which they could start adapting the electronic toolkit and build some of the prototypes they had created during the previous session. The engagement with the process of design and fabrication, including the imagination of difficult or impossible projects, allowed participants to engage in discussions and ideas for future projects that were not possible or imaginable before. As one of the music teachers pointed out, the activities I had provided in the previous iteration were exciting and useful, but he felt that the next step would require them “to have control over all the parts of the process” (Music Teacher). Following this request for a more “advanced” workshop in DIY electronics, I envisioned a second iteration of the “Acting for Sensing” in which participants were required to open up the technical encapsulation and deal with the numeric data returned by the sensors.

For this workshop, we used S4A (http://s4a.cat/), which is an extension for Scratch that consists of a visual programming tool allowing for the control of sensors and actuators attached to the Arduino board through a graphical user interface.

In this workshop, sociotechnical encapsulation moves in the opposite direction to the previous iteration: the technical complexity is exposed to participants and the objective of the activity is clearly defined into specific tasks and outcomes. During this activity participants had access to
the data coming from the sensors and used a visual programming tool to create a program that produced different responses depending on the specific value received by the sensors. The project created was called the **Welcoming Classroom**, which was a prototype developed during the previous workshop. It consisted of a design for a classroom capable of producing different types of greeting sounds and messages when students entered the classroom. In this project, teachers used movement sensors to monitor the activity inside the classroom. Depending on the readings obtained from the sensor they reproduced different audio files with pre-recorded messages.

![Image](image.jpg)

**Figure 10 – Creating a “Welcoming Classroom”**

**The Wireless Music Box** was another prototype created by the Art teachers envisioned as a portable device that could be used to reproduce sound effects during their presentations and students’ performances. Although the complexity and time requirements for its construction was far beyond the scope of the proposed workshops, Art and Music teachers contacted me afterwards and requested assistance in its fabrication.
5.4.4 Findings

Naïve Explorations and Peer Collaboration

The completion of the very first circuit or prototype always seems to have a significant impact on the motivation and willingness to continue the experimentation. After some participants had assembled their first artefacts, they tried to experiment on their own and attach other components, even if they did not yet know how these other components actually worked. For example, some participants attempted to attach a speaker instead of an LED or changed the sensing device to then observe what the outcome would be in the same actuator such as a DC motor. Although these explorations led to combinations that I did not envision during the design of the electronic toolkit, an important aspect is that they reveal how the completion of a relatively simple circuit could encourage participants to explore by themselves and diverge from the instructions and wiring diagrams provided. The sense of excitement and motivation to explore with the components of the toolkit was evident through various comments and reactions during the activity. “One just sees the creation happening (Painting Teacher); “This is great, but how do we scale this up and control the lights of a stage” (Theatre Teacher); “I want to create something that produces a surprise” (Design Teacher).

In cases when participants did not manage to get some of the components working as they expected, they focused instead on what they thought could be done based on the demonstrations and the feedback provided by other participants. Thus, encountering an electronic toolkit with a high level of encapsulation seemed to lead organically to the need for collaboration.

A key finding was that participants, who encountered difficulty connecting the input/output devices, were actually inspired by their peers, and richer prototypes were created due to the iterative exchange of ideas. In fact, being exposed to peers’ ideas and prototypes during the
design process led participants struggling with the microelectronics toolkit to not focus exclusively on achieving a working prototype, but rather to engage in the creation of ideas to take into account peers’ findings into new directions.

Whether providing immediate assistance to participants encountering difficulties, assembling their first electronic components introduced in the workshop, or leaving them to struggle for a short period of time and “figure it out” on their own, proved to have different results. In some cases, the sense of ownership and authorship expressed about their ideas and prototypes was significantly influenced by the degree of assistance provided.

**Challenging the Prescription of High-Technology**

The idea that new technologies are necessary “good” and therefore they need to be adopted in education was a contentious topic of discussion among Art teachers. In some cases, the lack of previous experience or knowledge about how to assemble and program electronic devices seemed to provoke a feeling of rejection and uncertainty. For example, during the focus group discussion prior to the workshops, some participants indicated that it was almost impossible for them to imagine applications of these artefacts since they had no knowledge about “what is possible” to do with them. One participant went further and pointed out that my enthusiasm about DIY initiatives made him feel that I had already been working with these technologies for a long time and to some extent these technologies had become to me somewhat “transparent”. But for him, as he explained, “these technologies are rather obscure and I can’t imagine yet what do with them” [Theatre Teacher].

The complexity of the devices and sensors had diverse and mixed reactions. Some participants manifested excitement and curiosity with my invitation to participate in the workshops. After
they had experimented with artefacts and immersed themselves in a hands-on activity involving the use of sensors and actuators for non-conventional purposes (e.g. the use of movement sensors to create a game or proximity sensors to create musical instruments), their perceptions about DIY electronics started to indicate possible avenues of exploration for their own classes.

Other participants were initially sceptical. Although they had seen some of these type of devices, they indicated that they had never thought about actively engaging in the fabrication of DIY electronics, nor even imagined that they could build sensing devices by following simple instructions. However, throughout the workshops these perceptions changed significantly. Engaging in the design of possible prototypes enabled teachers to partake in discussion about the great potential of these initiatives, especially if they were to be understood as “pedagogical resources” assisting in the exploration of new forms of achieving their existing pedagogical and learning objectives. For example, after the workshops, I was asked to conduct a focus group with Third Grade teachers who manifested interest in exploring how DIY initiatives could assist students (ages between 8-10) in conducting field observations and engage in inquiry practices about the environment (e.g. temperature, humidity, noise levels, light intensity).

**Teachers’ Discovery Through Workshop Iterations**

The introduction of a highly encapsulated electronic toolkit was often a source of multiple reactions among participants. The first encounter with the electronic toolkit produced mixed reactions; from hesitation and intimidation due to the technical complexity, to comments expressing both curiosity and concerns about how they could use these tools in their classrooms. The tiny pieces of equipment seemed to trigger an initial sense of rejection, or at least hesitation about what the workshop was actually about. Teachers expressed that there were many technical skills and complexity that they had to become familiar with. In other words, the explorations
with the electronic toolkit made them realize that they had to become literate; meaning the ability and autonomy required to continue the projects they had envisioned during the workshops. The follow up projects and prototypes provided evidence in this direction. Teachers changed their initial perceptions and realized that they did not have to know all the necessarily steps or understand all the technical details, but rather, that they would learn and “figure things out” as they engaged in the creation of their own projects.

One of these cases took place when one of the Arts teachers requested assistance to create an artefact that required using a single sensor to control more than one outputs (actuators). This was a functionality not allowed by the electronic toolkit. However, it is worth noting that in these cases when participants did not manage to get some of the components working as they expected, they focused instead on what they thought could be done based on their own ideas and the prototypes created by other participants. Thus, encountering an electronic toolkit with a high level of encapsulation and limited functionality seemed to lead organically to the discussion with their peers and collaboration. Participants encountering difficulties connecting some of the components were actually inspired by their peers, and richer prototypes were created due to the exchange of ideas.

5.5 Study 3: DIY Water Quality Sensing

The third study, “DIY Water Quality Sensing”, was an activity specifically designed to engage science teachers in the construction of a DIY scientific instrument. The study was motivated by the following questions: How can teachers relate to curriculum content and pedagogical strategies through engagement in the process of fabrication of scientific instruments? What are the emerging forms of talk, discussions, and cognitive trajectories afforded by this process?
The workshop was conducted with six science teachers, including biology (3), chemistry (2), and physics (1) and it took place in two sessions that lasted approximately two hours each. The first session focused on the construction of a DIY Conductivity Probe and data collection. The second session was dedicated to the creation of calibrating solutions and analysis of the data collected. All participants were provided with a copy of the Informed Consent Form (See Appendix A) that was translated in Spanish. The data collected for these studies included audio recordings of the workshop, follow-up interviews, photographs and researcher’s notes taken through the activity.

5.5.1 Type of Encapsulation and Structure of the Activity

In this variation of the DIY interventions, the type of encapsulation and structure of the activity introduced some variations in comparison with the two previous studies. The electronic toolkit included a pre-programmed Arduino microcontroller and all the required materials to build a probe for measuring the conductivity of water. Unlike the other case studies, the purpose of this activity was clearly defined, as summarized in the following table.

5.5.2 Workshop Activities

Table 6 – DIY Water Quality Sensing: Workshop Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Session 1</strong></td>
<td></td>
</tr>
<tr>
<td>Introductory discussions</td>
<td>15 min</td>
</tr>
<tr>
<td>Fabrication of the conductivity probe</td>
<td>1 hour</td>
</tr>
<tr>
<td>Collecting data/ Experimentation with calibrating solutions</td>
<td>15 min</td>
</tr>
<tr>
<td><strong>Session 2</strong></td>
<td></td>
</tr>
<tr>
<td>Creation of Calibrating Solutions</td>
<td>40 min</td>
</tr>
<tr>
<td>Activity</td>
<td>Time</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Collecting data/ Experimentation with calibrating solutions</td>
<td>30 min</td>
</tr>
<tr>
<td>Comparing measurements between DIY and professional probe</td>
<td>15 min</td>
</tr>
<tr>
<td>Discussions about the pedagogical value of the workshops</td>
<td>20 min</td>
</tr>
</tbody>
</table>

**What is Electrical Conductivity and why it Matters?**

The workshop started with a brief introductory discussion where I introduced a definition of the electrical conductivity of water and presented the goal of the workshop. The purpose was described as an activity in which they would learn how to build a DIY scientific instrument for measuring the concentration of dissolved solids in water. Additionally, participants were given a handout with definitions, diagrams and instructions for building the electronic circuit (See Appendix G). During this activity, I explained to the teachers that I had been experimenting with this sensor for a few months, and that my intention was to learn from them more about this topic. I also explained that measuring the conductivity of water is often an indication of its quality. As described in the handout provided, I pointed out that there is a direct correlation between the electrical conductivity and the total dissolved solids (e.g. different type of salt, such as sodium, potassium, or calcium), so that the DIY instrument we were about to build would allow us to capture these measurements.

After my brief introduction, and before moving into the fabrication of the DIY sensor, the teachers requested to discuss further about why the electrical conductivity was important to determine the quality of water, and how they could introduce this discussion in their own classes. An interesting reaction at this early stage of the workshop was that the teachers felt the need to provide a more descriptive and meaningful context for the activity. For example, one of the biology teachers asked: “Why do we measure the conductivity of water and when this is needed?” Other participants provided a varied array of answers, including explanations about the
chemical and physical properties of water that determine different levels of conductivity; examples from experiments in her classrooms; and anecdotes from their everyday life.

The following fragment provides a sense of the discussions that emerged among participants when asking about why and when they could use this type of sensor:

One question I have is why and when are these measurements needed? In which research context do we have to do these measurements?

[Biology Teacher – P1, Workshop audio recording, February 11, 2015]

This type of technology and measurements are important in ecology.

[Biology Teacher – P2, Workshop audio recording, February 11, 2015]

Yes, I know that in ecology this is important, but I want to listen to Antonio [The researcher] what ideas his has about this. Why do we do this? I know that in ecology, this is going to determine a chemical composition of the liquid medium, [and this] is going to determine the presence of specific communities [organisms]. It is clear that this has to do with the abiotic factors and other things, but I want to ask for what purposes do we measure it and when is this required? Of course that conductivity is important when there are certain solutes and solvents, there are levels of conductivity.

Yes, in fact here in microbiology, the water used for the crops environment needs to be totally free of ions [salt], because this alters crops.

[Biology Teacher – P1, Workshop audio recording, February 11, 2015]

The concentration of a solution affects biological processes in osmosis and diffusion, the chemical processes in the ability to form stalactites and stalagmites, the ability of crystallization. And these are very important in biological processes.

[Chemistry Teacher– P4, Workshop audio recording, February 11, 2015]

It is worth noting how the biology teacher (P1) seems to understand quite well the reasons why certain concentrations of salt are correlated with the type of organisms that can live in a liquid ecosystem. However, her question acts as a trigger for other teachers to elaborate further and collectively speculate about the importance of these measurements. With her question, the biology teacher (P1) also raises a pedagogical challenge: “why and when are these measurements
needed?”, implying how and why she could present this to her students. The question is an attempt to ask me (the researcher) to situate myself in the role of the teacher, and to provide ideas about how I think this could engage students. The responses provided by other teachers combined both specific aspects about the DIY Water Quality Sensor and observations about personal experiences. Throughout the workshop, the emerging discussions were not necessarily related to chemistry or biology, but about the pedagogical value of the activity, with an emphasis on how the project could be presented to the students and introduced in the context their own class projects.

The following comments indicates how one of the chemistry teachers (P4) included in her observations different aspects about her own knowledge, examples of projects she has conducted with students, and an assessment of the pedagogical value of engaging in this type of experiment.

Perhaps more than the conductivity, in chemistry and physics, there is a function and it is that each of these [pointing to the copper plates of the DIY sensor] are converted into cathode and anode, positive and negative. And one could introduce them in the ground, for example, and see what ions are attracted to the positive and which one to the negative.

[…] This [DIY sensor] has a goal, to measure the conductivity. I would put this as an example in a chemistry class, [whereas] he [the investigator] uses it here as an exercise for salted water. Then to show students that pure water is not a good conductor, the salted water is a better conductor.

[…] One would say that in general you know that salt water conducts well, but how much salt? […] What would be the most suitable concentration for the conductivity to be the best? This can be done with salt or other substances. And so they [students] learn to discover. We do this with [name of biology teachers (P5)], when we do a battery with lemon, acid battery, potato battery, or papaya battery.

[Chemistry Teacher– P4, Workshop audio recording, February 11, 2015]

It is crucial to note that allowing participants to reflect on the purpose of the activity at the beginning of the workshop seemed to trigger conversations among the teachers and the researcher that probably would not have happened otherwise. Finding explanations about the
pertinence of measuring dissolved solids in water seemed to lead teachers to elaborate and share their knowledge and actually find explanations about the value and purpose of building scientific instruments.

At the beginning of the workshop, I deliberately indicated that I did not know much about the implications of salt in water for human health – I pointed out only a few things I have researched during the design of the probe. This apparent lack of context was taken by the participants as an opportunity to elaborate on the possible applications of this sensor in the context of chemistry, biology and physics experiments in the classroom.

**Building the DIY Conductivity Probe**

After these introductory discussions, the teachers started the fabrication of the DIY Conductivity Probe. The participants formed three groups of two participants per group. In order to guide this part of the activity, I pointed to some samples of the DIY that I had previously created, highlighting the wiring diagrams in the handout. However, the teachers asked me to involve myself into the construction of the probe, so I started to build my own and led the fabrication process by showing the steps as I built my probe. This process involved using the soldering iron to attach cables to the copper electrodes, then the use of a glue gun for attaching the electrodes to the 3D printed scaffold. I advised participants to comment or raise questions at any time during the process.

*Figure 11 - Building DIY Conductivity Probe*
During this activity that lasted approximately one hour, several additional discussions amongst participants emerged. In the following sections, I present the most significant discussions and analyze some of the changes I perceived in participant’s attitudes during the fabrication process.

5.5.3 Findings

Making as Facilitator: Engagement and Motivation for Learning

Throughout the activity, an important discovery was to realize that participants’ engagement and enthusiasm in “making” provided an informal environment where they could discuss their own teaching practices. During the process of building and testing the DIY Conductivity Probe, teachers were thinking aloud and brainstorming about possible class projects. One of the chemistry teachers suggested that these DIY activities could be used to foster collaboration among teachers and engage them in interdisciplinary projects. Teachers expressed interest in the process of “making” things by themselves, beyond a particular interest on building a scientific instrument. I perceived evidence of such engagement in comments like “I love this, to do things with the glue gun” (Biology Teacher - P5); “The thing is that one gets excited with the “cacharreo” [tinkering]” (Physics Teacher – P6). Additionally, when some of the teachers were discussing about “institutionalizing maker activities” (Physics Teacher – P6) at least once a month, or while listening to teachers’ ideas for future projects with DIY electronics, it became clear to me that one of the biggest challenges teachers are facing today is to be able to create learning environments where they have autonomy for exploring elements of the curriculum. A key finding in this regard was that the teachers realized that the engagement and curiosity they had gone through during the fabrication of the DIY Quality Sensor, could be a valuable activity for their students.
The Pedagogical Value of Tinkering ("Cacharreo")

An important theme emerging during the discussions was the explicit question about how these types of DIY workshops could change the dynamics of the classroom and motivate both teachers and students. During the processes of soldering small pieces of copper – the electrodes of the conductivity probe – and wiring circuits in a breadboard, discussions about the value of tinkering ("cacharreo") became a prominent theme of the discussions among participants. Engaging in the fabrication of a scientific instrument seemed to enable speculation and the emergence of ideas about how these activities could help students develop fine motor skills (dexterity) and transform the classroom dynamics.

At the beginning of the workshop, during the introductory discussions, teachers were much more concerned about learning contents and objectives, as they engaged in questions about the role of DIY workshops in delivering class curriculum. However, it is important to note that discussions about the value of informality and building DIY artefacts emerged as they themselves became immersed into the process of building and testing a DIY scientific instrument.

Some teachers suggested having open and loosely structured activities at least once a month, especially for their classes on Friday afternoons. One of the biology teachers (P1) remarked that when students are tired conducting the class can be difficult due to their lack of engagement. When teachers reflected on the idea of having workshop sessions on a regular basis, an interesting theme emerged during the conversations, and this was the discussion about the

18 “Cacharreo” is often translated in English as “tinkering” or toying. In Spanish, the term “cacharreo” comes from the word “cacharro”, which literally means an old and often broken car. When this word is used as a verb “cacharrar” it means to engage in the work of repairing and exploration. Unlike the emphasis on skilful or clumsy that tinkering sometimes has, in Spanish this term is used in a quite positive way, meaning that someone enjoys engaging in making crafts and repairing things.
positive role they envisioned for these activities. The teachers suggested that exploratory activities\textsuperscript{19} involving crafts and DIY fabrication of artefacts were particularly engaging, and these should be considered a crucial requirement for learning.

The following excerpts about tinkering provide insight about participants’ engagement and ideas about the role of DIY and Maker practices in the classroom.

**Developing Fine Motor Skills**

Now looking at this breadboard I was thinking of an introductory course in electronics to develop these fine motor skills. [...] Students sometimes do not come prepared with these fine motor skills; working on this can help them.

[Physics Teacher– P6, Workshop audio recording, February 11, 2015]

But look this what [teacher's name (P4)] is doing! Such things one can do! And they [students] learn what is called fine motor skills, which is very important. And I do not think it's just a workshop, it may be once a month, it doesn’t matter [how often]; it is a free exercise and work on this.

[Biology Teacher– P1, Workshop audio recording, February 11, 2015]

*Chemistry Teacher (P4)*: This is great because they [the students] will arrive to robotics [class] and will do more cool things.

[Chemistry Teacher– P4, Workshop audio recording, February 11, 2015]

**Changing Classroom Dynamics**

Tinkering (“Cacharreo”) is cool because you get excited about it and then you can introduce aspects of mathematics, logic and programming.

[Chemistry Teacher– P4, Workshop audio recording, February 11, 2015]

\textsuperscript{19} This comment resemblance what other researchers like Ito et al (2010) have called “Hanging Out, Messing Around, and Geeking Out”.

140
For example, for those classes on Friday’s afternoons, which are sometimes terrible, sometimes “a camel”\textsuperscript{20} [difficult / tedious]. So you know for example that every three weeks on a Friday we have an open class; it is a class for playing.

[Biology Teacher– P1, Workshop audio recording, February 11, 2015]

It’s worth noting the comments made by the physics teacher (P6) about how DIY electronics can help students in developing fine motor skills, and the suggestion introduced by biology teacher (P1), where she goes as far as suggesting to formalize DIY and Maker as a new topic in the curriculum, where students making things is seen as a strategy to introduce change and motivation for both students and teachers.

**Thinking Like a Scientist: Controlling Variables**

During the experimentation with calibrating solutions\textsuperscript{21} and while listening to the conversations about fluctuation in the data, one of the biology teachers (P1) provided an interesting reflection about the value of DIY Science experiments. Her remarks pointed to the role of DIY Science in addressing questions about scientific conventions, the remarkable efforts that scientists in the past had to go through in order to control fluctuating variables, achieve accuracy and replicate their findings.

[...] Look at this [pointing to a teacher that is heating up the water while taking conductivity measurements], what he is doing is a good exercise for the students. How scientists get to control all variables in an experiment? This question is something we can ask [to students], because they may say: “this solution is getting warmer”, ha! The temperature, they say. Then, this becomes interesting. How did the

\textsuperscript{20} The teacher suggested with this idea that especially on Fridays afternoons both students and teachers are often exhausted. So she suggests that having a class in which students engage in making and fabrication of artefacts could be a good strategy to address this.

\textsuperscript{21} Calibrating solutions are control substances created by dissolving a known quantity of certain type of salt in de-ionized water (water with no dissolved solids). In this workshop, we used three calibrating solutions of sodium chloride: 100mg, 500mg, and 1000mg dissolved in one liter of water. These substances gave us a known conductivity value that could be then compared with the samples created by the participants.
chemists of the Eighteenth Century managed to obtain a total vacuum, or to control all the variables in order to make their experiments? I mean it was very difficult! Today, it might be true that technology has advanced, but what we have to say to the students is that at that moment they [the scientists] didn’t have electricity. The idea is to make students realize that great accomplishments of science are possible under very difficult historical circumstances, and they didn’t have such devices like this [pointing to the conductivity probe]. The scientists with such cleverness were able to create a vacuum hood in order to control the variables and better understand certain kinds of minerals.

[Biology Teacher– P1, Workshop audio recording, February 11, 2015]

**Renegotiating Cognitive Authority: Naïve Questions and Hypothesis Building**

The workshop seemed to allow teachers to move away from a position of cognitive authority, where they have to prove that they “know” (or should know) about certain topic. The informality and exploratory nature of the activity proved instrumental in changing teachers initial attempts to focus on question about curriculum, and rather manifested that they had enjoyed the exploration, the messiness, and even the encounters with error and failure. The playful and informal setting allowed teachers to talk freely, not only about their own uncertainties or understanding of the importance of measuring the electrical conductivity of water, but about many other topics not exclusively related to the workshop. For example, the conversations included a varied range of themes, from comments about the materials used in different types of batteries, difficulties encountered in soldering and connecting small pieces copper, to many other informal conversations about their everyday life.

The informal setting of the workshop paired with a friendly environment allowed teachers to feel comfortable asking rhetorical or naïve questions to which they probably should know the answers. It became evident from the initial remarks made at the beginning of the workshop, when they were trying to understand the conductivity data, that they were not afraid or uncomfortable of being mistaken in front of the other teachers. During the collection of data and
testing with calibrating solutions, teachers seemed to feel confortable questioning each other’s explanations and hypotheses, acknowledging that they did not understand some aspects. The following excerpt indicates some of the discussions afforded during teachers’ analysis of the data collected with the conductivity probe.

While the resistance increases… the lower is the conductivity, right?

[Biology Teacher– P3, Workshop audio recording, February 11, 2015]

Yes, the resistance and the conductivity have an inverse correlation

[Researcher Teacher– P1, Workshop audio recording, February 11, 2015]

So, the more solids are dissolved [in water] the higher is the conductivity

[Physics Teacher– P6, Workshop audio recording, February 11, 2015]

[.] and the dissolved solids, why are not readings fluctuating?

[Biology Teacher– P1, Workshop audio recording, February 11, 2015]

*Biology Teacher (P2):* because the solution is also changing

[Biology Teacher– P2, Workshop audio recording, February 11, 2015]

*Biology Teacher (P5):* this happens probably because there is sedimentation…

[Biology Teacher– P5, Workshop audio recording, February 11, 2015]

ha! The solution is not fully stable?

[Biology Teacher– P1, Workshop audio recording, February 11, 2015]

… probably the not all the salt is fully dissolved. Also it is likely that there is over saturation

[Biology Teacher– P5, Workshop audio recording, February 11, 2015]
Figure 12 – Analyzing Conductivity Data

Figure 12 depicts the activity where teachers examined the conductivity data thinking aloud and making hypothesis about the anomalies and fluctuations in the measurements.

Measuring the conductivity and testing with calibrating solutions allowed teachers to discover that if they immersed the probe in a solution for a few minutes, the value of the readings decreased over time, and then, if they stirred the solution, the readings increased. This event of discovering fluctuations in the data led the group of teachers to ask questions and formulate hypotheses about what is happening. A physics teacher (P6) suggested: “the temperature changes if you introduce friction into the water, and this increases the conductivity”. A biology teacher (P2) replayed saying that what was actually happening was sedimentation. As she explained: “over a few minutes of sedimentation, the conductivity decreases and the readings become more stable”. One of the biology teachers (P1) commented with surprise that the sensor was actually “too sensitive”, because minor variations (in temperature or sedimentation) were actually captured by the sensor. She went on and provided an interesting reflection about how this activity could be very useful to teach students about how scientists need to control variables in the laboratory.
One of the key outcomes of this activity was that participants discovered that adding only a little amount of salt in the solution produces a rapid increase in the conductivity. This discovery also led to further experimentation and discussion about how to use the calibrating solutions as a standard reference for the analysis of other water samples.

**Peer interactions and Interdisciplinary dialogues**

Teachers engaged in conversations about the artefacts that could be built to address specific class topics that they had worked on in the past but were not able to develop, due to lack of resources or knowledge about how to built them. Engaging in the fabrication of the DIY probe seemed to foster teachers brainstorming and discussions about how these types of projects would require different expertise and knowledge. For example, they mentioned that measuring the conductivity of water would require some basic technical knowledge and for this reason, they would have to work with other teachers, for example mathematics and physics teachers that could assist them in analyzing the data.

**Follow Up Projects**

**Building a DIY PH Sensor.** In an informal conversation After the DIY Water Quality Sensing workshop, one of the biology teachers (P2) asked me to assist her in building a PH sensor. She explained to me that the DIY Water workshop had inspired her to search online for tutorials and instruction to build other scientific instruments. The teacher shared with me the instructions and specifications she had found explaining how to build one’s own PH sensor. I explained to her that the components to build the PH sensor were certainty available in local stores, but I also explained that one of the major challenges with DIY sensors was calibration and reliability. In was quite surprising to me that she had already checked and read about this issues, as this convinced me once more of the positive impact that the workshops were having among the
community of teachers and how the teachers themselves were playing an important role as researchers of my own investigation. The teacher actually helped me understand why the accuracy of the DIY conductivity sensor could vary over time. As she explained, using copper for measuring electrical conductivity makes the sensor inaccurate in the long term because the surface of the electrodes changes over time due to oxidization, which decreases the conductivity of metals.

**Controlled Environment for the Growth Micro Organisms.** A few weeks after the DIY Water Quality Workshop, when conducting a follow-up interview with one of the biology teachers, she shared an idea for an artefact she wanted to build for her class on microorganisms. Her project involved the creation of a controlled environment where students could measure and change variables that influence the growth of different types of microorganisms. Some of the variables she wanted to measure included intensity of light (luminosity), temperature and humidity. The project she envisioned involved an artefact capable of changing these variables so that they could increase or decrease these variables.

One of the key motivations for this project was to repurpose an old aquarium that had been sitting in the school’s laboratory for almost a year, and she wanted to reuse it for a different purpose. The teacher suggested that she could recycle this old aquarium and use it as a container for the Controlled Environment for the Growth Micro Organisms. The images below show the aquarium and a prototype including sensors (light, humidity, temperature) and actuators (a fluorescent light bulb, a fan, a heater).
Figure 13 – DIY Controlled Environment for the Growth of Micro Organism

5.6 Conclusion

The design of research strategies that include the use of DIY electronics requires an immersion into a diverse and heterogeneous ecosystem of sociotechnical practices. The first part of this chapter described explorations and participation in numerous projects and events, followed by the design of my own prototypes and DIY toolkits, thus providing the bases for the formalization of an intervention strategy for the DIY and Maker initiatives as a setting in which to situate the study of emerging literacy practices. In the second part, I provided detailed descriptions and analyses of three case studies. Each study presents a different type of sociotechnical encapsulation in order to explore the advantages as well as the challenges of introducing DIY and Maker initiatives in elementary and high school education. The findings indicate that sociotechnical encapsulation – as an engagement in the fabrication of DIY electronics – can be introduced as a valuable setting for the exploration of emerging cognitive trajectories, the design of class projects, and reflection about participants own teaching practices. In the next chapter, I discuss further the finding of my studies in an attempt to formalize and evaluate the pertinence of sociotechnical encapsulation for the design of pedagogical interventions.
Chapter 6
The Affordances of Sociotechnical Encapsulation

Every exploration of diagnosis comes with the need to reflect on the trajectories that have been followed, both by the researcher and the participants; making sense of the unexpected interactions and the diversity of the data collected is an attempt for systematic and unified analysis. Such a reconstruction is crucial not only to evaluate the significance of a research project but an unavoidable step envisioning the next steps of the research. In this chapter I go back to key discussions introduced in the review of the literature, and address the challenges and conceptual understandings of literacy practices as lenses for the analysis of the findings.

The first section of this analysis details how the electronic toolkits and the script modalities can be formalized as an instrument of mediation enabling a varied array of cognitive trajectories. The second section situates sociotechnical encapsulation in the context of current research in Human Computer Interaction and examines how the research approach used in this dissertation contributes to discussions about the principles orienting the design of DIY experiences.

6.1 The Notion of Affordance

Psychologist James J. Gibson (1979, 1977) introduces the notion of *affordance* to describe how the environment can provide clues (information) that enable (or prevent) certain types of behaviour. This idea is later introduced to the field of Human Computer Interaction, by Donald Norman (1988, 1999) and since then, interaction designers have used this concept extensively as evaluation criteria well as a design principle. Affordance is an idea pointing to the relationships between actors and the environment (Norman, 1999). According to this view, artefacts, and
objects in general, are conceived as entities that have properties\textsuperscript{22}. If an actor perceives these properties, such properties have the potential to lead to a certain course of action (affordance).

Kaptelinin & Nardi (2012) have provided a comprehensive review of the notion of affordance as a salient concept in HCI research. They argue that the definition of affordances has remained relatively “vague”, describing a direct relationship between animals and the environment. Kaptelinin & Nardi stress that in order to account for complex interactions between sociotechnical artefacts and human action, this notion can be better understood through the lenses of Vygotsky’s mediated action; which provides a distinction between direct perception and cognitive activity mediated by the use of artefacts. It is in this sense that I use the notion of affordance in this dissertation. The interaction between actors and the environment does not occur only through direct perception, but rather, complex forms of cognitive activity require meditational tools, both physical and psychological. Along this view, the \textit{affordances of sociotechnical encapsulation} is presented as a research approach examining the multiple and unexpected types of activity emerging from the interaction between humans and artefacts.

6.2 The Co-construction of Tools and the Purpose of the Activity

In order to define the type of interventions conducted in my case studies, I adopted a vocabulary with quite specific meanings. The notion of \textit{sociotechnical encapsulation} has been used to describe two important components of this dissertation. First, sociotechnical encapsulation is a

\textsuperscript{22} Various controversies arise when attempting to conceptualize such “properties”. The key issue is to ask if these properties are merely out there and exist \textit{in} environment independent of human perception and action. This discussion is certainly out of the scope of this dissertation. A nuanced discussion in the context of HCI can be found in Kaptelinin & Nardi (2012); McGrenere, J., and Ho, W. (2000).
fundamental characteristic of human cognition. In Chapter 3, I presented the theories informing this particular view of cognition. Encapsulation entails recognizing the role of instruments of mediation and the interaction of both human and non-human actors. A second meaning of encapsulation emerges in Chapter 5, when this notion is operationalized and used to refer to technical and social aspects that are taking place in DIY and Maker initiatives. Sociotechnical encapsulation was defined as a combination of two dimensions: (1) the level of technical complexity hidden from participants in an electronic toolkit, and (2) the script modality used in the workshops activities: open-ended or directed towards a clearly defined goal.

In retrospect, I realize that it is crucial to attempt to use a common terminology, which can be shared with other scholars to refer to similar aspects and problems. A common vocabulary is also desirable to refer to the heterogeneous actors intervening in processes of designing and conducting my studies, such as electronics toolkits, script modalities, and levels of technical complexity. It is with this aim that I borrow the terminology introduced by Yrjö Engeström in his model of an Activity System.

Engeström’s (1987, 1999) model is a distilled formulation incorporating various theoretical developments in Cultural-Historical Activity Theory (CHAT). His model has been used extensively in many disciplines as a tool assisting researchers in the description and articulation of their findings within a unified explanatory model. It is crucial to note, however, that the use of a model for the analysis is always partial and exploratory. Models are suggestive and its value is to assist researchers highlighting possible relationships between subjects and contexts and other elements involved in an activity system. For a model to be useful, it has to be fully articulated, and this means that researchers need to examine how such models can provide a valuable tool for the analysis of their particular case studies and the data collected, which implies then a
commitment to empirical examination, rigorous documentation of the phenomena, and continued reflection and analysis (Lemos et al., 2013).

Engeström’s model describes six elements of an activity system: *Object*: the goal, intention, or objective towards which the activity is directed; *Instruments*: physical and psychological tools of mediation; *Subject*: an individual or group of people; *Community*: the social context of the activity, which can involve other activity systems; *Rules*: constraints or instructions provided for the activity; *Division of Labour*: the distribution of tasks among individuals or groups collaborating in the achievement of the object of the activity.

All these elements can relate or influence each other in various different forms. This is why they are presented in the form of a triangle (Engeström’s Triangle) connecting the elements with bidirectional arrows. Figure 13 illustrates an array of possible relationships (and trajectories) among the elements of the activity.

![Diagram of an Activity System](image)

Figure 14 - Model of an Activity System - Adapted from Engeström (1987, 2009)

One of the key ideas behind this model is that the *Object* of the activity is never fully defined *a priori* but rather needs to be understood as a result of the interaction (mediation) amongst actors. A similar idea is present in Actor-Network Theory; notions such as knowledge or power need to
be described as “network effects” emerging through processes of stabilization and co-
constitution between humans and non-humans. In Activity Theory, Engeström argues, the Object
of the activity (the purpose or intention) cannot be understood without careful attention to the
instruments of mediation and the context of the activity. As he explains:

An object of activity is not the same as mediating artifact, or tool. The two play
dramatically different, yet constantly switching roles in the unfolding activity. The
puppeteer's object is not reducible to the puppet; we need to examine the audience and
the play. (Engeström, 1996: 262)

This mechanism, the shifting of roles between the Object and the Instrument, provides an
important insight for understanding the meaning and role of sociotechnical encapsulation
throughout my interventions. Three elements in Engeström’s model are particularly relevant for
the analysis of my findings: Object, Instruments, and Rules. These elements can be used to
analyze the Sociotechnical Encapsulation Matrix defined in the Chapter 5. In can be argued that
the Technical Complexity and Script Modality describe an interaction between Instruments and
Rules mediating the definition and evolution of the Object of the activity. Table 7 presents a
summary of the findings of each of the studies indicating the electronic toolkit (instruments) and
the script modalities (rules), and the specific affordances relevant for the analysis of literacy
practices.
Table 7 - Sociotechnical Encapsulation and Literacy Practices

<table>
<thead>
<tr>
<th>Sociotechnical Encapsulation</th>
<th>Activity</th>
<th>Literacy Practices (Affordances)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Encapsulation/ Open-ended</td>
<td>Participants create artefacts displaying autonomous behaviour using a few electronic components.</td>
<td>Material fabrication assists in the progressive definition of the object of the activity. Reflections on the pedagogical value of the DIY practices. Hypothesis building about the role of material fabrication in exploring both scientific concepts and aesthetic dimensions.</td>
</tr>
</tbody>
</table>

S2A: Sensing for Acting (Iteration 1 – Pre-programmed Arduino)

<table>
<thead>
<tr>
<th>Sociotechnical Encapsulation</th>
<th>Activity</th>
<th>Literacy Practices (Affordances)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Encapsulation/ Open-ended</td>
<td>Participants use a pre-programmed electronic toolkit to explore the use of the sensors and actuators.</td>
<td>The complexity of the toolkit is intimidating at the beginning of the activity. Emergence of uncertainties about potential uses. Exploring non-conventional uses of technology. Becoming a student: teachers assume the role their students. Emergence of design prototypes for possible class projects. Reflections on the pedagogical value of the DIY practices.</td>
</tr>
</tbody>
</table>

S2B: Sensing for Acting (Iteration 2 – Programming Arduino from Scratch)

<table>
<thead>
<tr>
<th>Sociotechnical Encapsulation</th>
<th>Activity</th>
<th>Literacy Practices (Affordances)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Encapsulation/ Directed</td>
<td>Participants use a programming tool (Scratch) to control sensors and actuators</td>
<td>Engagement and motivation increases when creating functional artefacts implementing prototypes created in previous workshop (S2A). Initial intimidation of the electronic toolkit decreases. Teachers feel confident to continue on their own.</td>
</tr>
</tbody>
</table>
Reflections on the pedagogical value of the DIY practices.

**S3: DIY Water Quality Sensor**

<table>
<thead>
<tr>
<th>S-T-Enc</th>
<th>Activity</th>
<th>Literacy Practices (Affordances)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Encapsulation/Directed</td>
<td>Participants build and DIY Water quality sensors, test with different calibrating solutions and discuss fluctuation and accuracy of the data.</td>
<td>Emergence of discussions about the purpose of building scientific instruments in the classroom.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reflections on the pedagogical value of the DIY practices.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experimentation with water samples leads to questions about conventions in scientific measurements.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The complexity of the probe requires engaging in interdisciplinary dialogs (e.g. physics, biology, chemistry, education).</td>
</tr>
</tbody>
</table>

6.3 Encapsulation as an Evolving Instrument of Mediation

Different types of sociotechnical encapsulation act as cognitive instruments and scaffolds transforming different elements of the activity system. Throughout the workshops, changes in the rules or the instruments of mediation have profound impact in the cognitive trajectories afforded, including for example participant’s knowledge (subject), and the progressive definition of the purpose of the activity (object). In order to better understand the practices afforded by different types of sociotechnical encapsulation, in this section I analyze some of the unique aspects and commonalities in each of the workshops.

The first encounter with the electronic toolkit often introduces uncertainty about its possibilities, as participants are confronted with devices that they have not seen before. This first encounter entails realizing that there are specific skills and knowledge that are beyond participants’ current level of knowledge and expertise. This initial stage of uncertainty (or even perplexity) is followed by different trajectories of inquiry and exploration that can be attributed to the level of
technical complexity of the electronic toolkit and the script modality (rules) used in the workshops.

In the first case study (Toy Hacking Workshop), participants were given different types of components (e.g. motors, a tooth brush, cables, and batteries) but they received no instructions on how to connect them. This deliberate lack of guidance and the open-ended objective of the activity defined as the creation of an artefact that displays autonomous behaviour, seemed to be instrumental in fostering motivation and engaging in a process of exploration, of trial and error, through which the understanding of the possibilities of each component was achieved by engaging in the material fabrication. In this case, the low-level of technical complexity was achieved by providing electronic circuits with only two possible states: the batteries were connected to the motors or not. This relatively simple mechanism became transparent and internalized by the participants at early stages of the activity. Then, the transformation of the material arrangement of the artefacts leads towards the progressive definition of the overall purpose or function of the artefact. It can be argued that a low-level of technical encapsulation, paired with an open-ended definition of the object, is a type of workshop activity, and affords cognitive trajectories in which the purpose and goal of the activity evolves through iterative re-negotiations between the material fabrication and the narratives created throughout the process.

This type of sociotechnical encapsulation is particularly relevant to describe a key characteristic of DIY and Maker initiatives: participants’ motivation and curiosity tends to increase as the technical complexity is mastered throughout the activity, and thus, the focus of the design process evolves as participants start incorporate their own knowledge and interests.
In the second study (“Sensing for Acting”), the encapsulation introduced in the electronic toolkit confronts participants with an array of unknown components and possibilities. Increasing the technical complexity and the number of components furthers the challenges, as participants are required to learn how to use the toolkit by testing sample circuits before they can start the design of their own artefacts. This workshop introduced two different types of sociotechnical encapsulation. The first iteration of the study (“Sensing for Acting” - S2A) included a high level of technical complexity in the electronic toolkit. Participants were prompted with a loosely defined goal: “Sensing for Acting”. As described in Chapter 5, this idea was used to suggest the design of an artefact incorporating at least one sensor to create a response in one of the actuators. The first part of the activity involves learning about each of the components and understanding how these can be connected by following instructions and wiring diagrams. These exploratory stages are significant because they allow participants to discover what type of artefacts they are able to create and progressively discover the types of skill and knowledge that they will require to accomplish them. The second part of the workshop (S2B) focused on building the “Sensing for Acting” artefact. The selection of a sensor and a corresponding actuator requires participants to create a narrative: a story around the artefacts that defines its purpose and meaning. For example, a movement sensor can be used to produce a sound, but the key question that needs to be answered by the participants is how this can be used for their own purposes and thus explain the meaning of using particular sensors and actuators. In other words, during the first part of the activity, the electronic toolkit provides only suggestions for possible interactions or responses and the purpose of the activity is not necessarily relevant for the participants. After participants have discovered some of the possible combinations between sensors and actuators, it becomes possible to start the design of prototypes that include participants’ interests and previous knowledge, as well as ideas relevant to their own class projects. For example, teachers engage in
re-negotiations of the meaning of technology by repurposing the components for other non-conventional uses.

The second iteration of the workshop (“Sensing for Acting” - S2B) included a low-level of technical complexity, as participants were encouraged to open up the black box, controlling and changing the internal operations of the electronic toolkit in order to implement their own prototype ideas. In this case, the rules (script modality) of the activity direct the objective to specific tasks required to build a functional prototype. This transformation of the initial toolkit can be understood as the emergence of a new instrument of mediation leading to new cognitive trajectories, including both technical and pedagogical questions. For example, participants were required to learn about the sensitivity and accuracy of the sensors, as they were creating different outcomes based on variations of specific numeric measurements. It is worth noting that the motivation and willingness to learn about the technical details and creating specific computer programs and algorithms emerged as participants discovered how to relate their artefacts to their own teaching practices and ideas for future class projects.

The third study (“DIY Water Quality”) involved a highly encapsulated electronic toolkit for the construction of a scientific instrument that participants had to build according to strict specifications. In this case, the purpose of the artefact was defined from the beginning of the activity, but the engagement with the construction and experimentation with the sensor allowed teachers to explore how the instruments could be used in the context of their own pedagogical practices. It is possible to argue that when the goal of the artefact is narrowly defined, and the electronic toolkit is highly encapsulated, the activity removes the need to understand the technical details and allows participants to focus on other tasks and discussions beyond the specific functionality of the conductivity sensor. For example, participants engaged in
interdisciplinary dialogs and hypothesis building and discussed their own teaching practices and pedagogical commitments as well as the value of adopting DIY and Maker initiatives as a key component of their teaching strategies.

6.3.1 Formalizing Two Types of Mediation

The use of a high-level of encapsulation (toolkit) affords at least two types of mediation. The first type takes place at the first encounter with the electronic toolkit. The high level of technical complexity introduces various cognitive challenges, for example questions such as: how does it work? what can do with it? why is this relevant to my teaching practices? This first encounter situates participants in a position of challenge and uncertainty, where they need to learn about what each component can do and explore what is possible. Moreover, the toolkit introduces an array of possible solutions for problems that do not yet exist, as they are not initially relevant for the participant. For example, sensors measuring movement or distance bring with them an explicit function and solution. However, the function of the sensor needs to be localized, and articulated within a specific context comprised by participants’ own interests and knowledge as well as other actors such as the academic community, the pedagogical commitments of the institution, among others. The explorations in localizing and making sense of the sensors and actuators afford a second type of mediation. This takes place when participants have discovered some of the possibilities of the toolkit by following instructions and wiring diagrams.

These two types of mediation are not necessarily sequential but coexist and influence each other throughout the interventions. It can be argued that these evolving roles of the instruments of mediation interact and transform each other and such interaction constitutes a fundamental dynamism enabling the emergence of multiple and unexpected cognitive trajectories.
6.3.2 Progressive Definition of the Object of the Activity

The key point that I want to make about DIY and Maker initiatives is that we may not need a clear and sharply defined object of the activity in order to engage in meaningful cognitive trajectories and inquiry practices. This may sound counter intuitive for many teachers and researchers, as it is often argued that the design of any teaching experience must start with the definition of learning outcomes and objectives. Throughout the interventions described in Chapter Five, it was revealed that the engagement with the material fabrication of electronic artefacts does not need to start with a clearly defined goal or objective towards which the activity is directed. In fact, the value of such engagements seems to require different lenses – as Engeström (1996) points out, a ”shifting role” between the intention of the task and the instruments of mediation. These explorations with practices of de-re-encapsulation (progressively and selectively disclosing the internal complexity of the artefacts), act as a powerful strategy for advancing the definition and the Object (intention) of the activity. My claim is that loosely defined goals and high levels of sociotechnical encapsulation can act as facilitators of meaning making and enable in-depth understandings, as these practices emerge through multiple and unexpected cognitive trajectories led by participant’s own interests and motivations and the engagement with material fabrication.

In Chapter 3, I examined how the notion of encapsulation has been used to examine the stabilization of knowledge practices through specific technologies (Latour, 1991). This idea has been so influential amongst HCI scholars informed by STS, that the opening of black boxes of technology has become a fundamental, if not as an imperative task, for a “critical” approach to society and technology. However, what if we think about technology, not as a negative black boxing, but as a positive encapsulation enabling as well many other possible and unexpected
affordances? Encapsulation is not, exclusively, a strategy for inscribing values in technology, or making “society durable” (Latour, 1991). Differently, encapsulation needs to be understood as a fundamental mechanism enabling meaning making and innovative forms of cognition; precisely, because it is a mechanism that invites one to explore cycles of openness (de-encapsulation) and closure (re-encapsulation) as a strategy for critical and in-depth understanding.

In my interpretation of “cognition in the wild” (Hutchins, 1995) and “cognitive trails” (Cussins, 1992), the object of the activity (in the CHAT sense) does not require a centralized subject or consciousness, at least not fully defined before the interaction with the environment and diverse instruments of mediation. In fact, the insight indicated by these authors points to an opposite direction, or rather, to a bi-directional causality between cognition and the environment (Cussins, 1992, 2012). A better way of understanding “object-directedness” is not to sharply define the intention a subject has towards an object. Intention, as well as many complex cognitive tasks, occurs as a result of a mutual co-constitution of the subject and the environment.

Informed by this view, the electronic toolkits and script modalities explored in this dissertation were specifically designed to allow participants to engage in multiple ways of assisting and further defining the cognitive tasks. This particular way of designing interventions reveals DIY and Maker initiatives not simply as a pedagogical recourse for didactic purposes, but rather as a setting and a methodological strategy that can assist the diagnosis and the emergence of innovative literacy practices through re-negotiations between the material environment and participants own interests and knowledge.
6.4 Bringing DIY and Maker Initiatives into the Classrooms

Fostering critical literacies can be understood as a challenge about the exploration of teaching methods and practices and less about a specific curriculum. The value of introducing DIY and Maker initiatives into the classrooms needs to be seen as a question about how we teach or make available alternative learning experiences, rather than an exclusive focus on what we teach, such as the content specified in a particular curriculum. Throughout my studies I encountered that this discussion was not a key topic of debate both amongst scholars and school teachers. On the one hand, introducing DIY workshops triggered questions about what are the knowledge and specific skills that someone can learn from these activities. On the other hand, some participants argue that the key issue is not so much to be pro or against technologies, but to focus on the how, and whether any of these tools can help teachers finding alternative ways of improving teaching practices.

In a similar vein, constructionist researchers have brought attention to how DIY and Maker initiatives can provide material and conceptual resources to engage in a critique of notions of content, competencies, and learning objectives in education (Papert & Resnick, 1995; Resnick & Rosenbaum, 2013). A crucial question that arises in discussions about fostering critical thinking is a pragmatic challenge: how do we do this? For example, what specific practices can engage teachers and students in discussions about definitions of literacy or the relationships between social and technical dimensions? The research strategy explored in this dissertation constitutes an attempt to indicate a possible avenue for answering this pragmatic question. Engaging in the fabrication of material artefacts and the design of experiences directed to foster progressive exploration of technical complexity (encapsulation) constitutes an innovative orientation; it can
reveal why DIY and Maker initiatives are relevant for education, but more significantly, it provides a design principle that can inspire the design intervention strategies.

This research project focused on exploring how DIY technologies and practices can assist teachers in discovering alternative ways of teaching and learning. Throughout the studies, the engagement with the fabrication of electronic artefacts was revealed as a valuable activity allowing school teachers to reflect on their own teaching practices, and envision the design of pedagogical explorations with DIY technologies.

6.4.1 Not Teaching Universal Skills but Facilitating Processes of Becoming

An important aspect of the interventions presented in this dissertation is that they were not deliberately intended to teach or provide specific technical skills, at least not exclusively. Initially, the workshops were perceived among teachers as an opportunity to learn about emerging technologies – such as open hardware and software platforms, or electronic devices such as sensors and actuators. However, as my studies were conducted and followed up with various projects and discussions, the focus on technical skills revealed only one dimension, and perhaps not the most significant for the understanding of the value of DIY and Maker initiatives to situate questions about emerging literacy practices. When conducting interviews after the workshops it became clear that participants had started to realize that the aim of these engagements with the fabrication of DIY electronics could play crucial roles in facilitating critical reflections about technology and emerging forms of inquiry, teaching, and learning. Throughout the studies, the activities proved instrumental in facilitating teachers’ reflection on their own notions of literacy and professional practice. For example, the workshops allowed the emergence of discussions about the value of DIY activities in raising awareness of black-boxed
(encapsulated) technologies, and envisioning strategies for increasing students’ motivation and curiosity.

These findings suggest that DIY and Maker initiatives should not be simply understood as a set of specific skills or literacies (i.e. Information, computer, media literacies) but rather as processes of becoming a participant in heterogeneous communities. DIY and Maker initiatives are relevant to questions about literacy when they are considered as open ended practices in which participants discovered skills and knowledge by means of becoming participants in emerging communities of practice (Cf. Lave & Wenger, 1991). The crucial aspect is that engaging in practices of discussion and negotiation with sociotechnical encapsulation is not simply a process acquisition of universal skills and competencies.

The pertinence of DIY and Maker initiatives, as settings in which to situate questions about literacy, seems to be beyond specific skills and knowledge. Using DiSalvo’s (2012a) terminology, such an attempt seems to imply a pretention to normalize the agonistic, which is precisely one of the salient characteristics of DIY initiatives, which in many occasions are deliberately attempting not to resolve a problem, but rather to sustain an ethos of permanent exploration.

6.4.2 Starting with not well-defined Problems

We face an important shift in pedagogical orientations when attempting to introduce DIY and Maker initiatives into the classrooms. A traditional approach to teaching and learning is grounded on the premise that meaningful, genuine (as well as predictable) learning practices require well-defined problems and learning outcomes. As this traditional view sustains, only after a problem (or learning objective) has been defined, the learning activity can be designed to
progressively assist the exploration of solutions. Responses to this paradigm in the learning sciences include discussions about the value of ill-defined problems and more recently, the work of Manu Kapur (2010) on Productive Failure.

Similarly, in the context of information systems design a predominant view revolves around the idea of gathering requirements. In this view, computer programmers and designers are often taught that there is a need for exhaustive definition of the requirements prior to the design and development of information infrastructures. It is argued that the design of a solution cannot start without a comprehensive understanding and definition of the problem. Some critical responses to the limitation, if not impossibility, of exhaustive definitions of requirements for information systems include the work of various scholars in Participatory Design such as Ehn (1987), Woolgar (1991), and Suchman (2009).

These two orientations, one in education and the other in the information systems design fields, seem to be challenged by numerous experiences in DIY and Maker initiatives where the outcomes as well as the artefacts often start with loosely defined problems.

The DIY and Maker experiences discussed in this dissertation did not start from well-defined problems, or with an exhaustive definition of requirements, or learning objectives. Differently, starting with loosely defined problems and engaging in the physical fabrication of electronic artefacts proved a valuable practice for school teachers to explore innovative designs and electronic prototypes for purposes that they had not envisioned before. The iterative nature of DIY practices provides an important methodological lesson: the engagement with the process designing and making of DIY artefacts brings attention to the value of starting with loosely defined problems and requirements, as these introduce the need for progressive discovery and
exploration. This methodological insight is relevant for educators and information professionals because it suggests that DIY practices constitute a setting that can facilitate the emergence of literacy practices that are meaningful to participants. In other words, DIY initiatives need to be seen as a valuable pedagogical framework that places an emphasis on facilitating practices where participants are encouraged to progressively define the goals and content of their own learning.

6.4.3 Designing and Sustaining Educational Technologies

One of the key challenges of introducing any technological innovation into the classrooms is the need for long-term support. Quite often the introduction of a new educational technology tends to fail because the infrastructure provided requires specialized computer programmers and coordinators to sustain the sociotechnical practice. Once the investigator and the support team leave the research site, the teachers are often unable to sustain the technology that was introduced. The idea of introducing DIY and Maker initiatives into the classrooms suggests a different strategy. Teachers and students need to be able to sustain their projects and technologies. This is why my studies focused on relatively simple toolkits that could open up the possibility to think about possible applications and future developments, while exposing teachers to the challenges entailed in designing, building and sustaining the DIY and Maker initiatives within their own communities.

Another reason for failure of educational technologies, which is not related to technical complexity or technical knowledge, is the question about the relevance for those engaged in the activity. As one of the participants pointed out: “your toys seem to come with a solution for a problem [e.g. the DIY water quality sensor], but we have not identified these measurements as a problem that is meaningful for us, at least not yet” (Humanities Teacher). A bottom-up approach is required when attempting to introduce DIY and Maker initiatives in the classrooms, and this
implies that the design process needs to emerge from problems that are shared by the community of teachers and students.

6.5 Conclusion

Sociotechnical encapsulation, defined as a combination of levels of technical complexity and the script modality, can act as important scaffolds enabling the exploration of cognitive trajectories. Through the lenses of Activity Theory, the type of interventions described in this dissertation can be analyzed as tools of mediation allowing school teachers to envision hands-on and project-based experiences that introduce the use of DIY electronics in their classrooms. The encounters with different types of encapsulation provide avenues for developing open-ended trajectories of inquiry and learning led by participants’ interests and previous knowledge. In this chapter, I have indicated that introducing DIY and Maker initiatives into the classroom requires considering not simply universal and technical skills, but rather the processes of becoming participants in evolving and heterogeneous sociotechnical practices. In order to achieve this, the important role of progressive exploration of the definition of the tasks orienting the learning trajectories needs to be taken into consideration.
Chapter 7
Designing Tools For Interpretation
and Critical Thinking

This dissertation started with the motivation of exploring research strategies capable of addressing concerns amongst various scholars, and educators in particular, about the impact of rapid technological change on the definition of skills and knowledge required for participation in contemporary societies. The approach taken to address these broad questions about the relationships between technology, society and literacy led me to an investigation about Do-It-Yourself (DIY) and Maker initiatives as a setting in which to situate the study of a new ecosystem of literacy practices portraying innovative and unique re-appropriations of technology. In Chapter 1, I argued that DIY and Maker initiatives, and DIY electronics in particular, are allowing novel forms of collecting, interpreting, and sharing information and knowledge. For this reason, I made the case that researchers in information studies, design, and education need to pay careful attention to how these practices enable people to engage creatively and critically in the construction of new forms of evidence, collaboration, and re-negotiations of meaning in their everyday life and professional practice.

Encounters with Sociotechnical Encapsulation is an investigation of these emerging practices facilitated by the engagement in the fabrication and the discussion of DIY and Maker initiatives. This examination included an extensive review of the definition of literacy practices, my own explorations with the design of electronic toolkits, and an empirical component including three case studies exploring the construction of DIY electronics with school teachers.
In this concluding chapter, I provide an overview of the research project, highlighting the role of each chapter in addressing the research questions, summarize the contributions and limitations, and finally indicate some future avenues of research.

7.1 Reviewing of the Research Project

The primary question giving direction to this research was: *what are the affordances of variable levels of sociotechnical encapsulation in fostering inquiry practices and cognitive trajectories?*

In order to address this question I formulated five additional questions examining specific aspects.

- *(Q2)*: How do we better conceptualize and empirically study the various types of skill and knowledge practices emerging in DIY initiatives?

- *(Q3)*: If the engagement with fabrication of physical artefacts can contribute to both diagnose literacy practices and foster critical and creative reflection, how then do we study these practices and the effects of sociotechnical encapsulation?

- *(Q4)*: What are the affordances of variable levels of sociotechnical encapsulation in participants’ collaboration, motivation, and engagement?

- *(Q5)*: What are the specific emerging knowledge practices fostered by DIY and Maker initiatives using microelectronics, for example, when used for environmental and self-personal sensing?

Examining the challenges entailed in definitions of literacy and understanding the role of technology in shaping socio-cultural practices are two important components of this dissertation (Q2 and Q3). In Chapter 2, I introduced a discussion of the various challenges involved in
attempting to define literacy as a set of universal skills, such as reading, writing, and mathematical thinking. Building upon scholars in New Literacy Studies, I argued that the diversity of information modalities and technologies requires moving beyond functional definitions of literacy, such as those advocated by influential publications from UNESCO and OECD. The idea of multiliteracies brought attention to dimensions of literacy encompassing social, cultural, and technological practices (Street, 1984). Chapter 2 revealed the inadequacy of predominant discourses such as the “information age” and the “knowledge society”; as they tend to bring with them restrictive definitions that disregard political agendas and cultural diversity. An important achievement of this chapter was to reveal that DIY and Maker initiatives cannot not defined exclusively in terms of specific “technical skills”; they include a diverse array of “social skills” and “cultural competencies” (Jenkins et al., 2007).

In Chapter 3, I examined conceptual and methodological frameworks for the study of literacy practices emphasizing the role of technical, social, and cultural aspects in complex forms of cognition. Each of the theories provided distinctive elements of a sociotechnical approach for the understanding of literacy practices. The central idea is that physical tools and socio-cultural practices are fundamental components of cognition. Situated Learning indicates how the acquisition of knowledge needs to be understood as a process of becoming a participant within a community of practice. Distributed Cognition highlights how certain complex cognitive tasks cannot be conceived without the interaction of technical artefacts and the coordination among people. Actor Network Theory (ANT) introduced a framework for understanding sociotechnical encapsulation as a mechanism of stabilization of knowledge practices that take place through the agency of both human and non-human actors. The relevance of this view is both conceptual and methodological. At the conceptual level, ANT allows expanding the object of analysis to
heterogeneous networks, including physical artefacts and individuals, as well as other entities of such as organizations. At the methodological level, ANT provides an ethnographic strategy: “following the actors” in order to trace the process of translation and stabilization. The key argument developed in this chapter indicates an important consideration: knowledge is fundamentally a construction; it is produced and sustained by specific sociotechnical practices and situated within particular contexts.

(Q3): If the engagement with fabrication of physical artefacts can contribute to both diagnose literacy practices and foster critical and creative reflection, how then do we study the these practices and the effects of sociotechnical encapsulation?

This question addresses two important themes of my dissertation. The first aspect is a question about the role of engaging in material fabrication of DIY artefacts; the second, points to the search for adequate methods for the study of these practices. These two aspects are addressed in various parts of this dissertation. At the end of Chapter 3, (Section 3.3), I pointed to emerging trends in Human Computer Interaction, design, and information fields indicating how DIY and Maker initiatives include a diverse ecosystem of innovative practices in the production and use of technology. These practices cannot be assessed or studied with traditional metrics such as efficiency and productivity, but rather they require considering many other criteria such as “levels of engagement”, and “enjoyment of use” (Boehner & Sengers, 2005), as well as new methods and intervention strategies for understanding how these initiatives are fostering critical thinking about the social, ethical, and political ramifications of technology (Ratto, 2011a). In Chapter 4, I argued that DIY and Maker initiatives encompass heterogeneous and often not well-established communities, and this requires not a traditional ethnographic approach, focused on one single research site, but rather a “multi-sited” approach (Marcus 1995) capable of tracing
similar issues across multiple sites and communities. In Chapter 5 (See section 5.1.6), I introduced sociotechnical encapsulation as a research approach for the study of DIY and Maker initiatives. This approach included considering two main components: (1) the level of technical complexity that is hidden from participants and encapsulated in the electronic toolkits, and (2) the Script Modality, which describes the level of definition of the workshop activity as either open-ended and exploratory, or directed to the fabrication of an artefact with precise specifications defined prior to the intervention. This methodological approach constitutes one of the key contributions of my research, and for this reason, in the next section I discuss in more details its implications as an orientation in the design of information artefacts and experiences.

(Q4): What are the affordances of variable levels of sociotechnical encapsulation in participants’ collaboration, motivation, and engagement?

(Q5): What are the specific emerging knowledge practices fostered by DIY and Maker initiatives using microelectronics, for example, when used for environmental and self-personal sensing?

Questions 4 and 5 inquire about the possible outcomes of an intervention that adopts sociotechnical encapsulation as a research approach. In chapter 5, (See sections 5.3.3, 5.4.3, and 5.5.3) I address these questions in the context of each case study. One of the key findings included discovering how highly encapsulated electronic toolkits have profound impact on participants’ motivation and levels of engagement, as well as in facilitating emerging literacy practices. Electronics toolkits that do not require participants to understand all the technical details, in order to create functional artefacts incorporating their own interests and expectations, were revealed as an important factor in fostering motivation and curiosity, as well as leading participants to relate to technology in ways that they had not experienced before.
The “affordances of sociotechnical encapsulation” is the name that I have given to the multiple and unexpected trajectories of inquiry and learning facilitated by engaging in the design and fabrication of DIY electronics and the progressive discovery of technical complexity. Some of these practices include: the co-construction of functional and aesthetic dimensions; excitement and the need to be resourceful; dealing with frustration; the emergence of naïve explorations and peer collaboration; tinkering as a pedagogical strategy; and, thinking like a scientist and engaging in hypothesis building through the construction of scientific instruments.

7.2 Sociotechnical Encapsulation as a Research Approach

In the 1980’s, the idea that technology is inevitably interpreted in different ways depending on the social, cultural and political contexts was revolutionary. As a reaction to ideas of technological determinism, this orientation pointing to the social construction of technology (SCOT) was a critique as well as a suggestion for new directions in understanding how technology and society relate to each other. In recent years, several perspectives have emerged in information and design fields addressing questions about the value of engaging in material fabrication and DIY artefacts. “Reflexive Design” and “Critical Making” are two of these perspectives inspiring the overall design of my research strategy and they are particularly relevant for the analysis of sociotechnical encapsulation as an orientation in the design for electronic toolkits and pedagogical interventions introducing DIY and Maker initiatives.

Technologies can be designed to foster multiple interpretations. As Boehner explains, this approach “advocates an orientation of designing for openness to multiple interpretations, recognizing that the incompleteness of a design at the hands of a designer is not a weakness but an asset of the design process “ (Boehner, 2006:365). Throughout the studies described in this
dissertation a fundamental concern included evaluating how specific technological artefacts can be used as scaffolds for multiple interpretations and cognitive trajectories.

One of the key ideas of Critical Making (Ratto, 2011a) is the design of activities through which people can engage in re-negotiation of relationships and values that are often taken for granted when interacting with sociotechnical artefacts. This deliberate attempt to examine the values inscribed (black-boxed) in technological artefacts can be seen as a diagnostic dimension highlighting the importance of engaging in the fabrication as well as the repurposing of technology as an avenue for achieving deeper understanding of values and interactions prescribed by its designers.

One of the key aspects of my research is to show how these discussions about interpretative flexibility and the situated nature of meaning making are taking place through the design and fabrication of DIY electronics. In particular, exploring how the notion of sociotechnical encapsulation can contribute to discussions about the idea of “openness” and “transparency” of technology, while pointing to an important avenue in fostering interpretation and critical thinking. Sociotechnical encapsulation not only does acknowledge that agency, participation, and meaning-making are always situated and open, but it attempts to advance a methodological strategy for the exploration of specific forms of agency and participation; for example, DIY microelectronics for environmental and self-personal sensing are some of these strategies.

Opening the black boxes of technology is in fact a crucial strategy to engage in critical examination of a particular phenomenon as well as a key methodological direction. A key point raised by scholars in STS and research informed by ANT is to ask about the forms of use that are not open to negotiation and examining to what extent the “opening” of these boxes requires
inspection of values and normative dimensions. Such an approach commits to critical theory as it aims to re-imagine and re-negotiate these values, eventually transforming the sociotechnical practices that sustain them.

The impact of such interventions on participants’ re-negotiations and reflections constitutes one of the main contributions to the conceptualization of literacy as a sociotechnical practice. The studies presented in this dissertation can be understood as interventions seeking both diagnostic and transformative outcomes. The diagnostic approach observes and documents participants’ process of discovery, as they learn about unknown and possible uses of technology through engagement in the process of making DIY electronics. At the same time, the interventions are transformative in the sense that they deliberatively attempted to challenge participants’ conceptions about the society and technology, and foster discussion about the pedagogical value of DIY initiatives.

The notion of sociotechnical encapsulation presented in this dissertation shares certain aspects with the idea of black boxing (e.g. Latour, 2005) and its focus on studying the processes of stabilisation and translation (Section 3.6). At the same time, however, sociotechnical encapsulation differs from ANT’s black boxing by introducing a new focus: the role of practices of both de-encapsulation and re-encapsulation as fundamental mechanism in fostering emergent literacy practices. One key difference, or rather a contribution to ANT-informed research is that the study of literacy practices, in particular in the context of DIY and Maker initiatives, the notion of encapsulation suggests not only an examination of the progressive stabilization of interactions amongst human and non-human actors (opening the black-boxes), but also the closing mechanisms. This entails a consideration of the fundamental cognitive role of highly “obscured” or encapsulated artefacts emphasized by theories of situated learning and distributed
cognition (Sections 3.2 and 3.3). Through the lenses of Cultural Historical Activity Theory, the encapsulation mechanism was described in terms of cycles of internalization and externalization and the role of instruments of mediation acting as scaffolds of the cognitive activity.

Sociotechnical encapsulation agrees with ANT’s notion of black boxing on the importance of examining the inscription of values in technological artefacts, but differently from ANT’s methodological and diagnostic approach, I argue that sociotechnical encapsulation focuses on the practices of both stabilization and de-stabilization of knowledge practices. In my studies, I described this approach as a progressive discovery of the internal complexity of DIY electronic artefacts that is facilitated using different types of script in the workshop activities. The “encounters” with different types of complexity provide an array of possibilities for the emergence knowledge practices. The process of discovering the internal complexity of the artefacts is not a linear process that increases the transparency of the artefacts. This process of mastering the interactions with certain types (high and low) of encapsulation can act powerful cognitive scaffolds as these practices allow to create new types of encapsulation that become relevant for the exploration of different cognitive trajectories that evolve according to participants’ own interests and knowledge. In short, the contribution that I want to make with the notion of sociotechnical encapsulation is to reveal the pedagogical value of engaging in material fabrication of electronic artefacts and the role of constant evaluation of the levels of technical complexity as a mechanism for the diagnosis and the transformation of literacy practices.

7.2.1 DIY and Maker Initiatives as Practices for Innovation

DIY initiatives are challenging the notion of the expert, by providing examples of appropriation and re-purposing of technology, indicating avenues for new and more sustainable economies as well as encouraging local production (Gershenfeld, 2005; Gershenfeld & Vasseur, 2014). It can
be argued that there is in fact a “knowledge economy”, but innovation does not seem to come simply by providing the tools or information. DIY initiatives are showing that successful and creative uses of technology addressing local problems require organized and resilient communities. This implies recognition of knowledge practices challenging the idea of technology and knowledge as universal commodities or skills, and therefore introducing new notions of expertise. Thus, DIY initiatives provide not only a framework for conceptualizing innovative knowledge practices, but also a pragmatic approach highlighting how specific communities engage in adapting and making technology as strategies for the imagination and creation of solutions to their own problems. In other words, DIY initiatives can be seen as a contestation to universal sociotechnical solutions. The key idea is not simply to adapt and personalize solutions and technologies; the real challenge is to re-think the assumptions and the problems themselves in ways that are meaningful to local communities. In this regard, DIY initiatives and Critical Making experiences in particular, can provide valuable strategies for diagnosing and re-conceptualizing black-boxed sociotechnical phenomena.

7.2.2 Sociotechnical Encapsulation: Conceptual and Methodological Framework

DIY and Maker initiatives are not a homogenous field or site, nor a distinct community in which the social scientist can immerse and learn from, seamlessly. The study of these initiatives requires understanding that the presence of the researcher is already an “intervention” transforming the very object of study. So this is the challenge: how do we study such phenomena to acknowledge the active engagement of both researcher and participants? Researchers looking at DIY and Maker initiatives cannot assume that these communities and practices constitute a well-defined and distinct object of study. In doing so, popular use of the labels “DIY” and “Maker” often fail to recognize this heterogeneous nature of the phenomena and consider these
practices almost as an explanatory principle. Any attempt to introduce these types of practices in education or other contexts needs to recognize that these practices are diverse and multidimensional, not well-defined, and this implies the need to explain why and how such practices can reveal important and significant for particular contexts and communities.

The research strategy used in this dissertation attempted to address these issues as follows. First, I became familiar with DIY and Maker events and attempted to identify some distinctive characteristics of the knowledge practices emerging in these diverse and loosely defined DIY “communities”. Second, I formulated hypotheses about the role of sociotechnical encapsulation in facilitating such practices. Third, I designed an intervention strategy attempting to re-create, to some extent, the exploratory, material, and discursive practices that I observed in these communities and in my own explorations. Finally, I designed specific intervention strategies and toolkits and went to the field; bringing these tools and activities to school teachers, I observed, and discussed with them the affordances and possibilities of DIY and Maker initiatives in the context of their own professional practices.

These experiences suggest that sociotechnical encapsulation can allow educators and HCI researchers, to see the design of interactions with computers as a sociotechnical practice. Additionally, the “impact” or the “effects” of these interactions cannot be evaluated only by considering notions of effectiveness or productivity. Rather, a sociotechnical perspective to DIY and Maker initiatives situates the question about the interaction between humans and computers fundamentally as a question about emerging forms of knowing in which technical and social encapsulation co-construct the affordances of the activity.
7.2.3 Designing Toolkits for DIY and Critical Making Experiences

The design, creation, and testing of electronic toolkits can be significantly improved when they are explicitly directed to facilitate participant’s engagement in experimental fabrication, critical, and in-depth analysis of the practices to enable and support them.

Having provided detailed descriptions and analyses of the motivations and design processes I went through in this dissertation, I expect to advance the specification of the challenges, both technical and pedagogical, needed to assist intervention strategies in formal education settings, but also in non-conventional learning environments such as museums, maker events, science centres, and after school workshops.

As a research approach, sociotechnical encapsulation is an invitation to both diagnosing the scope of cognition (literacy practices) and its transformation through the engagement in material fabrication. Such an invitation is an interventionist approach in which the research process itself is understood as an iterative exploration of its affordances. This entails a constant evaluation of the intervention strategies. Sociotechnical encapsulation as an interventionist approach provides as well an opportunity for research in Human Computer Interaction to further examine how the design of information artefacts and experiences can be designed to foster multiple interpretations, innovative and critical thinking.

7.3 Limitations and Future Research

In addition to a description of the contributions of this research, it is important to acknowledge some limitations and avenues for future research. The intervention strategy adopted in this dissertation brings questions about the generalizability of the findings and the completeness of the sociotechnical Matrix introduced as a model of “ideal types” informing the design of iterative
workshops (Section 5.1.6). It is crucial to recognize that this methodological approach, did not attempt to argue that other scholars adopting these methods would necessarily arrive at the same conclusions and results. The findings of this dissertation need to be understood as a contribution to the definition of the emerging literacy practices emerging in DIY and Maker initiatives, as well as an intervention strategy that can inspire other researchers and teachers to continue their own explorations in designing electronic toolkits and interventions activities for the classrooms and other settings.

The case studies discussed in this dissertation revealed that the format of the DIY workshop is on its own a particular type of short-term intervention strategy significant for engaging school teachers in discussion about the pedagogical value of DIY and Maker initiatives. The affordances and emerging knowledge practices facilitated through experimentation with variable levels of sociotechnical encapsulation indicated how the workshop format comprised an intervention strategy capable of fostering teachers’ discussion specifically associated to their own contexts, interests, and knowledge. For this reason, rather than seeing short-term interventions as a limitation, this exploratory approach introduces key questions for future research; including for example: what could be the benefits as well as the institutional challenges of introducing DIY and Maker practices in long-term projects, eventually accompanying teachers throughout an entire academic year? What new types of sociotechnical encapsulation and the script modalities can be defined and extended to for studying emerging trajectories of inquiry and leaning through engagement in the fabrication of DIY artefacts? Future research will need to expand this model by continuing the exploration with other types of encapsulation and further discussion about the advantages and the limitations of loosely defined intervention scripts in fostering learning experiences.
Appendices

Appendix A – Form of Informed Consent

Name of the Study: Encounters with Sociotechnical Encapsulation: Exploring diagnostic and pedagogical interventions for the study of literacy practices in DIY and Maker initiatives

Principal Researcher: Antonio Gamba-Bari  
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Purpose: This study seeks to explore and better understand the social and technical dimensions of the emerging forms of literacy in Do-it-Yourself (DIY) and Makers initiatives. The study focuses on analyzing the benefits as well as the pedagogical challenges that arise through the discussion and the fabrication of DIY microelectronics for environmental and personal-self sensing.

Participant Responsibilities: This study will involve the commitment to participate in the following activities: (1) answering an online survey about your experience with information technologies and DIY initiatives. (2) Attending to a workshop using microelectronics components. After activities (1) and (2) a sample of participants will be selected for a follow-up interview. For this reason, your responsibilities may also include (3) participating in an interview with the researcher for approximately 45 minutes.

Participant Rights: Participation in this study is voluntary, and you may choose to withdraw from the study at any time, and for any reason, without reprisal. Any data collected during the study will be kept anonymous and confidential, and will not be sold to a third party. The participant has the right to request the investigator not to be photographed or video recorded during the workshops sessions as well as to request not to be audio-recorded during the interview (if applicable).

Risks: There is no personal risk to participants in this study.

Benefits: Although participating in this study will not entail any monetary compensation, participants will have the opportunity to learn about microelectronics as well as to exchange and discuss with other participants about the benefits and the pedagogical challenges of DIY microelectronics. Additionally, participants will contribute to advance the study of interventions fostering and diagnosing emerging forms of literacy in DIY initiatives and Maker movements.

Dissemination: The results of this study will be published as journal articles and presented at conferences. Your participation will be kept confidential. Your name and other identifying information will be known only to me and will not be included in presentations or written reports. If you would like to be invited to a presentation of the study’s results in Toronto, or receive a written summary of the findings, please give me your contact information.
If you have any questions about this study, you can contact the researchers:

Antonio Gamba-Bari                      Matt Ratto
antonio.gambabari@mail.utoronto.ca      matt.ratto@utoronto.ca
(416) 554-8300                          (416) 946-5415

If you have any questions about your rights as a participant in this study, you can contact the Office of Research Ethics at the University of Toronto at ethics.review@utoronto.ca or 416-946-3273.

Consent to Participate Statement

I have fully read and understood this informed consent form. The study described has been explained to me, and my questions have been satisfactorily answered. I agree to participate in this research study, and can withdraw from the study at any time without reprisal.

- I agree that the researcher can take photographs of me, my designs and prototypes during the workshop (OPTIONAL) Yes___ No___
- I agree that the researcher can video-record me, my designs and prototypes during the workshop (OPTIONAL) Yes___ No___
- I agree that the researcher can audio-record our interview (OPTIONAL) Yes___ No___
- I would like to hear about the findings of this study and be invited to a presentation and/or receive a written copy of the results Yes___ No___ (if yes, please provide your contact information: phone, email)

Participant Name (please print): ____________________

Signature: ____________________

Date: ____________________
Appendix B – DIY Prosthetics: Toolkit and Activities

Pre-programmed microcontroller powered with a 9 volts battery

Toolkit components: Push buttons, LEDs, Speaker, DC Motor, Vibrating motor, Servo Motor, wiring cables

The images below describe the process of designing and building a conductivity sensor: 1) Design of 3D models; 2) Printing 3D models; 3) Cutting Electrodes with PCB cutter; 4) Assembly of Conductivity Probe.
Appendix D – Sensing for Acting Workshop: Script
Activities

1. (15 min) Presentations: participants are asked to briefly introduce themselves and mention some of their interests in attending to the workshop.

2. (20 min) Presentation of the electronic toolkit: the researcher delivers a short talk about DIY and maker initiatives and provides a description of the components available in the electronic toolkit.

3. (30 min) Testing components: participants are organized in groups of 2-4 and then asked to experiment with the components in order to learn how to connect and make them operable.

4. (10-25 min) Break

5. (15 min) Introduction of “Thought Provoking Probes”: the researcher introduces the first set of questions guiding participant to reflect on: a) what type of sensing they want to use, b) the reasons for selecting the sensing device(s), and c) the expected outcome of the prototype.

6. (15-30 min) Prototype Design: participants are invited to discuss the questions and use (as needed) various forms of textual and visual representations on a large piece of paper.

7. (45 min- 1 hr.) Building the Artefacts: participants are asked to start building the electronic artefact. During this task the researcher and other workshop facilitators walk around assisting participants on any technical difficulty they may encounter, while also taking notes of their observations.
   a. Socializing preliminaries: after 20 min, the researcher interrupts the activity calling the attention of all groups and asking a member of each group to briefly describe to all the other groups the following: a) what are they sensing, and b) what will be the output (e.g. sensing light to produce a sound, or sensing proximity to produce vibration, etc.)
   b. The activity continues, and participants are informed that they have 30 additional minutes to wrap up and finish their projects

8. (30 min) Presenting the final Product: participants are asked to arrange on their tables all textual and visual prototypes and the final electronic artefact. Each group is given 5-10 minutes to present to the all the other groups their final work and answer the following questions:
   a. What did you sense, and why the sensor(s) was selected?
   b. What is the purpose of your artefact?
   c. What problems did you encounter during when designing and building the artefact?
d. Did it work? Yes, no, what was missing, etc.?
e. What other uses of your artefact you envision?
f. Do you have any ideas to make the prototype better?
Appendix E – Sensing for Acting Workshop: Electronic Toolkit

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Actuators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Sensor</td>
<td>DC Motor</td>
</tr>
<tr>
<td>Movement Sensor</td>
<td>Vibrating Motor</td>
</tr>
<tr>
<td>Potentiometer</td>
<td>Push Button</td>
</tr>
<tr>
<td>Distance Sensor</td>
<td>Servo Motor</td>
</tr>
<tr>
<td>1K Resistors</td>
<td>LEDs</td>
</tr>
<tr>
<td>Wiring Cables</td>
<td>Speaker</td>
</tr>
</tbody>
</table>
Appendix F – Sensing for Acting Workshop: Wiring Diagram

A: Providing power to the Bread Board; B: Connecting an LED; C: Introducing a Push Button; D: Control brightness of a LED with a Potentiometer; E: Control brightness of a LED with a light Sensor; F: Control a Servo Motor with a Potentiometer; G: Control blinking pattern of an LED with a potentiometer; H: Musical instrument with a Potentiometer; I: Musical instrument with a Light Sensor.
Appendix G – DIY Water Quality Sensing: Electronic Toolkit
References


Freire, Paulo. (2000) Pedagogy of the oppressed /New York : Continuum,


