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Contents

Abstract

Educational robotics (ER) is a subset of educational technology that includes robotic kits and social robots utilized with a goal to facilitate teaching and learning. Scientific publications on educational robotics are commonly anticipated by references to constructivism and constructionism. However, in philosophy, social sciences and cognitive science, constructivism is not a unified framework but a conglomerate of at least six different branches with diverse ontological, epistemological and pragmatic positions. This thesis takes a form of a critical survey where my aim was to map and to evaluate what constructivism means in and for educational robotics research. To meet this goal, I collected and studied 57 ER publications dated 2000-2018. Following an extended introduction into constructivist debates in philosophy and cognitive science, and the discussion how these influenced contemporary educational paradigms in the first and second chapters of the thesis, in the third chapter I proceed to lay out the insights I gathered during my survey of educational robotics literature. As expected, interpretations ranged from less theoretically informed where constructivism is reduced to any instances of hands-on manipulations of robotic technology, to more informed where constructivism is interpreted through the lens of subject-centered constructivist strands (Piaget-derived cognitive constructivism and its spin-off constructionism). In the latter group, notions associated with authentic education paradigm, such as collaboration, personalization, exploratory learning, and others, are addressed either as pedagogical strategies or as objects of research on their own terms. Though fewer in numbers, the field is also represented by studies that integrate concepts from social constructivism with the overall authentic education orientation. Here, Vygotskian concepts such as zone of proximal development, more knowledgeable other and scaffolding are commonly referred to. The thesis concludes with a broader discussion and my suggestions for future research. Given that to date there exists no thorough overview of constructivist influences on the field of educational robotics, I hope my work can function both as an introduction into the field of educational robotics through the prism of constructivism, and as a useful reference for future empirical studies.

Zusammenfassung

Bildungsrobotik (ER) ist eine Untergruppe der Bildungstechnologie, die Roboterbaukästen und soziale Roboter einsetzt, um Lehren und Lernen zu vereinfachen. Wissenschaftliche Publikationen im Bereich der Bildungsrobotik beziehen sich häufig auf Konstruktivismus und Konstruktionismus. Konstruktivismus stellt jedoch weder in der Philosophie noch in den Sozial- oder Kognitionswissenschaften einen einheitlichen, theoretischer Rahmen sondern vielmehr eine Ansammlung von mindestens sechs verschiedenen Zweigen dar, welche sich in ihren ontologischen, epistemologischen und pragmatischen Positionen unterscheiden. Diese Masterarbeit ist eine kritische Untersuchung der Forschung zu Bildungsrobotik, um die Bedeutung von Konstruktivismus innerhalb von und für diese auszuarbeiten und zu evaluieren. Hierfür wurden 57 ER Publikationen zwischen 2000 und 2018 gesammelt und in Hinblick auf ihr Verständnis von Konstruktivismus analysiert. Nach einer detaillierten Einführung in die Konstruktivismusdebatte in Philosophie und Kognitionswissenschaften sowie einer Diskussion über den Einfluss dieser Debatte auf zeitgenössische Bildungsparadigmen in Kapitel eins und zwei, werden im dritten Kapitel die Erkenntnisse zusammengefasst, die in der Auseinandersetzung mit der Literatur zur Bildungsrobotik gewonnen wurden. Wie erwartet bewegten sich Interpretationen von Konstruktivismus zwischen theorie-schwächeren Auslegungen, in denen Konstruktivismus auf jegliche Fälle praktischer Manipulation der Robotiktechnologie reduziert wurde, und theoretisch-fundierteren Auslegungen, in denen Konstruktivismus durch Subjekt-orientierte, konstruktivistische Stränge, insbesondere dem von Piaget abgeleiteten, kognitiven Konstruktivismus und dessen Ableger Konstruktionismus, interpretiert wurde. In Publikationen, die ein informierteres Verständnis von Konstruktivismus aufwiesen, wurden Begrifflichkeiten aus dem Paradigma des authentischen Lernens, wie Zusammenarbeit, Personalisierung und aktiventdeckendes Lernen, entweder als pädagogische Strategien oder als eigenständige Forschungsobjekte behandelt. Das Forschungsfeld beinhaltete zudem, wenn auch seltener, Studien, die Konzepte aus dem sozialen Konstruktivismus mit einer allgemeinen Orientierung der authentischen Bildung verbanden. Solche Studien bezogen sich häufig auf Konzepte Wygotskis wie etwa der Zone der nächsten Entwicklung, der Rolle der kompetenteren Anderen (more knowledgeable other) und Scaffolding. Die Arbeit schliet mit

einer allgemeineren Diskussion sowie Vorschlägen für zukünftige Forschung im Bereich der Bildungsrobotik ab. In Anbetracht der Tatsache, dass bislang eine ausführliche Übersicht über die Einflüsse von Konstruktivismus auf den Bereich der Bildungsrobotik fehlt, erfüllt diese Arbeit hoffentlich zwei Nutzen: Sie soll zum einen als Einführung in die Bildungsrobotik aus einer konstruktivistischen Perspektive, zum anderen als nützliche Referenz für zukünftige empirische Forschung in diesem Bereich dienen können.

Chapter 1

Introduction

1.1 Motivation and research questions

> Meaning, value and feelings precede cool logic and the austere beauty of calm, disinterested rationality. [...] actual minds are a precursor to possible worlds, and it is good to listen to voices speaking to us from possible worlds about values, excitements, arguments and visions.
>
> Morrison (2008, p. 23)

At the time of the thesis concept drafting, for a number of reasons - of which the course on dynamical systems in biology by Dr. Johannes Jäger, prefaced by the lecturer's introduction into process philosophy and William Wimsatt's scientific perspectivism, warrants an honorary mentioning - I was enchanted by the philosophical and scientific approaches informed by complexity science. Concurrently, given my position as a junior researcher at the Austrian Institute for Artificial Intelligence in a project aiming at modeling a synthetic mentor character, I was dedicating a lot of time to exploring the role of technology in contemporary learning settings. Coupled with my professional background as a language teacher, it was only expected that I found myself pondering the question what complexity thinking can offer to the ways we approach learning and teaching in the context of technology-enriched educational environments. However, as luring as my original intent to dive into complexity thinking and the promises it holds for the future of education was, a master thesis is not only a costume rehearsal of a scientific project, at least in my case, it is also a learning experience of how to curb one's enthusiasm and how *not* to approach a scientific enterprise in the future. What the reader is presented with today embodies only a fraction of the original grand-scale ambitions, the first chapter of the project I envisioned back in the days. Namely, this thesis represents the outcomes of my attempt to critically evaluate the role of constructivism for the rapidly growing field of educational robotics. The underlying motivation for this work was my wish to articulate, in a clear and evidence-based manner, what it was that left me so unsatisfied with many of the current self-proclaimed constructivist practices and made me want to seek for different approaches in the first place.

What does complexity science have to do with constructivism and robots? What could possibly motivate such a colossal investment of time and intellectual labor into an exploration of interpretations and practices related to a single and already extensively debated and disputed term? And, finally, what do deliberations on and variations of the idea that knowledge is not "found" or "discovered", but is actively construed, have to do with robotic kits and social robots? These are all excellent questions that warrant answers.

There exists no standard definition of educational robotics. In its narrow interpretations, the term usually refers to the application of robotic technology in teaching and learning contexts, where, by building and/or programming a robot learners master concepts and ideas in robotics and related fields, such as physics or math (Jung & Won, 2018). A more extended definition also incorporates collaborative and interactive human-robot environments, where a robot plays a role of a teacher's assistant or a peer learner (Karim, Lemaignan, & Mondada, 2015). While I will return to the definition of the field further in the body of the thesis, what matters here is that - regardless of the scenario of application and the role robotic technology is to play - in educational robotics, similarly to educational philosophy more broadly, it has become almost a common place to refer to constructivism as a perspective [1] that has had significant influence on how learning and teaching are thought of and practiced (Olssen, 1996; Riegler, 2015; Noddings, 2018; Wink, 2006; Davis & Sumara, 2002; Mubin, Stevens, Shahid, Al Mahmud, & Dong, 2013). In the words of Brown (2005, p. 2), "constructivism is presently accepted as the most relevant view of learning and that education policies, education models and education practices focus on". Indeed, as I was skimming-through the recent literature on educational robotics in preparation for my yet-to-happen scientific affair with complexity thinking, constructivism and constructionism were the terms I kept encountering routinely in the abstracts and introductions to scientific publications, many of which with very different research designs and objectives. In

[1]When faced with the choice whether to refer to constructivism as a 'perspective', 'framework', 'paradigm' or a 'theory', at this point, following Mewborn (2005), I decided in favor of the term that connotes a world-view that influences a generic stance one takes in their professional life, rather than something akin 'theoretical framework' that is associated with more explicitness and robustness. Why such choice between different labels even presents itself I hope will become clearer in the coming chapter.

that respect, two realizations followed quickly: 1. If I am to suggest that complexity science can pave the path to the bright future of educational robotics, I am first to explicate what it is that I find lacking in the current constructivism-dominated discourse on educational robotics 2. Despite the wide prevalence of the term, not only what different authors mean by constructivism differs, but the individual interpretations assigned to constructivism, in the best case scenarios, frequently stand separately from the study designs and lesson plans discussed by the same authors, and, in the worst case, pose a direct contradiction to these. In other words, to move beyond constructivism, it would first necessitate to understand what constructivism is, and what are in the words of Phillips (1995) its good, bad, and ugly faces in the context of educational robotics. Which finally brings me to research questions that motivate this thesis:

- What are the different interpretations assigned to constructivism in the current literature on educational robotics?
- What unities these interpretations? How do these interpretations differ?
- What are some of the common themes/trends associated with different interpretations?
- What is the positive influence of constructivism on the field? Where and how it may be that some interpretations are misguided or redundant?

1.2 Methodology and content

To solidify what was said in the previous sub-section, the purpose of this thesis is to study how constructivism is defined, interpreted and practiced within the field of educational robotics. To seeks answers to these question, I felt it was first necessary to establish some common ground, or a point of reference, at the background of which I can proceed to explore constructivist influences in ER. To sketch out this foundation for further research, in the first two chapters of the thesis I focused on the meanings of constructivism in philosophy and cognitive sciences. I was interested to find out what it is about this movement that led to the paradigmatic shift in how we think about education; and how constructivist influences are embedded in the contemporary pedagogical approaches. This is why, the first chapter of the thesis is devoted exclusively to the overview of constructivism as a framework in philosophy and cognitive science, its main branches and key concepts. Given that I counted at least six different strands of constructivism, each with its own debates and disagreements, an all-encompassing overview that would do due diligence to all the authors and points of views, is not feasible. Instead, I decided to focus on the concepts and authors who had the most profound influence on the constructivist pedagogy. That is, the concepts of knowledge (i.e., what it is and how one comes to know), the role of the intrapersonal cognitive processes and interpersonal social processes for learning and development, and the role that the body plays in these; and authors such as Jean Piaget, Ernst von Glaserfeld, Lev Vygotsky and, last but not least, the Chilean cognitive scientists Francisco Varela and Humberto Maturana.

The second chapter proceeds to discuss how constructivist ideas inform current approaches to education. I rely on the Authentic Education paradigm and Democratic Citizen Education paradigm, as represented by Davis, Sumara, and Luce-Kapler (2015), to sum up critical pedagogical moments that can be traced back to various constructivist branches. In this chapter I will also speak about the challenge of translating an extremely varied and rich framework such as constructivism into actionable pedagogical and didactic practices.

In the third chapter, I finally direct my focus to the field of Educational robotics (ER). Here, I firstly sketch out the definitions of the field, list its different branches, and address common arguments for the introduction of robotic technologies in to educational settings. I proceed to what constitutes the core of this thesis: a critical survey of the main interpretations and research trends associated with constructivism. This survey is grounded in the corpus of 57 scientific publications (peer-review journal publications and conference proceedings)[2], with occasional deviations into additional topical literature where I find it useful to emphasize or illustrate a certain point. I structure the main trends and insights I gathered under the four groups of publications that I classify as 1. Casual Constructivism 2. Informed Constructivism 3. Perspectives on Social Constructivism and, finally, 4. Grounded cognition approaches in ER. I introduce these four groups in separate sub-chapters, accompanied by the illustrations from selected studies and my critical remarks.

I summarize the main findings of the literature survey in the fourth chapter. Here I discuss how the insights I gathered speak to the role of constructivism for the ER and to the challenges that it presents. In reliance with my critical remarks, in this chapter I also lay out some suggestions for the future empirical studies.

1.3 Limitations

While, to the best of my abilities, I attempted to conduct this investigation in a systematic and transparent manner, I remain aware that no critical overview can be performed from an out-of-nowhere perspective. This is to say that, in my scientific work, I also abide by (socio-) constructivist principles and, in contrast to imagining myself as an independent, neutral observer

[2]The selection procedure for these will be introduced in more detail in 4.2

who merely describes the facts as she witnesses them, I regard my work as a grounded process of sense-making. As such, this process is inevitably biased by my prior academic background (culture studies and semiotics), the epistemological stance I take (social constructivism, process-orientation) and the assumptions and intuitions I had at the onset of this work and those developed additionally as I progressed with the readings. I hope that - despite the inevitable explicit and implicit biases - my work can still serve as a helpful guide to the main themes in respect to constructivist influences in ER and suggest ways how to approach the empirical designs of future studies in a more informed manner. My objective in this thesis is not to advocate for nor argue against the use of robotic technologies in educations. I will address some common arguments in support of ER (i.e., ER activities as promoting collaboration and problem-solving skills). However this will be done mainly with a purpose to explore how and whether such arguments are in fact evidence-based, and what is the nature of this evidence in respect to constructivist pedagogy. ER as a field is extremely heterogeneous; I will discuss in 4 the tasks, the models used, the learning objectives, the quality of the studies (i.e., data collection methods, interpretations of results etc.) vary drastically. Coupled with the ongoing debates on what constitutes "successful learning", and on the challenges of assessment of ER activities (this topic is especially pertinent in the context of constructivist pedagogy where the general orientation is more on the process rather than on a fixed outcome of learning), and the relative youth of the field, researchers, myself included, are not yet in a position to make any definitive judgements about the overall success and usefulness of ER for teaching and learning. This decision will be shaped as the field matures, and more informed and unified methodologies for data collection and analysis will be proposed and tested.

While an extremely important topic in the context of education where topics such as trust, vulnerability and care are of concern, in this thesis, I will not address the matters related to ethics unless absolutely necessary. In the latter cases, my objective is yet again not to provide resolutions and definitive answers, but to point the reader in the direction where more reflections are necessary for ethically grounded research practices. I wish to specify that, in my research practices and overall professional stance that I take, I abide by the non-replacement principle: robots may only do what humans should but cannot do (Seibt, Damholdt, & Vestergaard, 2018). It is my strong belief that - no matter the form it takes - the objective behind any introduction of robotic technology in K-12 education should not be to replace human teachers. To the contrary, I argue for the technology only inasmuch as it enables and enriches teaching and learning experiences, and allows for the learners and teachers alike to flourish.

Finally, the critical survey is conducted based on a limited sample of 57 publications. At this point, it is hard for me to speak on the matter of the scalability of these results. I will discuss further in the thesis that the field is also represented by the studies where the authors do not make explicit references to constructivism but that are, despite that, constructivist in spirit, proposed methodology and the aspects that the researchers turn their attention to. This is to say that it is possible that the filters applied during the literature selection procedure are exclusive of a large bulk of studies that fall under this category. Additionally, my choice to present the findings under four groups - though grounded in the trends I witnessed in the literature - is still rather subjective and open to criticism.

Last but not least, the first two chapters of the thesis should not be taken as an exhaustive overview of existing constructivist literature. As I have already pointed out, such literature is vast, and no agreement exists as to what constructivism is even among the constructivist scholars. Thus any attempt at systematizing will be reductive and, no doubt, will misrepresent some authors and completely leave out others.

1.4 Relevance

The amount of literature on educational robotics is vast and increasing evermore. Among this literature, publications that refer to constructivism and/or constructionism in the theoretical grounding sections prevail. However, to date there exists no critical qualitative examination of the interpretations that constructivism receives in these works.

In 2017, Asiksoy and Ozdamli (2017) attempted an overview of available research on technology-based learning informed by constructivist approach. However, in this overview they also operate on a reduced definition of constructivism, and their focus is on the quantitative representation of the research methods, research designs, data collection instruments, types and sizes of samples, data analysis, and other characteristics associated with the 81 publications they review. That is, no critical interpretative analysis is provided.

The emphasis in my work is on the interpretative component omitted in the publications thus far. Beyond providing a qualitative examination of the literature in the field of educational robotics, I believe that additional value is presented also in my mapping of the dominant trends in educational robotics onto broader constructivist debate in philosophy, cognitive science and educational sciences.

Chapter 2

Constructivism: sketching the Swiss knife

> The term constructivism, with its ideological overtones, suggests a single philosophy and a uniquely potent method - like one of those miracle knives advertised on late-night TV that will cut anything, even tin cans. But we could look at constructivism in another way, more like a Swiss army knife with various blades for various needs.
>
> Perkins (2006, p. 11)

One of the main challenges of examining constructivist interpretations in educational robotics has, in fact, little to do with the latter. The origins of a lot of terminological confusion and misinterpretations can be attributed to the fact that no agreement exists about what constructivism means, even among the most prominent constructivist thinkers. How are we to examine the praxis of something that evades a fixed definition and does not come with an instruction manual but only as a set of loose suggestions? In the epigraph to this chapter, David Perkins, the professor of Teaching and Learning at Harvard Graduate School of Education, compares constructivism with a Swiss knife with various blades for various needs. In this chapter, I will attempt at describing some of the constructivist "blades".

Being a sketch rather than a naturalistic portrait, mine will present the reader only with a general outlook of constructivism; I will highlight its most popular "blades", describe their most characteristic features, while omitting the nitty-gritty conceptual details.

Based on the contrustructivist texts I read, I identified at least 6 strands that fall under the umbrella term of constructivism. Each of these is represented by different thinkers and different ontological, epistemological and pragmatic positions. The six strands are: 1. Radical constructivism (often associated with the works of Münich born, Vienna educated American philosopher Ernst von Glaserfeld) 2. Cognitive constructivism (originates in the works of Jean Piaget) 3. Second-order cybernetics, with prominent authors such as Heinz von Forrester, Gordon Pask and Stafford Beer, 4. Enactivism, dominated by Francisco Varela and Humberto Maturana 5. Social constructivism where Lev Vygotsky and John Dewey are the authors anyone interested in this strand will inevitably come to discover and, last but not least 6. Operational constructivism represented primarily by Niklas Luhmann. My focus in this overview will be primarily on radical constructivism, cognitive constructivism, social constructivism and enactivism as the fours branches that are most commonly associated with educational debates. While Luhmann who in turn was inspired by the second-order cybernetics and extended it into realm of social communication (Scott, 2004), also put forth a theory of education (Baraldi & Corsi, 2017), his works are rarely cited in the textbooks on education philosophy and learning sciences. Similarly, second-order cybernetics - while it had a considerable influence on other constructivist strands - in the context of contemporary teaching and learning literature, is mentioned only marginally.

To structure the overview, I will rely on the most prominent dualisms (individual mind vs. social context, relativism vs. realism etc.) piercing constructivist debates and important concepts (e.g., knowledge, representation) that stir disagreements. I will begin the chapter with an attempt to provide a positive definition of constructivism. That is, I will lay out what I identified as the elements that are common to all strands of constructivist thinking. The chapter will proceed to discuss the most noticeable dualisms. While I do not set it as my objective to necessarily overcome these dualisms, I will, however, discuss how, in some instances, these dualisms need not to be perceived as such.

2.1 Constructivism, loosely and most likely falsely, defined

Not only the role that constructivism has played for epistemology and education sciences is debated (Davis & Sumara, 2002; Phillips, 1995; Gil-Pérez et al., 2002; Matthews, 2002; Hyslop-Margison & Strobel, 2007; M. G. Jones & Brader-Araje, 2002), the very understanding of what constructivism is - a philosophy (Perkins, 2006), a perspective (Golding, 2011), a theory of knowledge (Lorsbach & Tobin, 1992), a paradigm (Riegler, 2001), a theory of learning (Matthews, 2002), - or something different altogether is a subject of many heated debates. Bickhard (1997) notes that it is easier to sketch out the commonality that diverse forms of constructivism manifest in their opposition to certain classical positions e.g., behaviorism and cognitivism, than to identify the joint positive proposal that they offer. Similarly, Phillips (1995) ironically remarks in his widely cited paper 'The Good, the Bad, and the Ugly: The Many Faces of Constructivism' that even the most sketchy account of constructivism is destined to be faced with criticisms as the adepts will inevitably object that their constructivism is anything like that. That said, I will take the risk to subject myself to inevitable criticism and provide some definitions grounded in the commonalities that allow to talk about all the six distinct theories listed above as branches of constructivist tree.

Constructivism first emerged as a concept in literature in the 1970s (Davis & Sumara, 2002) and has since been portrayed as a powerful response to behaviorism and information-processing perspectives with their mechanistic and reductionist focus on environmental stimuli, reinforcement, and performance output as the target of learning (Von Glasersfeld, 1995; Liu & Matthews, 2005). In the introduction to his seminal work 'Radical Constructivism: A Way of Knowing and Learning. Studies in Mathematics Education', Von Glasersfeld (1995, p. 1) defines constructivism as an "unconventional approach to the problems of knowledge and knowing". The unconventionality is associated with the cornerstone constructivist premise that knowledge does not exist independently of the knower, but is personally and socially construed. This comes in sharp contrast to the correspondence theories that underlie traditional education, and wherein knowledge is understood in terms of mapping of the aspects of external reality onto the concepts in mind (David, 2009; Davis et al., 2015). In positing the centrality of interpretative mechanisms, constructivism does away with the notions of "objective reality" that lays outside of the observer waiting to be "discovered", and with the notion of "correct" representations of such reality. Instead, constructivism asserts cognizing agents' active quest for knowledge (Olssen, 1996; Terhart, 2003).

2.2 Constructivist debates

The emphasis on interpretative structures, situatedness and the active role of cognizing agents in construing knowledge is where all constructivist forms agree. Where the interpretations differ is in whether the focus in the study of learning and knowledge-formation should be on the structures within the individual mind, or on the social domain within which the mind operates. Also, some of the most charged disagreements between various constructivist forms and their opponents stem from different epistemological positions they assume; and - more to the point of my research - from varying interpretations of the role that constructivism has played for the theories of education and didactics.

In what follows, I will attempt at sketching out what drives this divergence in constructivist positions by mapping them along the common dichotomies (e.g., personal vs social, objectivism vs relativism, cognitive vs epistemological constructivism) that I encountered while studying the literature. Given the number of publications that use constructivism as a keyword - 3000 from mid-1970s to 2007, according to Tobin (2007), and 1728 in combination with 'education' from 2007 to 2018 [1] - I can only do so in very broad brushstrokes. In agreement with Cole and Wertsch (1996), I will also note that radical polarization is more typical of the conversations surrounding the key works of constructivism rather than the source works themselves. In other words, my suggestion to the reader is not to take the aforementioned dualities at their face value, but to treat them as indicators of the emphases that different authors placed in their theories.

2.2.1 Units of study: intrapersonal versus social

The main distinction between subject-centered (also referred to as cognitive or radical constructivism) and social constructivism can be tied to the focus that is placed on either knowledge-construing processes within an individual mind (Piaget, 1970; Von Glasersfeld, 1989), or on the knowledge-networks as extended to the domain of social interactions, and the role that cultural mediation (e.g.,language) plays (Vygotsky, 1980; Wertsch, 1985; Davis & Sumara, 2002; Stetsenko, 2016; Gergen, 1999) in their formation.

In academic and educational literature, subject-centered constructivism is traditionally associated with the works of the Swiss psychologist Jean Piaget, who sought to identify the mind structures that underlie cognitive behaviors typical of each developmental stage (Noddings, 2018). The key figure for social constructivist is the Soviet psychologist Lev Vygotsky, whose theoretical approach is characterized by the study of the social processes and the role that cultural artifacts, such as language, play for the individual developmental processes (Wertsch, 1985; Davydov, 1995; Vygotsky, 1980). In 4, we will see how these two thinkers, alongside Seymour Papert, continue to exert profound influence on the field of educational robotics.

For cognitive constructivists, the emphasis on the individual mind is associated with the assumed primacy of biological development for learning (Piaget, 1970). In contrast, social constructivists focus on the higher-order psychological and cognitive development which are understood as proceeding from socially and culturally embedded learning activity: "Every higher psychological function was external because it was social before it became an internal, individual psychological function; it was formerly a social relationship between two people." (Vygotsky, 1980). Hence, every cognitive function e.g., voluntary attention, logical memory, concept for-

[1] http://apps.webofknowledge.com

mation and other, in the course of development first appears on the social level and, later, on the individual level (Daniels, 2016). Natural, biological functions within this view are regarded as preconditions for the development of specific psychological functions but they do not determine the course of the mental and linguistic development (P. E. Jones, 2008), contrary to the Piaget-inspired subject-centered constructivism.

The confusion between these two constructivist strands typically arises in discussions of relationships between personal and social domains. For example, terms such as 'learning' and 'knowledge' are used both in reference to individual knowledge-production and systems of knowledge produced collectively. This also leads to debates regarding what an "appropriate" unit of constructivist analysis should be. In the subject-centered constructivist forms, it is understood to be structures of and the emergence within an individual mind, while in social constructivism, it is shifted towards the kind of phenomena that subject-centered constructivists would normally bracket out as context or perturbations - language, cultures, social interactions, collectives etc. (Davis & Sumara, 2002; Wertsch, 1985).

Different emphasis in regard to the units of study - individual mind vs social structures - associated with the two perspectives is also reflected in the interpretation that the concept of knowledge receives. In subject-centered constructivist approaches, knowledge is interpreted as an individual cognitive model that a cognizing agent construes on the grounds of their prior experiences and in interactions with the world (Tobin, 2007). From this point of view, interactions with others and with environment, though certainly have a potential to influence a cognizing agent, cannot compel the knowledge formation as such (Howe & Berv, 1999). Within social constructivist framework, knowledge is spoken of in terms of collectively shared conceptual networks that individuals and groups construe together in communication with each other. Hence, knowledge-networks will not be bound to an individual mind, nor are they to be found somewhere "outside" of it. Rather, their locus is understood to be in between cognizing agents (Castelló & Botella, 2006).

While both subject-centered and social constructivist forms posit that no knowledge is ever objective and universal, in personal constructivism, the validity of knowledge is assessed in terms of its viability for a cognizing subject (Von Glasersfeld, 1996, 1998), whereas for social constructivists, knowledge and its validity criteria are inseparable from the inter-subjective agreement and society-mediated contextual factors, e.g., history, social context, gender etc. that the knowledge networks were produced and maintained within (Wink, 2006; Stetsenko, 2016). We can see how different criteria of validity can and do pose a significant challenge for formal educational structures, wherein methods of assessment need to be agreed upon. I will return to this point again in 4.

While omnipresent in second wave constructivist debates, subject-society polarization does not do justice to the complexity of the views expressed in original works of Piaget and Vygotsky. Though in his empirical studies Vygotsky indeed emphasized social dimension for learning and development, in his theoretical musings, he recognized that the individual and socio-cultural lines of development are intertwined:

> Cultural development is superimposed on the processes of growth, maturation, and the organic development of the child. It forms a single whole with these processes. It is only through abstraction that wecan separate one set of processes from others.

(Vygotsky (1960) in (Wertsch, 1985, p. 41))

Similarly, Piaget spoke of the interplay between individual and collective intellect:

> [...] there is no longer any need to choose between the primacy of the social or that of the intellect: collective intellect is the social equilibrium resulting from the interplay of the operations that enter into all cooperation. (Piaget, 1970 cited in (Cole & Wertsch, 1996))

2.2.2 Epistemological skepticism and skepticism skepticism

As discussed in the preceding sub-chapters, one of the central constructivist principles is that knowledge does not exist independently of the subjects who seek it. This skeptical epistemological position - that is, no truth is ever universal and awaiting to be "discovered" - is often associated with radical constructivism (Olssen, 1996; Phillips, 1995) and seems to cause most of the confusion and a hefty portion of the criticism from outside and even from within constructivist camp. However, Von Glasersfeld (1989), Riegler (2001), Davis and Sumara (2002), among others, stress that the radical constructivist anti-realist stance is not to be mistaken for the denial of existence of the material world and reality itself. Rather, the skeptical epistemological position assumes that the status of reality is irrelevant (Riegler, 2015), as there is no way to separate between the reality and the agent (individual or group) acting in and making sense of it:

> If our concepts are derived by abstraction from experience, there are no grounds for belief that they could capture anything that lies beyond our experience (Glaserfeld 1991, as cited in (Osborne, 1996, p. 6)).

As mentioned in 2.2.1, what replaces the concept of Truth and its accurate representation is the notion of *viability*. Actions, concepts and conceptual operations are viable if they fit the contexts they are applied in (Von Glasersfeld, 1995, 1998). This is why any quest for objective and observer-independent knowledge when posited as a goal of science and education, from within this perspective, is epistemologically misguided. To quote Kenneth Gergen as cited in Hyslop-Margison and Strobel (2007, p. 75), "On an epistemological continuum, objectivism and constructivism would represent opposite extremes". Predictably, critics object that epistemology thus formulated is detrimental for the praxis of science and education as it borderlines relativism and idealism. Namely, if knowledge is understood as subjectively constructed and "good enough" as long as it is viable for the knowledge-construing agent, radical constructivism, according to its critics, faces serious challenges in providing any solid criteria for differentiating knowledge from belief (Phillips, 1995; Osborne, 1996).

In turn, Von Glasersfeld (1995, 1998) responds that it is a mistake to interpret epistemological skepticism as synonymous to "anything goes". A particular model developed by a cognizing agent will be tested against the actions and models of others. If the predictions made based on one's model are corroborated by others, a degree of validity will be assigned to the given model. However, as Phillips (1995) points out, this still does not explain how one would go about construing and validating a model about phenomena that lay outside of human perceptual apparatus. Osborne (1996) echoes this concern in a discussion of the ideas in science that have originated from overcoming intuitive reasoning and employed imagination in conceiving how the world might be.

Even though radical constructivism is a more frequent target of the criticisms pertaining its anti-realist epistemology, social constructivism is not immune to similar challenges. Particularly, some critics accuse social constructivism of failing to provide a convincing explanation as to what the criteria for the validation of knowledge in science are or should be:

> "The only criteria of fit become socially negotiated criteria, as we construct our human meanings via conversations. But if these criteria are confined to different social processes, of power and persuasion, then the fit achieved is limited to various types of social compliance or consensus, rather than to features of the natural world. The part played in this process by perception and experiment, or more generally feedback from the non-social world, remains fuzzy." (Fox, 2001, p. 28)

In the educational contexts, epistemological skepticism again will present a serious problem for teachers as it obscures the criteria of assessment of their students' performance Olssen (1996) and poses a real challenge for the cirriculum design (Osborne, 1996).

While agreeing with the broader anti-objectivist stance (i.e., no knowledge exists independently from the knowers' perspective), some authors posit that constructivist thinking needn't necessarily be divorced from realism (Cupchik, 2001; Arias Maldonado, 2011; Wimsatt, 1994). Here one ought to recall that, much like with constructivism, there exist multiple forms of realism in philosophy and philosophy of science (B. Campbell, 1998; A. Miller, 2002), and some of the misunderstandings and heated debates regarding constructivist epistemology could be resolved if participants on both sides recognized the difference in interpretation assigned to this notion by the opposing party [2].

Latour provides a poignant but not inaccurate summary of this mishmash of epistemological positions:

> A radical is someone who claims that scientific knowledge is entirely constructed out of social relations; a progressist is someone who would say that it is partially constructed out of social relations but that nature somehow leaks in at the end. At the other side of this tug-of-war, a reactionary is someone who would claim science becomes really scientific only when it finally sheds any trace of social construction; while a conservative would say that although science escapes from society there are still factors from society that leak in and influence its development. In the middle, would be the marsh of wishy-washy scholars who add a little bit of nature to a little bit of society and shun the two extremes. This is the yardstick along which we can log most of our debates. If one goes from left to right then one has to be a social constructivist; if, on the contrary, one goes from right to left, then one has to be a closet realist (Latour, 1992, p. 5).

Matters get even more complicated when we consider that some authors insist that epistemological and ontological constructivist claims should be kept strictly apart (Von Glasersfeld, 1996; Riegler, 2015), while others argue that such separation is impossible. For instance, Olssen (1996) asserts that constructivist epistemology is also quasi-subjective as it is a position that can never be verified. As a logical consequence - whether desired or not - metaphysics will inevitably creep in.

Calls for (in)separability of ontological, epistemic and cognitive constructivist propositions are also echoed in the debates on the role and definition of education. While some, like Grandy (2009), Matthews (2002), Gil-Pérez et al. (2002), suggest that researchers should bracket out

[2] There have been thorough attempts to espouse constructivist epistemology with realism. Unfortunately, discussing these in details falls outside the scope of this thesis. For (to my mind) convincing examples of such attempts, readers can refer to works of the philosopher of biology William C. Wimsatt, and specifically his concept of *robustness* (William, 2005), and to the author, more known in cognitive science circles, Mark Bickhard, who argues that constructivism postulates realism as soon as one moves away from the understanding of representations as having an encoding nature (Bickhard, 1997).

any metaphysical and epistemic constructivist musings and focus instead on the cognitive and pedagogic constructivism (Matthews, 2002) because it is the only dimension of constructivism that is not a subject of opinion, but can be empirically grounded in the studies of learning processes; others object that no serious conversation about education can take place if we do not assume a clear epistemological stance towards what knowledge is and how one comes to know (Wink, 2006; Noddings, 2018). Noddings (2018, p. 78) formulates it thus:

> Teachers do not usually share the epistemologists' concerns about the foundations of knowledge, but there are several reasons why teachers should be concerned with epistemology. First, teachers need to make decisions about the status of material they teach: Is it true? Does it matter whether it is true? Second, teachers need to evaluate the "knowledge" that comes to them from educational research. Third, teachers must decide whether the knowledge long reserved for a few students should or can be made accessible to all.

While I am not in a position to provide any definitive resolution to this debate, my personal stance aligns with that of Noddings: I believe that one cannot hold a serious conversation about constructivist pedagogy while completely bracketing out the questions regarding what constitutes knowledge, how we come to know, and why we study the concepts we study as a part of institutionalized curricula. It is my assumption that avoidance of these discussions is partly responsible for the overall challenge of evaluating and assessing the educational robotics activities, as I will discuss in 4.

2.2.3 Knowledge: linguistic or/and embodied?

In the preceding segments I touched the tip of the iceberg that are constructivist debates, pierced by real and false dualisms and contradictions. Before I conclude this chapter, I would like to address yet another concept widely used and as widely disputed within constructivist discourse. Namely, I will touch upon how *knowledge* is interpreted within embodied and enactive cognition frameworks.

To anticipate likely objections, I will specify that - while in the introduction to this chapter I listed embodied cognition and enactivism among the 6 strands of constructivism, and will continue to operate on this assumption - not all authors will agree with this classification. For example, Li, Clark, and Winchester (2010) argue that enactivism represents a paradigmatic shift away from constructivism. Furthermore, like constructivism, embodied and enacted cognition do not come in a form of a unified framework. They belong to the so called grounded cognition approach (Barsalou, 2010) which houses as many as six distinct claims, some more contradictory than others: i) cognition is situated ii) cognition is time-pressured iii) cognitive work is off-loaded to the environment iv) the environment forms part of the cognitive system v) cognition is for action, and, last but not least, vi) cognition is body-based (Wilson, 2002). My reason to consider embodied and enactive cognition frameworks as belonging to the constructivist orientation and to address them in the thesis is primarily pragmatic: as I will discuss in 3, embodied and enactive component of learning and teaching are an important topic of research in educational robotics where learning activities are frequently presented as more hands-on and where learners are invited to construct conceptual knowledge by interacting with physical objects in space and by engaging their bodies in these interactions, in contrast to more traditional educational environment where students are supposed to sit still and listen to verbal instructions of the teacher.

In 4 I will discuss how this plurality of positions - the situation that seems to be very common when it comes to anything constructivist - also results in the terminological confusion in educational robotics studies where embodied and enacted cognition are used interchangeably, and the boundaries between the two approaches, at least in my experience, are rather blurred. Unfortunately, setting these boundaries clear is outside the scope of this thesis. In what follows, I will bracket out these terminological inconsistencies and focus instead on what distinguishes these approaches from other constructivist strands, and how it applies to education.

Broadly speaking, the theories of embodied and enacted cognition, commonly associated in the cognitive science circles with the works of the Chilean scientists Francisco Varela and Humberto Maturana, posit that cognitive processes are rooted in *bodily* interactions with the world. That is, the entire structure of an organism (in contrast to just mind or brain) participates in "bringing forth" of the world in a continual process of interactions with environment. Per Begg (1999), enactivism emerged as a result of five interrelated influences: criticism of constructivism, criticisms of the Cartesian dichotomies, phenomenology, non-cognitive knowing and issues in biology.

From the perspective of grounded cognition approach, knowledge (or, broadly, cognition) is understood as being non-representational (in a sense that there is no direct mapping of external reality to mental representations). Alternatively, arguments are made for the embodied nature of representation as such (Bickhard, 1997, 2004). From this point of view, learning, in contrast to being supported by higher-order cognitive processes and open to linguistic articulation, is grounded in the biological realm and sensory-motor action (Holton, 2010; Kiefer & Trumpp, 2012). Thus cognition should not be approached as a matter of an individual having a cognitive structure that determines how the individual can think (e.g., Piaget-derived cognitive constructivism); instead, organism as a whole is continually changing its structure and in that "determines its own actions on itself and its world" (Reid 1996 cited in (Holton, 2010)).

When within other constructivist strands knowledge is viewed as a human construction and, as we discussed, is evaluated either in terms of its viability for the knower (radical constructivism) or in terms of its match to inter-subject agreement that is socially and culturally bound (social constructivism) - and both of these views are based on the divide between the self and the world (Begg, 1999). In turn, within grounded cognition approaches knowledge is understood in terms of *action*: the cognizing agent must be able to act within environment well enough to survive in it. Knowledge here is not something external, it is represented in the structure of the cognizing agent as the knowledge of its environment.

What relevance do the theories of enacted and embodied cognition have for education? What are we to do in respect to the proposition that knowledge is grounded in bodily action and that body is implicit in every cognitive act?

Of primary relevance to this investigation, grounded cognition theories highlight the importance of sensory-motor interactions and perceptual systems during learning (Kiefer & Trumpp, 2012). As I will discuss in 4.7, this is especially relevant in the context of educational robotics activities where conceptual knowledge emerges simultaneously through learners' bodily activity, and activities of manipulating a physical object such as a robotic kit.

Chapter 3

Constructivist Influences in Education

Conversations about education encapsulates discourses as different as i) research methods (i.e., how to study education?) ii) practice of education (i.e., pedagogy and didactics) iii) philosophy of education. In this chapter, I will focus primarily on pedagogy and didactics. Firstly, I will present some general remarks in respect to the challenges that constructivism presents for those who attempt to translate its concepts and principles into coherent pedagogical solutions. In the second half of the chapter I will sketch out some of the positive outcomes of such attempts. That is, I will discuss how constructivism has informed modern educational paradigms and pedagogical approaches within these.

3.1 Pedagogy: art or science?

Watkins and Mortimore (1999) define pedagogy as neither science (interpreted in the positivist key) nor art but *craft*. According to these authors, pedagogy is "any conscious activity by one person designed to enhance learning in another" (Watkins & Mortimore, 1999, p. 17). Berstein (cited in Daniels (2007, p. 154)) defines pedagogy as a sustained process whereby "somebody acquires new forms or develops existing forms of conduct, knowledge, practice and criteria, from somebody or something deemed to be an appropriate provider and evaluator". Notice that these definitions incorporate someone/something in a role of a *teacher* and someone in a role of a *learner*. This suggests that, in contrast to *didactics* where the focus is on teachers' role and activity, pedagogy is a broader term that also encapsulates activities and processes from the perspective of the learners.

In 2013 Harvard commencement speech [1], Finnish educator, author and scholar Pasi Sahlberg shares that back in the days when he was a young aspiring scholar, he had two theories on how to educate children. Now that he has two children of his own, and a solid career in education sector he has no theories left. In his words, he is an educator without theories. Though uttered with a degree of irony, Sahlberg's words have profound truth to them. Nothing is straightforward when it comes to pedagogy; like in parenting, in pedagogy, one cannot expect to find laws. The absence of a unified theory and established, universally shared practices is indeed something that characterizes constructivism-inspired pedagogy.

3.2 Constructivist pedagogy. A pessimistic foreword

It has become a common practice - to which my own work is no exception - to pre-empt texts that announce 'constructivism' and 'education' as their keywords with a statement of acknowledgement of the sizable influence that constructivist theories have had on pedagogy and learning sciences. However, little agreement exists in respect to the nature of this influence. There are several reasons for this.

Terhart (2003) suggests that there are four protagonists that form background for constructivist didactics: radical constructivism, neurobiology of cognition, systems theories, and current conceptions developed in the field of cognitive psychology. Hence, already at the onset of our exploration we are presented with four very different conversations, on the side of didactics only. Furthermore, - and as implicitly suggested by the four protagonists specified by Terhart - it is easier to interpret constructivism as a theory of learning and not as a theory of teaching (Abdal-Haqq, 1998). That is, it is easier, conceptually and methodologically, to study isolated processes of learning (e.g., concept formation) than contextual processes and external factors that accompany learning. The latter may be one of the reasons why the emphases in the current studies in educational robotics, as I will discuss in more detail in 4, is predominantly on the concepts and pedagogical constellations that are inspired by subject-centered constructivist strands (i.e., cognitive constructivism, constructionism, embodied cognition framework) in contrast to those derived from social constructivist branch.

To stir the constructivist pot furthermore, some authors go as far as to suggest that constructivism, despite widespread references to it, has not in the core of it proposed anything new that diligent educators did not known all along without necessarily grounding it in constructivist jargon:

> [...] constructivist didactics really does not have any genuine new ideas to offer to

[1] https://www.youtube.com/watch?v=WeMM-hL0KFY

> the praxis of teaching. Rather, it recommends the well-known teaching methods and arrangements of self-directed learning, discovery learning, practical learning, co-operative learning in groups. I think that new constructivist didactics in the end is merely an assembly of long-known teaching methods (albeit not practised!). (Terhart, 2003, p. 42)

Even Von Glaserfeld himself admitted that the increasing number of references to radical constructivism in educational literature had made him feel uneasy. According to the Munich-born philosopher, theory of constructivism was introduced with a genuine hope, but it turned out to be nothing but a flop as a teaching methodology:

> In any case, as radical constructivism holds that there is never only one right way, it could not produce a fixed teaching procedure. At best it may provide the negative half of a strategy. As I have often said, constructivism cannot tell teachers new things to do, but it may suggest why certain attitudes and procedures are fruitless or counter-productive; and it may point out opportunities for teachers to use their own spontaneous imagination. (Von Glasersfeld, 1995, p. 178)

Davis and Sumara (2002) agree with this and add that many popular constructivism-derived ideas such as "learner-centered education", "discovery learning", "group work" and others, in practice have been distorted to the point of no recognition. Further, Phillips (1995) argues that the tendency toward epistemological relativism (see 2.2.2) has lead to the situation that, in some classrooms, teachers fail to question or ask for the rational justification of the knowledge-concepts produced by their students. Terhart (2003) also notices the overall weakening of the radicalness of the constructivist argument as one transitions from the level of reflection to the level of operation.

The loss in translation between constructivist theories and praxis, according to Perkins (2006), starts already at the level of pedagogical theory. For example, the same activity e.g., group work, can be emphasized both as radical constructivism-inspired (students test their schemes against others) (Von Glasersfeld, 1998), or as social constructivism-inspired, wherein shared understanding is used to propose a solution or design an artifact (Jackson, Karp, Patrick, & Thrower, 2006). As we shall see, this will also hold true for the field of educational robotics where collaboration is discussed both in subject-centered and social constructivist terms.

In defense of constructivist pedagogy, Gil-Pérez et al. (2002) suggests that the criticisms often aim at a wrong target, while in fact ignoring the substantial existing contributions. Namely, the specific narrowly-focused constructivism-inspired studies (e.g., about concept learning, attitudes to science and others) have contributed to a body of knowledge that supports the calls for engaging students in the (re)construction of scientific knowledge for the meaningful and lasting learning. Nevertheless, Gil-Pérez et al. (2002) agrees with Mathews (1997), Wink (2006) and others alike in that in order to make constructivism work, constructivist pedagogy should be considered separately from constructivist epistemology.

To add to the challenges faced by constructivism-inspired pedagogy furthermore, Holton (2010), lists the following criticisms: i) if all cognition is active, then even mechanical, mindless learning must be active. ii) Difficulty of assessment: even von Glaserfeld (von Glasersfeld, 1993) admitted that the challenge of assessment remains the most difficult one. Namely, if there is no use telling students they are wrong, what should be the formal ways of assessing and evaluating what it is that students know and understand? iii) Guidance: some educators conflate constructivism with pure unguided discovery learning. Adopting constructivist approaches does not mean complete abandonment of lectures and direct instruction. However, how do we know how much guidance is required? iv) Grounding problems: here we return to the challenge of divorcing epistemology from cognitive constructivism. What is the nature of knowledge, and what is the relationship between knowledge and the world? v) last but not least, oversimplifications of embodied cognition theories. Embodiment is oftentimes boiled down to making something "hands-on", or being physically active while learning and teaching.

As I will discuss in 4, all these criticisms are pertinent to the field of Educational Robotics where constructivism is routinely reduced to the ambiguous notion of *active learning* and the questions regarding assessment, degree and quality of guidance, and other human and non-human factors that contribute to successful outcomes of the educational robotics activities, are either considered only superficially or, in the worst case scenarios, dismissed entirely.

Armed and warmed up by such extensive critique, in the rest of this chapter I will, however cautiously, focus on the positive suggestions and pedagogical guidelines that are associated with constructivism. I believe that this summary - though non-exhaustive and schematic at best - will be useful to set background for the critical analysis undertaken in 4. To structure the conversation, I will introduce two major paradigms in contemporary education - authentic education and democratic citizen education. It is my assumption that these two paradigms are helpful as they: i) have dominated mainstream education discourse in the recent decades ii) are grounded, among other influences, in two distinct models of constructivism-inspired pedagogy. Whereas authentic education has its roots in subject-centered and cognitive constructivism, and in the works of Piaget, further developed by Ernts von Glaserfeld, democratic citizen education draws inspiration, in addition to gender studies, cultural studies and other, also from social constructivism. As we shall see in 4, this bipartite distinction is also quite common in the research in educational robotics.

I will note that my objective is not to evaluate whether and till what extent constructivism-inspired pedagogy outperforms more traditional approaches, as it is also a subject of heated debates [2]. Neither my choice to focus on authentic education and democratic citizen education paradigms is to be taken as an indicator that traditional education has been eradicated, or that it is necessarily inferior. It is important to remember that neat categorizations rarely represent the complexity of the real-life processes. No classroom in the world will be organized and, what's even more important, function *exclusively* in agreement with a single educational paradigm, be it traditional education, authentic education, or any other. The reality, as one has come to expect, is always more complex, messy and unpredictable to conform to our models of it.

3.3 Authentic education paradigm

The shift from traditional correspondence theories-inspired education began from drifting away from the assumption that learning is about traversing some sort of gap between the learner and the knowledge toward an essentially radical constructivist understanding of learning as an ongoing adaptive life process. This shift, according to Davis et al. (2015) has led to the renegotiation of the role of learners as actively construing their knowledge, and to the acknowledgement of the role that the body plays in this process. Whereas in traditional education body is something that needs to be tamed as it stands "in the way" between the knowledge and the learner, following the paradigmatic shift toward constructivism and enactivism, learning is now recognized as an *embodied activity* (Proulx, 2008; Riegler, 2001).

How does this shift toward embodied, enactive and learner-centered view on learning processes translate into pedagogic and didactic strategies? What can educators do to facilitate and enable learning in the context where mere verbal instructions, as were common within traditional pedagogy, do not suffice? First and foremost, according to Von Glasersfeld (1998), it is essential for the learner to be able to associate linguistic concepts of the explanation to those they already have in their mind. Thus, it is critical for educators to establish an adequate *model of the learners' conceptual network* within which the learners assimilate new information as experience will only be perceived as novel if it triggers a perturbation relative to an expected result within the existing knowledge scheme. Then only the experience may accommodate, and a novel conceptual structure will restore the cognitive equilibrium. As the most frequent source

[2] For example, see Sahlberg' (Sahlberg, 2011) and Sahlgren's (Sahlberg, 2011) dispute on the role that constructivism has played for the success of the Finnish educational system

of perturbation for the learners is understood to be interaction with others, it is one of the roles of the teacher to enable the conditions for such to take place. In practice, this often translates into promotion of "group learning", where different solutions to a problem can be exchanged and discussed.

Respectively, the focus on learner's knowledge-construing processes as grounded in their prior experiences and existing knowledge schema also calls for the redefinition of what constitutes a "correct solution" to a problem. The latter is now divorced from the notion of "objective truth" that has to be transmitted to deficient (i.e., knowledge-lacking) learners. Instead of rejecting learners' solutions as "wrong", constructivist teacher will *seek to explore* how students understand the problem and what their path to solution is. From there on, the task of a teacher is to *assist* the learner in apprehending the advantage of deploying conceptual models with wider range of applicability in the experiential world than the ones that they have at a given time:

> In the traditional view, schools are seen as institutions that are to impart value-free, objective knowledge to students. For constructivists there is no such thing, because they see all knowledge to be instrumental. The first thing required, therefore, is that students be given the reasons why particular ways of acting and thinking are considered desirable. This entails explanations of the specific contexts in which the knowledge to be acquired is believed to work (Von Glasersfeld, 1995).

Negotiation of meaning thus becomes an integral part of curriculum (Lorsbach & Tobin, 1992). Learners ought to be provided with opportunities to make sense of new concepts and problems by comparing what they know to new experiences and resolving the disagreements between the two. As pointed out earlier, negotiation of meaning can also involve classroom peers. Active listening, discussions and defending one's own position over another and selecting the most viable theories, instead of passive consumption of pre-selected knowledge units, becomes an integral part of classwork.

According to Davis et al. (2015), the focus on internal equilibrium inspired by pedagogy thus formulated is one of the key driving forces behind the emergence of *authenticity* as an orienting principle in education. Authentic education (AE) respects the *individual learner's history* and nurtures *individual's potential*. Learner can no longer be seen as deficient, with the new knowledge brought from the outside by the teacher to compensate for the deficiency. Instead, differences between learners are recognized and respected:

> This moment in formal education came to be characterized by real/authentic problems, to be structured through genuine/authentic inquiry, to afford students trans-

formative/authentic feedback, and to nurture the learners unique/authentic being (Davis et al., 2015, p. 67).

Following Von Glasersfeld (1995) and others, we can summarize the critical pedagogic moments within authentic education paradigm as following:

- Learning experiences should be in agreement with the current knowledge and abilities of the learner: learning tasks should be differentiated for learners, individual abilities and difficulties should be taken into account.

- Teaching rather than training: an understanding that learning is dependent but not determined by teaching; improvisational rather than implementation-oriented mindset.

- Unleashing individual potential: respecting individual differences and enabling learner's intrinsic motivation rather than relying on extrinsic motivation such as grading.

- Orienting role of language: instead of simply relaying information, it is the task of the teacher to orient students in certain direction by triggering associations-making.

- Importance of perceptual materials engaged in the classroom: as concepts are not inherent in things but have to be constructed, this can be done in reference to materials at hand. The emphasis is again on the active role of the learner in building their knowledge, while the teacher's role is facilitating.

- Learning about learning: emphasis on learners' meta-cognitive skills. Focus on learning processes that advance learners' conceptions of learning and enabling learners to see themselves as active agents in learning (Watkins & Mortimore, 1999).

- Conversations instead of critique: powerful learning experiences are tied to the learners' discovery that what they are doing does not work in different context. Such self-generated crisis is more conducive to learning than criticism.

3.4 Democratic citizen education paradigm

Emphasis on the individual within AE paradigm has brought about significant shifts in how learning and teaching are conceived. However, this paradigm does not provide satisfactory answers to the questions what it is we are educating for, and how one should go about designing a curriculum given that knowledge is now thought of as a dynamic and individual-experience driven.

As suggested by the name of the paradigm, Democratic Citizen education (DCE) emphasizes individual learners as a part of a collective and sees school as a form of a political body (Davis et al., 2015). From this perspective, the role of the schooling system is not limited to serving individual learners' needs. Rather, it should be approached within a broader societal context, where shaping of learners' culture and values is equally, if not more, important as empowering their cognitive development. In that, learners not only learn new concepts associated with different fields of study, but also how to behave and how to relate to one another. Recall that within AE paradigm learners are recognized as sufficient. Now, according to Davis et al. (2015), they are recast yet differently as *partial* as their worldview is considered both incomplete and biased. It is the role of the schooling system and educators to help their students in developing awareness and recognition that it is due to this partiality they participate in dynamic and dependent relationships with other humans:

> Yet if agency as all human development is acknowledged as a continuous work in progress and an evolving struggle for a unique contribution to a world shared with others, then recognizing our incompleteness and the need for us all to learn and become more fully agentive, throughout the life span and together with others, opens up possibilities for teaching- learning with a pedagogical stance without connotations of deficiency or inferiority in need of correction. (Stetsenko, 2016, p. 349)

Learning within this paradigm receives a social constructivist interpretation as it is understood as a social process that happens in the interaction with others (Jackson et al., 2006), where such interaction and knowledge networks generated are historically, culturally and politically shaped (Stetsenko, 2016).

Pedagogy thus formulated can never be politically indifferent. Willfully or not, it will always adopt a particular social pattern, in accordance with the dominant societal structures (Daniels, 2016). Hence, the duty of the educators is to acknowledge their role in the formation of learners' values and to steer those towards ideals of democratic society that emphasizes social equality and vision of the future where all citizens have equal access to the resources to realize their development (Stetsenko, 2016). The focus is thus on the interconnectedness of the individual subjects and the social realm (Ernest, 1994). The ideals of social justice and equality constitute, according to Stetsenko (2016), the core of Vygotsky's theoretical tenets, methodology, and practical application. Remember that for Vygotsky learning is inseparable from becoming enculturated into social roles and social practices. Hence, any analysis of learning should also extend to incorporate the activity of all participants of the educative process i.e., teachers, social surrounding, society at large.

As discussed earlier in the sub-chapter on the subject-centered/social constructivism dichotomy, knowledge from this perspective is also not neutral but socially and historically situated. In that, Piaget, according to Vygotsky, is wrong to think that scientific facts can exist in isolation from theory that they originated within.

The shift of focus from the individual toward the social dimension suggests that, within DCE, *collectivity* is emphasized both as a topic and means of education:

> Most of the advice for teachers within a frame of Democratic Citizenship Education is concerned with collective process or, more accurately, with the simultaneity of enabling individual learning and fostering collective knowledge building. (Davis et al., 2015, p. 154)

As I will discuss in 4, collectivity, manifested in collaborative learning and group activities, in educational robotics is also discussed as a pedagogical tool (i.e., one strategy among many to achieve desired learning experiences and outcomes) and as a topic or desired outcome in its own terms. That is, learners are invited to engage in group project also with an aim to help them to improve collaboration-related social skills.

From this point of view, learning extends beyond mere scientific concepts and skills formation (so called, epistemic skills) to incorporate also social and developmental dimension. Instruction ("developmental teaching") is now seen, alongside of facilitating concept-formation, as driving the psychological and social development of the learners. In this context, Vygotsky's concept of zone of proximal development (ZPD) and scaffolding come forth. Curiously, Vygotsky himself never specified the forms of social assistance to learners that constitute scaffolding and ZPD. As suggested by Moll et al. (1990), Vygotsky wrote about collaboration and direction, and about assisting children through demonstration, leading questions, and by introducing the initial elements of the tasks solution., but never extended beyond these generalities. I will return to this point and to more in-depth discussion of the concepts of ZPD and scaffolding in 4.6.

In respect to viewing teacher as a facilitator, recognition of the individuality and current developmental stage of each learner, and conceptualization of learning as an active, situated process, democratic citizen education paradigm derives from authentic education.

While learners are still recognized as individuals with different needs and abilities, the emphasis in the democratic citizen education paradigm shifts from supporting the individual learners knowledge and skills formation to helping them to develop also as persons and citizens. In this context, the role of cultural artifacts such as language, and other psychological and material tools is often discussed.

To summarize this sub-chapter in the form of pedagogical approaches;

- Situatedness: Teaching is about organizing and manipulating the situations that learners inhabit. In so doing, teaching enables what learners are able to be, while contributing to the shape of society.

- Participation: enabling understanding one's role in dynamics of social processes through which knowledge is produced. In practice can be implemented by involving learners in group work and participatory projects. Emphasis is on cooperation rather than competition.

- Conscientization: helping students to raise awareness to others' perspectives; helping them to recognize privileges and partialities embedded in established patterns of acting.

- Learning about learning: pedagogy within democratic citizen education is about being able to also consider the circumstances in which pedagogy is being shaped and implemented. Teachers should be aware of their own partiality; discuss not only theories and concepts but the circumstances that lead to their formation (Davis et al., 2015)..

- Dialogic learning: the goal of education is not to provide learners with a set of predefined knowledge. Instead, the thing to be learned is learning itself. Hence, teachers need to be even more teachable that their students. (Daniels, 2016) and should remember about the partiality of their own knowledge and remain sensitive to the context of emergence of their pedagogy. One of suggested ways of teaching about learning is through promoting dialogue and *dialogic learning*.

- Teaching as empowering: teaching should seek to expand possibilities and uncover what is usually tacit (i.e., forgotten histories, hidden ideologies and power structures etc.). Teaching should empower and give voice.

- Reciprocal teaching: learner works together with teacher or peer on developing understanding without being directly "taught".

One will notice that, while many of the pedagogical aspects presented above overlap to a large degree with those featured within authentic education, their broader emphasis on the social, political and normative components makes them harder to approach in practices. For example, one can agree that teaching should seek to uncover tacit and empower under-represented voices. But how exactly should one go about it in their everyday classroom work? The ambiguity associated with social constructivism- inspired educational paradigms is understandable but it has also been an obstacle: as I will discuss in the coming chapter, references to social constructivism in educational robotics are relatively scarce comparing to those to Piaget-derived cognitive constructivism.

3.5 Interim conclusions

In the spirit of declared transparency in respect to my own biases 1 and to anticipate next chapter, I admit that my initial position regarding the majority of the constructivism-grounded research in educational robotics was rather skeptical, if not to say, arrogant. "Surely what they do is a simplified, distorted version of constructivism", - was my unofficial research hypothesis at the onset of this project. However, knowing what I know now, I am left humbled. As this and the preceding chapter I hope have made explicit, constructivism is a powerful yet not uncontested term that encapsulates diverse discourses that resist straightforward translation into pedagogical and didactic approaches. The analysis that I will present in the fourth chapter does not nullify my initial hypothesis, at least for a proportion of the reviewed studies. However, given the heterogeneity of constructivist approaches and the ongoing conceptual and methodological debates, I am much more apprehensive of the poor interpretations of constructivism in ER, and sincerely admire those selected studies where the authors took pains of not only providing a solid theoretical grounding for their research, but succeeded in incorporating it in the sound study designs and lesson plans.

As for the reconciliation of the constructivist debates, I am left with an impression that a hefty portion of the dualisms and contradictions discussed are in fact false. Each of the positions articulated is true on their own terms but, individually, it can only account for one part of the much larger picture. Similarly, I am left thinking that the confusion pointed out by Perkins (2006) in respect to different (i.e., radical constructivism versus social constructivism) interpretations of the same educational activity (e.g., collaborative learning) is not only understandable, but unavoidable as long as one insists on carrying over the individual-social dichotomy onto the classroom processes. Teaching and learning cannot be reduced solely to what happens within an individual brain, neither only to the social interactions and socio-cultural context. Both these components co-exist and enable each other. Both, Piaget-driven and Vygotsky-driven constructivist pedagogies are helpful in designing curriculum and teaching and learning practices; the former in respect to what we know about developmental stages, cognitive processes and learning as it is shaped by an individual brain and body, the latter - in respect to recognizing how knowledge formation is also a communal, value-driven practice where reciprocity, dialogue and shared meaning negotiation are critical.

Chapter 4

Constructivism in educational robotics: critical survey

In the preceding chapter I discussed how constructivism is customarily distinguished as a framework/philosophy that has had a sizable influence on teaching and learning sciences. This trend extends to the field of educational robotics (ER) where constructivism and constructionism, with the spin-off approaches such as activity based learning, inquiry based learning (Williams, Ma, Prejean, Ford, & Lai, 2007), problem-based learning (Denis & Hubert, 2001; Socratous & Ioannou, 2018), project based learning (Khanlari, 2016), design-based learning (Resnick & Ocko, 1990), to name a few, are routinely referred to in the theory grounding segments of the current topical literature. In the words of Alimisis (2013, p. 68): "An appropriate educational philosophy, namely constructivism and constructionism, the curriculum and the learning environment are some of the important elements that can lead robotics innovation to success". One does not need to go far to find more evidence of constructivism informing the ER activities and research: glancing through the web page of the Automation and Control Institute (ACIN), a robotics group based at the Vienna University of Technology, one will easily notice explicit references to the works of Piaget, Vygotsky and Papert [1].

But remember that what stands behind the ever-present term 'constructivism' is not clear-cut at all. What do ER researchers mean when they refer to constructivism to inform their study designs and lesson plans? How do their interpretations agree with or diverge from the constructivist interpretations discussed in the preceding chapters? Before I present my answers to these questions, in the first block, I will introduce the field of educational robotics in more detail. I will talk about how the field is defined, touch upon its roots in the 1970s MIT Media

[1] https://www.acin.tuwien.ac.at/en/vision-for-robotics/outreach-with-educational-robotics/our-scientific-approach/

Lab and list principle subject domains and the types of technology commonly deployed in the field. I will also discuss why some of the intrinsic features of robotics technology allow for an easy, albeit, at times, superficial, links with constructivist pedagogy. The chapter will proceed to the methodology section where I will present the process of the literature search, selection and analysis that I deployed in order to critically evaluate the interpretations that constructivism receives in the field of ER. The results of the content analysis will follow. Specifically, I will discuss the four bigger categories/groups of studies, differentiated by the kind of emphasis they make in respect to constructivist discourse, that I identified in the course of the content analysis of the seed materials. In the same section, I will highlight selected case studies to illustrate how constructivism-inspired pedagogy can enable ER, but also to point out aspects that I found conceptually and methodologically problematic.

4.1 Introduction to educational robotics

4.1.1 Definition

To date, there exists no precise definition of educational robotics. A considerable proportion of the current literature in the field is dominated by the narrow definition that goes back to the works of Seymour Papert and the colleagues at the MIT Media Lab in the 1980s. According to the narrow definition, educational robotics comprises learning activities aimed at developing learners' technical knowledge and skills by the means of constructing and programming a robotic model (Frangou et al., 2008). However, recent trends call for the extension of this definition to include, alongside robotic kits as tools for learning, also social robots that participate in interactive learning scenarios in a role of a peer or teacher's assistant. With this extension in mind, educational robotics can be broadly defined as a subset of educational technology that includes robotic kits and social robots, utilized with a goal to facilitate teaching and learning.

Gaudiello and Zibetti (2016) propose a tripartite schema to differentiate between a wide range of activities, programs and practices that exist under the umbrella of educational robotics: i) learning robotics ii) learning by robotics, and iii) learning with robotics. As the category name suggests, *learning robotics* refers to the kind of activities and applications wherein learners use a robot as a platform/tool to learn robotics and engineering in an active, hands-on way. In turn, *learning by robotics* includes robotic technologies used as a medium between a subject and learners, e.g., a robotic kit embodies a concept in math, or physics, and is used to help learners to master this concept in a tangible, active way. Finally, *learning with robotics* comprises learning activities where human-like or animal-like robots act as assistants to teachers or companions to learners. For example, such robots can display multimodal content or can accompany learners in various tasks (e.g., matching words and images, memorizing new words, improving handwriting skills etc.)

In my work, I will rely on the extended definition: that is, my analysis will encompass literature that covers activities and robotic applications within all three branches of educational robotics.

4.1.2 Overview of popular models

As the broad definition of educational robotics suggests, the devices that fall under this subset of educational technology can take very different forms, and include physical manifestations that range from robotic kits, toy robots and, finally, social robots. Robotic kits are programmable construction kits that allow learners to construe and/or program robots (Jung & Won, 2018). Toy robots are ready-made commercial robots, normally used for entertainment and play, but that can be adapted for the use in educational settings. Social robots are based on artificial intelligence; they will display (a degree of) autonomous behaviors and can engage in social interactions with learners. In learning contexts, social robots incorporate socially interactive robots (SIR) and Social Assisstive Robots (SAR).

The kinds of robotic kits comprising learning robotics and learning by robotics categories are numerous, and the number keeps growing as technology advances. To those interested to know more about the models that exist to date, I suggest to seek the overview studies by Vandevelde, Saldien, Ciocci, and Vanderborght (2013), Alimisis and Kynigos (2009) and Sullivan and Heffernan (2016). Here, I will restrict myself to laying out the three broader categories proposed by Blikstein (2013) in the paper covering the history of development of multicontroller-based kits used in educational settings. According to Blikstein's classification, the most popular and widely spread category of devices encountered in ER are LEGO Mindstorm bricks. Per Vandevelde et al. (2013), Mindstorms are built around a programmable microcomputer brick that can control up to 3 motors and read up to 4 sensors. The motors and sensors can be connected to a control unit using snap connectors; the brick itself can be programmed using a graphical programming language or, alternatively, using one of the many third-party applications that support languages such as C++ or Java. This category of robotic kits departs from the pioneering work of the MIT Media Lab in the 1980s. The underlying common feature of these devices is that, while their functionality (e.g., sensors values and control devices) remains exposed, the inner workings are hidden from users. The second category of robotic kits, according to the author, is comprised of the second wave educational robotics devices that expose most of the underlying electronics to the user. Blikstein names the BASIC Stamp, Wiring, and the Arduino boards as the most popular representatives in the given category. Finally, the third category is composed of devices that break away from the traditional programmable kits in that they do not require a computer to be programmed. This feature enables selective exposure to the workings of the device and allows for user interactions at a different level of abstraction. Some of the devices that fall under the latter category are Topobo, Braitenberg Blocks, and Cubelets. *Social robotics* category similarly embraces a wide range of different robot models where, among the humanoid robots, the most popular ones are Nao [2], Pepper (Tanaka et al., 2015), Rubi (Movellan, Tanaka, Fortenberry, & Aisaka, 2005) and, among animal-like robots, - Aibo (Decuir, Kozuki, Matsuda, & Piazza, 2004) and Pleo (Chen, Wang, et al., 2011). As pointed out earlier, in contrast to robots that are used as tools for learning robotics (i.e., learning robotics) and STEM education (i.e.,learning by robotics), robots that fall under learning with robotics category, are designed to deliver learning experiences through social interaction with learners (Belpaeme et al., 2018).

4.1.3 Educational robotics and related subject domains

Given the wide range of appearances, differing hardware and software systems and functions, it is not surprising that the kinds of learning activities and learning objectives associated with different educational robotic devices will also vary significantly (Jung & Won, 2018; Komis, Romero, & Misirli, 2016).

Based on the overview of current research in ER, Mubin et al. (2013) identifies four groups of educational domains where robots are commonly deployed: 1. robotics and computer education 2. non-technical scientific subjects such as math and physics 3. second language acquisition and, finally, 4. assistive robotics, where robots are introduced with an aim to facilitate cognitive development of users. While these four groups indeed represent the subject domains where educational robots are most commonly deployed, some researchers argue that the potential of educational robotics extends beyond these four groups to include arts (e.g., music. For example, see (Bærendsen, Jessen, & Nielsen, 2009) or drama). Of the four groups outlined by Mubin et al., per Frangou et al. (2008), activities that are tailored to attend to learning objectives in the context of STEM subjects, dominate. The popularity of ER for teaching STEM subjects is commonly explained by the multidisciplinary nature of robots, where a combination of technical (engineering) skills with understanding of concepts in physics, electronics, mathematics and programming, is required for successful completion of learning tasks. Another popular argument for the use of robots to teach STEM subjects is that ER can increase students' interest towards

[2] According to Belpaeme, Kennedy, Ramachandran, Scassellati, and Tanaka (2018), the dominance of Nao can be explained by its relatively cheap price, wide availability, technical robustness and ease of programming

these subjects and even influence their future career choice (Holmquist, 2014).

In respect to the specific activities that integrate ER applications, Catlin and Blamires (2010) identified 28 different methods/scenarios for using educational robots (e.g., as a catalyst, in demonstration, games, in group tasks, in a problem solving task, as a creative experience, to name a few).

It is important to note that a significant and important part of robotics related activities transpires at robotic competitions and tournaments. While these activities can and, most likely do, bear educational character, the latter is not necessarily the emphasis and the postulated goal of such events (D. P. Miller & Nourbakhsh, 2016). Hence, here and further on I will focus solely on the research that describes intracurricular and extracurricular ER activities that are designed specifically with a learning objective/process in mind. However, no exclusions based on the learners' age group or the type of learning task will be made at this point.

4.1.4 Weighted arguments for the deployment of robots in education

It has been my observation that educational robotics is frequently mentioned in the context of the so called *21st century key competencies* that include collaboration, critical thinking, creativity, problem solving and computational thinking (King & Gura, 2007; Alimisis, 2013; Romero & Dupont, 2016; Afari & Khine, 2017; Socratous & Ioannou, 2018). The common shared assumption in the field seems to be that ER activities correlate positively with the named skills. Catlin and Blamires (2010), in the Principles of Educational Robotic Applications (ERA), list the following aspects of the ER activities that are, in the authors' view, associated with the development of the mentioned skills: 1. Engagement: 2. Sustainable learning: and 3. Personalization:

Despite such an impressive list of competencies believed to be associated with ER, authors generally agree that, to-date the field is yet too young and more research is necessary to speak to the success of ER activities conclusively. The literature on ER focuses predominantly on describing activities in robotics educational programs, while the discussion of the effectiveness of such activities is limited and is often based on anecdotal evidence (Williams et al., 2007). The results of the content analysis I conducted support this observation .

When it comes to the evaluation of the success of the ER activities, an additional challenge comes with the difficulty to conceptualize and agree on the measure of "success". This challenge is especially prominent in the context of constructivism-inspired approaches that are, by definition, more open-ended and process- rather than outcome- oriented. The above said suggests that no prescribed methodology exists that has been conclusively demonstrated to be causally related with a positive learning outcome. Also, even if in the context of a single study such causal relation is supported by empirical evidence, it is premature to speak about the transferability of the skills gained to other domains, or even to the overall significance of the findings [3].

Despite an advised degree of caution when it comes to the over-enthusiastic claims about (variously defined) successes of the ER activities, it is nevertheless true that ER activities *may* enable a more active, situated and exploratory learning and afford for the integration of concepts from different fields in one activity. Following Toh, Causo, Tzuo, Chen, and Yeo (2016), we can classify the studies that show positive correlations between ER activities and learning into four groups, based on the type of learning/skill improved: i) cognitive ii) conceptual, iii) language, and, finally, iv) social (collaborative) skills [4].

What are the features of educational robots that are commonly associated with constructivist [5] learning? The tacit agreement seems to be that, by their virtue, robotic technologies - where a direct participation in building and/or programming of a robot by the learner is required - afford for *active learning* (D. P. Miller & Nourbakhsh, 2016); and, very much in the spirit of authentic education, engage learners in learning tasks by "capturing their imagination" (Vandevelde et al., 2013) and allowing to create meaningful connections between learning activities and the world. In the words of Khanlari (2016):

> My experience, as a robotics instructor who tried to integrate robotics into k-12 schools as well as higher education, confirms the existing literature surrounding the use of robotics for the purpose of creating authentic learning environments. I witnessed that robotics has the potential to create an environment which is connected to students prior knowledge and experiences (e.g. building soccer robots) and helps students truly retain learning in a meaningful way. This kind of authentic problems and projects, which are touched and felt by students, leads them to produce ideas and engages them in the process of knowledge building. Based on my experience, robotics also provides an opportunity in which students feel what they learn is not useless knowledge; rather, it is applicable in the real world.

However, to anticipate the critical overview of the literature on the ER robotics, I would like to share my observation that the notion of active learning (as one of the cornerstones of

[3]For more on this, see (Denning, 2017)

[4]This classification is proposed based on the overview of studies where the subjects were very young learners. Also, it is yet to be determined whether these skills are transferable.

[5]Here, I understand constructivist learning in a trivial sense of active, embodied, exploratory learning in contrast to more traditional, verbal instruction driven learning

constructivist pedagogy) in the context of ER - while appropriate in many instances - is more often than not trivialized. Manipulating a robotic kit may indeed present itself as active in contrast to learners passively consuming verbal instructions. However, one of the questions that it raises is: does manipulating a physical artifact suffice to label such an activity as "constructivist learning" [6]? And if not, what other factors have to be considered?

Before I proceed to the discussion of this and other critical points associated with constructivist concepts and pedagogical approaches in ER, the coming section I will introduce the procedure I used to collect the literature that informed my analysis.

4.2 Survey methodology

4.2.1 Literature search and selection

The literature search and selection were conducted in several stages. The first stage took place at the onset of the work on this thesis. Given my limited knowledge of the field of educational robotics at the time, the objective behind the preliminary round of literature collection and reading was to inform myself in respect to the key trends and directions of research. No system for the selection and tracking was used other than directing my attention to the overview papers and a limited number of think pieces published in the recent decades. At this stage, a freely styled reading diary was used to keep track of the key points in respect to the papers read, and my impressions regarding these.

Once I had informed myself about the main trends in the field, I moved on to the second stage of the literature search and selection. Here, the primary objective shifted toward pooling together, in a more systematic manner, literature for the content analysis, with an emphasis on the texts that explicitly refer to constructivism and/or constructionism. The search was conducted via two scientific literature search tools: Clarivate Analytics' Web of Science (WoS) and Google Scholar. For the WoS search, the combination of "education" and "robotics" and "constructivism" and/or "constructionism" was used. For the selected period of 2000-2019, this procedure yielded in total 2000+ results. To these results, the following filters were applied. For the domain: education research, psychology multidisciplinary, social sciences interdisciplinary, sociology, computer sciences interdisciplinary, education scientific disciplines, robotics. For the document type: articles and proceedings. The resulting 733 publications were further sorted by relevance and citation count. While 'robotics' was one of the search words, many of the 733 publications did not in fact concern educational robotics. To filter these out, within the results

[6] This is emphasized by the, by now, trivial fact that all cognition and, hence, any learning is already "active"

collected, I further searched for "robotics", which returned 32 publications. The abstracts of these were read and further 21 papers were selected based on the following criteria:

- Paper had to be accessible via University of Vienna subscription services.
- The language of the publications had to be English.
- For overviews, theoretical pieces and empirical studies, the focus had to be on a physical robot(s) in learning settings. Papers that addressed online learning (i.e., virtual tutoring agents), augmented or virtual reality applications, were excluded.
- Constructivism/constructionism had to be explicitly mentioned in the body of the text [7]
- The text had to incorporate an explicit discussion of learning/teaching processes. Papers where the focus was on the technical description of the architecture and functionalities of a robotic kit/model of a robot exclusively, were excluded.
- Papers with a focus on assistive robotics (e.g., where robots were used in interaction scenarios with learners with cognitive disabilities, such as autism) were excluded. Learning objectives and pedagogical approaches used in this context differ substantially from the "standard" teaching-learning environments and fall outside the scope of this thesis.

This procedure yielded in total 15 publications.

Similar procedure was repeated for the Google Scholar search engine; combination of search words "education AND robotics AND constructivism OR constructionism" was used for the period of 2000-2019; patents and citations were excluded. This returned 15,500+ results. The significantly higher number of returned publications can be explained, among other reasons, by the fact that the GS algorithm searches for the keywords in abstract and in main body of the publications, while in WoS the search is confined to abstracts only. For obvious reasons, even a very superficial overview of 15,500+ papers, when not relying on the natural language processing and machine learning methods, does not present itself possible. To limit the pool, I sorted the search results by relevance, and proceeded to collect the papers, using the selection/exclusion criteria outlined above, from the first 10 pages (this number was chosen arbitrarily) of the returned results. Upon elimination of duplicates, this procedure resulted in 28 papers. Summed with the 15 publications collected via WoS search, the 43 publications selected at this stage form the core literature that was used for the content analysis.

During the preliminary literature overview, it was my observation that the field boasts publications that discuss teaching and learning related processes/approaches that conceptually rely

[7] With some exceptions that will be addressed later.

on a different (not constructivist) theory or philosophical discourse (e.g., actor-network theory, Alfred North Whitehead's process philosophy), but that can, in many aspects, be interpreted as constructivist. Also, as I progressed with reading, it became evident that, whereas Piaget, Papert, Resnick and Vygotsky are the four authors mentioned routinely, the references to other prominent constructivist authors, such as Ernst von Glaserfeld, who, to a large extent, shaped the discourse on constructivist pedagogy, and to the theories of embodied and enacted cognition are scarce. In the light of these observations, where I saw useful, additional literature search was conducted with an aim: i. to verify that the search terms used for the core literature pool collection are not exclusive of a potentially important bulk of literature (this is how I came to compile and additional pool of ER literature that is grounded in embodied and enacted cognition frameworks) ii) to maintain an overall broader outlook. For this search, specific targeted keywords, such as "von Glaserfeld" or "embodied cognition", were added in combination with "robotics" and "education". Finally, a limited number of publications that highlighted approaches/aspects of constructivist thinking in ER were identified additionally through citations and references in the core literature pool. Including these additional sources, the total number of publications that were formally included in the content analysis was 57.

4.2.2 Literature content analysis procedure

To anticipate and to frame the introduction to the procedure and results of the content analysis of the literature collected, I believe a brief reminder of the main research questions that motivated this thesis is due:

- What are the interpretations that constructivism receives in the field of educational robotics? For the content analysis, I broke this question into two subparts: i) what are the explicit definitions assigned to the term? ii) What are the main themes associated with differently emphasized definitions?
- How are the definitions given map on to the constructivist debates outlined in the first chapter of the thesis? Which are the aspects of constructivist thinking that preserver, and which get lost/distorted? What could be the reasons for this?

These questions reveal that my interest is not to represent the outcomes of my research in terms of numeric values (e.g., how many times 'social constructivism' is mentioned). Rather, it is my intention to tap into the trends and sense-making processes that drive the ER discourse in the context of constructivist pedagogy. Instead of a standard bibliometric research [8], I elected

[8] For an example of a bibliometric study of literature on educational technology based on constructivist approach to learning, I refer the reader to Asiksoy and Ozdamli (2017).

qualitative content analysis as a methodology to ground my overview. Hsieh and Shannon (2005) identify qualitative content analysis as a research method. Qualitative content analysis, according to these authors, focuses on the features of language as a communication vehicle with attention to the semantics and contextual meaning of a text.

To facilitate the analysis of the text data collected, an Excel spread sheet was created, where the seed literature (57 papers in total) was represented by the publications' title, year of publication, authors, source title (journal/venue title), the search procedure via which the paper was collected, and, finally, abstracts. Upon the first round of reading, categories, such as cited constructivist authors (e.g., Piaget, Papert, Vygotsky etc.), the type of educational robotics discussed (e.g., learning robotics, learning by robotics, learning with robotics) and the kind of publications (e.g., an overview, a presentation of empirical study, discussion of proposed lesson plans etc.) were filled where applicable.

As I proceeded, and more common themes and patterns emerged, to account for these in a structured manner, I divided the texts into three broad groups: 1. Casual constructivism 2. Informed constructivism 3. Perspectives on social constructivism. This classification is based on the combination of the following three dimensions: i) the depth and the degree of reliance on the source works that authors display when defining constructivism (i.e., extended definition in contrast to constructivism as equated to "active learning") ii) the emphases that the authors make in their conceptualizations of constructivism (i.e., whether on the level of theory references are made to subject-centered constructivist authors and concepts, or to social constructivist authors), and iii) whether and how the conceptual part is integrated with the proposed lesson plans/empirical studies.

Additionally, I will also review briefly some of the studies that touch upon the role of the body and bodily activity in and for learning and teaching in the context of ER. As I discussed in 2.2.3, conceptually the theories of grounded cognition (e.g., embodied cognition, enactivism) stand somewhat apart from the classical subject-centered and social constructivist frameworks. This divorce is also noticeable in the field of ER where studies that are grounded in these approaches commonly stand separately from those grounded in Piaget-derived constructivism, Papert's constructionism and Vygotsky's social constructivism [9]. Even though the principle objective of this thesis is to critically review the works associated with classical constructivist interpretations, I believe that, on the grand scale, it is impossible to talk about hands-on learning without considering the sensory-motor processes that underlie it; especially given the empirical evidence for the much less blurred divide between the higher-order symbolic representations

[9] I would like to point out that Vygotsky never referred to himself as "social constructivist". This label was attributed by the scholars who followed him (Liu & Matthews, 2005)

driven knowledge and that rooted in the sensory-motor representations (Barsalou, 2010). Hence, my decision to include this topic in the overview. I would like to point out that the studies that I will refer to when discussing embodied and enactive cognition theories in the context of ER research are not a part of the seed literature. Additional search had to be conducted for these.

As any attempt at classifying highly unhomogeneous texts, my proposed grouping, though not entirely arbitrary, is open to criticism. While I recognize certain degree of artificiality in the distinctions I propose, I hope that they are nevertheless useful in providing a structured overview of the dominant trends and associated challenges in ER in respect to different branches of constructivist thinking and constructivist pedagogy. However, it is important to remind the reader of my biases: that is, even though I strove to approach the texts without preconceptions, my reading of the publications must have been influenced by the extensive reading of constructivist texts that laid foundation to the discussion in 2 and 3. Additionally, my background in humanities and general inclination toward social constructivist and phenomenology-inspired, process-oriented approaches, must have influenced the final outcomes of my analysis in ways that I myself may not fully be aware of. In other words, had I approached the analysis from the perspective of an adamant behaviorist, my interpretations and critical remarks most likely would have differed. Fortunately or unfortunately, subjectivity is part and parcel of qualitative methods. As an author and a researcher, I hold no solution as to how to overcome this challenge other than being as transparent as possible in respect to where I come from, and what motivates my personal stance.

In the remaining sections of the chapter I will present the results of the content analysis. The overall general impressions will be followed by a detailed presentation, supported with case studies, by the main themes that I identified within each group of publications, and my critical remarks.

4.3 Survey results

4.3.1 General impressions

As expected, definitions of constructivism in the literature on ER vary. It has been my observation that the general trend is to refer to constructivism as a *learning theory* (Stergiopoulou, Karatrantou, & Panagiotakopoulos, 2016; Bærendsen et al., 2009; González, Jiménez, & Ovalle, 2010) or, less frequently, as a *pedagogy* (Miranda, Bolea, Grau, & Sanfeliu, 2012) or *theory of education* (Afari & Khine, 2017) or, simply, *theory*. The constructivist authors that dominate the theory-grounding sections are Piaget and Papert. Following the discussion in 2 and 3, the popularity of these authors, coupled with the emphasis on constructivism as a learning theory, suggests that the research focus is rather on the intrapersonal processes that underpin learning (Piaget-derived), or learner-centered ER practices that involve some form of hands-on manipulations of physical objects (Papert-derived), or a combination of both (Messaoud & Romero, n.d.; Altin & Pedaste, 2013; Tocháček & Lapeš, 2012).

However, the prevalence of the Piaget-derived constructivist thinking in the field of ER does not mean that this is where constructivism-inspired discussion stops. Though fewer in numbers (12 out of 57), my seed literature also incorporates works that refer to social constructivism, predominantly through the writings of Lev Vygotsky. These works either address, conceptually and/or empirically, aspects associated with social dimensions of learning and teaching, or argue for the integration of cognitive and social constructivist branches and attempt at consolidating their proposals in the empirical designs.

In my overview, out of the three groups of publications, the first two (Casual Constructivism and Informed Constructivism) are dominated by the subject-centered constructivist theory and theoretical considerations derived from Piaget and Papert, and, less frequently, Resnick and his notion of learning by design. As the group labels suggest, the distinction between the groups is motivated by the variations in the quality of definitions provided and the extent to which authors strive to integrate constructivist concepts in the empirical designs they develop.

I labeled the third group of publications Perspectival Social Constructivism. While all authors of the publications in this group conceptualize their work as influenced by social-constructivism and, most frequently, the works of Vygotsky [10], the socio-cultural dimensions that different authors choose to study (e.g., the role of social interactions for development and learning, technology as a semiotic system etc.) vary. I will explore this variation in more details in the related sub-chapter.

Within Casual Constructivism and Informed constructivism groups, publications that are structured around applications and activities aimed at promoting skills and concepts in robotics (learning robotics) or concepts in STEM subjects (learning by robotics) dominate. While studies in Perspectival Social Constructivist group can also target STEM subjects, in terms of robotic applications used, Perspectival Social Constructivism group is where we will find most of the studies that deploy social robots. This is hardly surprising given that these robots, as we discussed earlier, are designed to participate in some form of social interaction with learners, hence aspects associated with the nature, quality, structure, role and meaning (for human participants) of such interactions come forth.

[10]However, references to Piaget and Papert are also frequent. As I will discuss further, in the context of ER, studies that focus *exclusively* on social constructivist concepts are rare, for a good reason.

Finally, the fourth group (Grounded cognition theories in ER) includes studies from all three branches of educational robotics. Irrespective of the kind of robotic application and the task domain, the objective in these studies is to investigate how bodily activity and bodily modalities accompany and structure learning and teaching in the context of robotic actitivities.

These broad remarks are meant to provide a general orientation in respect to the three groups. In what follows, I will review each of the groups in more details. The presentation of my findings will be structured around the main themes that I identified during the content analysis.

4.4 Casual constructivism

As anticipated in the prior discussion, the publications that I classified as "casual constructivism" reference constructivist authors such as Piaget, Papert, Resnick. However the authors commonly leave the concept of constructivism either un- or underdefined, or equate it with the concept of *active learning*. While at the first glance the idea of active learning does not pose a direct contradiction to constructivist thinking and constructivist pedagogy - quite the contrary - the conceptual weakness of these studies, as I see it, is in the assumption that some sort of hands-on manipulation of a robotic technology is i) a sufficient condition to characterize it as *active learning*, ii) a sufficient condition to refer to such an activity as constructivist iii) that such an activity is pedagogically useful because i) and ii).

It has been my observation that there is no agreement in the field in respect to the notion of active learning. Here, I will focus on this concept only inasmuch as it is associated with constructivist pedagogy. Namely, let us explore how this concept is dealt with in the studies from the core literature.

One interpretation of active learning in the field is associated with learners' agency. For example, in Romero and Dupont (2016), an otherwise well though-through theoretical study, the authors present their critique of ER activities from the perspective of learners' involvement. In the authors' view, some ER activities cannot be called constructivist because they lack learners' agency. Based on this criticism, the authors propose to distinguish between activities according to the degree of active engagement of learners: from mere passive exposure to co-creative robotic projects, oriented to solve a realistic challenge. While this suggestion makes perfect sense and does indeed help to distinguish between different ER activities, what the paper assumes but lacks the empirical evidence for is that collaborative projects, where the learners' active engagement is the highest, will be more successful comparing to the projects where learners are, according to the proposed scale, "less active". To paraphrase, the assumption seems to be that the more learners' agency, the more "constructivist", therefore, the "better" an ER activity is. However, the link between learners' agency and informed constructivist pedagogy is not as straightforward [11]. The questions remain: when is endowing learners with more agency more appropriate? How does one evaluate the outcomes of ER learning activities differentiated by the degree of learners' active involvement?

Overall, the challenge of evaluation of the success of an ER activity is an omnipresent topic in the field, regardless of the quality of the study and the definitions of constructivism provided. Constructivist pedagogy as process- rather than outcome-oriented, as we discussed, proposes no unified method how to approach the topic of evaluation and assessment. Coupled with the heterogeneity and relative youth of the field, this challenge is more than understandable. The reason for me to address it in this here is that, beyond the challenges presented by the constructivist approach in its own terms, many studies in this group lack consistent evaluations of the activities discussed, even in respect to the conceptual frameworks as laid out by the authors themselves. That is, it has been my observation, that some authors dedicate substantial efforts into describing the technical aspects associated with the activities they design; sometimes, these are accompanied by extended theoretical introductions. However, what is commonly left wanting are the sections on evaluation of these activities in respect to the goals they were intended to achieve.

An example to illustrate this point is the work by Miranda et al. (2012). Once again, the superficial reading of the paper suggests that the authors give due diligence to defining constructivist pedagogy. In the opening section of the publication, "constructivist methodology" is defined as following: "Students [...] are invited to work on experiments and authentic problem-solving; with selective use of available resources according to their own interests, research and learning strategies". Further, following Papert, robotic technology is seen as a "new way of thinking". The authors proceed to listing how robotics activities can contribute to learning (i.e., by their collaborative nature, enabling of dialogic learning etc. - all valid points) and move on to the detailed presentation of an ER workshop and the technology used in this workshop. Despite such a promising start, the evaluation of the workshop conducted is limited to a short paragraph that provides no information in respect to the experiences of learners when it comes to "collaboration" and "dialogue". The only conclusion that the authors present us with is that, after a set of questions [12], it is concluded that the participants found the experience "very fruitful and their interest in enrolling in an engineering degree is higher than ever". The reasons

[11] As we will discuss further, for an activity to be pedagogically useful, other aspects, such as teacher's or instructor's guidance, are necessary

[12] Notice that no information on the methodology used to collect the answers is provided

why participants found it interesting, the specifics of their experiences, and how these provide an argument for constructivist learning and ER activities, are left for readers to guess.

Similarly, Stergiopoulou et al. (2016) provide a detailed description of the H&S Electronic Systems platform they deployed in an ER workshop designed to teach basic principles of automatic control systems and programming in primary education, discuss the technical advantages of this technology and then proceed to introduce the methodology for the two two-hours sessions in two public primary schools in Patras. While there were three data collection methods used in this investigation (monitoring, recording of groups' discussions, completion of short questionnaires before and after the activity), based on the text of the publication, it remains unclear how exactly the workshop conducted ties into constructivist approach other than by the general principle of hands-on learning. The authors do not discuss it, neither they discuss whether the learning gains could have been similar had a more traditional, instruction-driven, approach been used.

Another critical remark regarding the publications within this group is that, in some studies, the authors suggest a technology that can be integrated in classrooms, while providing no details nor guidance in respect to how exactly given technology should be handled by teachers. In other words, what should be a learning scenario, sequence of steps and tasks? For example, in (Messaoud & Romero, n.d.), the authors describe how they simplified an mBot's technical features and endowed it with a personality in order for it to be more engaging for younger learners. The resulting robot, encapsulated in a shape of a ladybug, was named CocciBot, and the authors suggest that teachers could "easily integrate" such a robot in collaborative learning activities. However, no specifications nor examples of such activities, nor arguments as to why these should necessarily be easy for the teachers are provided.

To summarize the main critical points in respect to interpretations of constructivism in this group of studies:

- **Reducing constructivism** to the process of building and/or manipulating a robotic artifact (in contrast to passively consuming information presented by the teacher or instructor); it is my assumption that such narrow interpretations suggest that the authors refer to constructivism as a form of tribute, or out of inertia, dictated by other works in the field, without much considerations for the philosophical and pedagogical tradition that stands behind the term nor for what other aspects, associated with teaching and learning (e.g., role of guidance/scaffolding, structure and dynamics of collaborative work etc.) should be considered in the context of constructivist pedagogy . This results in the publications where the aspects of constructivist approach used are left unreflected.

- **Little to none evidence** that such a hands-on ER activity is preferential over more traditional instructional approaches; or that it leads to successful and lasting knowledge and skills formation, in alignment with the established learning objectives.
- **Under-defined learning scenarios**: few authors define what the learning objective of a proposed ER activity was, and what was the manner and extent of the guidance provided to the participants; how these tie into constructivist pedagogy is also not discussed.
- **Limited assessment of an activity or workshop**: reader is left uninformed to what went well, what were the main challenges, what the experiences of teachers and learners were.

To anticipate possible counter-critique that the objective behind these studies was not to provide arguments in support of constructivist learning and teaching. Rather, their focus was on specific technology, its features and advantages, with some examples of how it can be implemented. However, while I do agree that these more narrowly focused studies are still useful, my critique pertains the broader question of why we do what we do. In other words, I believe that sometimes, behind the narrow focus, we forget that the solutions we propose have to be for the benefit of the stakeholders (teachers, learners and broader community). Hence, we cannot bracket out the discussion on what constitutes such a benefit, how it compares to more traditional approaches, and finally what the stakeholders themselves think about their experiences.

A softer, perhaps, of less immediate importance but of relevance for my work, critical point pertains instances of concept devaluation: that is, unmotivated and unreflected use of the term "constructivism" that is dictated by the trends in the field while bearing no actual influence on the empirical work of the authors.

That said, I would like to stress that, though I take a certain critical stance to the studies selected in respect to how they define and realize constructivist pedagogy, it does not necessitate that the authors' work is not useful or is of low quality. My aim in this section was rather to highlight some of the problematic or further development inviting aspects of educational robotics technology studies.

4.5 Informed constructivism

As a reminder, the unifying criteria for the publications I review under this label is as following: the authors ground their work in subject-centered constructivist approaches and their spin-offs, such as constructionism. However, unlike the publications discussed in the preceding section, the authors provide informed and elaborated definitions of constructivism and strive to integrate these with the empirical work they conduct in a manner that is consistent and transparent.

Commonly, the definitions of constructivism in the publications in this group are also grounded in Piaget and Papert and stress, apart from the general notion of hands-on learning, already addressed in the previous section, the importance of respecting learners' current knowledge schema and authentic processes of sense-making:

> Probably the most tangible influence of constructivism onto the field is the idea that learning is an active, exploratory process, through which meaning is constructed by learning on the basis of what their current knowledge schema. (Frangou et al., 2008).

Given that this group is the most numerous, and the publications that comprise it are extremely heterogeneous, I structured the presentation of the insights I gathered by the main themes that I came across repeatedly while studying the seed literature. These themes are: i) Constructionism (here understood as discourses that address hands-on, exploratory learning by construing a physical object to be shared with a community) ii) Collaboration (how group work enables individual processes of learning) and, last but not least, iii) Personalization (the idea of respecting learners' existing knowledge schema and individual processes of sense-making).

Notice that the distinction between these themes does not necessitate that the processes they encapsulate exist separately or independently from each other, or that any of these can be said to be more important than any other. To the contrary, as I discussed in 3.3, they are all part of the authentic learning paradigm and jointly work to support learners.

4.5.1 Constructionism: learning as exploration

The role of Seymour Papert and colleagues from the MIT Media Lab for the foundation and development of the field of ER and its current conceptualizations is hard to over-estimate. This is why, before I discuss studies in ER that focus on constructionism and associated concepts, a brief overview of constructionism as a movement, its core principles, and divergences from the classical Piaget-derived cognitive constructivism, is warranted.

Influenced by the ideas of Dewey, Montessori and Piaget, Papert believed that children learn by doing and thinking about what they do. From this perspective, the foundational elements of educational innovation must be "better things to do and better ways to think about oneself doing these things" (Papert, 2005, p. 161). According to Papert, his theory builds up on the two dimensions implicit but not elaborated in Piaget's work: knowledge structures that can develop (as opposed to those that are already present in a child, an idea that is conceptually close to Vygotsky's zone of proximal development), and the design of learning environments that can enable the formation of such novel knowledge structures Papert (1980). To paraphrase, Papert's theory, commonly referred to as *constructionism*, expands on the subject-centered constructivist proposition that learning is about building knowledge structures by introducing the idea that this is enabled by the contexts where learners are consciously engaged in constructing an artifact:

> The process reminds one of tinkering; learning consists of building up a set of materials and tools that one can handle and manipulate. Perhaps most central of all, it is a process of working with what you've got. (Papert, 1980, p. 173)

Technology, such as computers and robotic kits, plays a crucial role in designing learning environments wherein learner can explore on their own terms and in accordance with their interests. The power of these devices is in their universality: as they can take different shapes and perform different tasks, they can appeal to a wide range of different learners. By working with technology, children construct their personal *microworlds* and, like painters, express their personal styles rather than sticking to a pre-established plan. Such activity is iterative and emergent. Constructionism shifts emphasis from Piaget's idea about the biological and universal cognitive development to learners as individuals, who express their voice with their preferred representations, artifacts and objects-to-think with (Cho, Lee, Cherniak, & Jung, 2017).

For Papert, the idea of emergent, iterative learning through the activity of constructing an artifact goes back to the 1970s, the time when, having observed primary school students carving soap in an art class, made him wonder what a "soap-sculpture math" class would look like? This resulted, first, in a LEGO/Logo project, where a group of children were using computational material in a creative task of building a snake. Where knife was used to shape soap in the art class, math was used to shape the movements of the snake, while physics was used to figure out its structure. In 1971 Papert and Solomon published a memo '20 Things to do with a computer' (Papert & Solomon, 1971), where a lot of activities described involved connecting some sort of a gadget to a computer and programming it to perform e.g., a puppet show. According to Martin, Mikhak, Resnick, Silverman, and Berg (2000), these projects proposed robotic design activities, before a general-purpose robotic construction kits became available. In the 1980s, Papert's research group began a collaboration with the LEGO Group. As a result of this collaboration, the first LEGO/Logo system became commercially available in the late 1980s.

Papert's ideas have had an extensive influence on the field of ER. Constructionism aligns especially well with the learning by robotics branch, where construction and programming of robots is transparent and invites learners' engagement and stimulates their creative thinking Alimisis (2013).

In what follows, based on my literature pool, I will present some of the highlights of how

Papert's ideas are put into practice in today's ER activities.

Constructionism and hands-on learning

Constructionist activities are iterative and emergent. In this context, the concepts of *trial and error* and *learning by experimenting* are frequently addressed. For example, Bærendsen et al. (2009) present RoboMusicKids project wherein modular robotics is used to allow young participants (aged between 10 and 12) without any prior musical knowledge or skills to express themselves musically by experimenting with intelligent I-BLOCKS. Intelligent I-BLOCKS are self-contained computer units that communicate with each other when they are physically connected. Each of the blocks represents a musical instrument (e.g., guitar) or a sound (i.e., vocal); in total 6 instruments, with 6 variations for each side of the block. To help the users to remember specific variations, I-BLOCKs change colors depending on their orientation. By connecting blocks in different ways, users can experiment with musical composition. The authors, who ground their work in Papert, suggest that this approach relies to a high degree on intuition and creative trial and error. The entire project incorporates several stages. At the exploratory stage, children in groups experiment with placing the blocks in any order without any specific goal. The main intention behind this stage is to allow them to explore how to activate different loops and to figure out which instruments or sounds are represented by each of the blocks. At the second stage, children were invited to make music collaboratively. This is when the participants paid more attention to the actual outcome of their compositions and to the preferences they had for the sound they produced. Finally, the children were invited to compose their individual piece of music. The observation that the researchers had was that every participating child was able to create a well-sounding and personal musical piece.

While this elegant study is an excellent example of how constructionist ideas can be put into practice to achieve meaningful results, the critical point to remember in the context of approaches that rely on trial and error is that not every exploration will be successful if it is unconstrained and unguided. Additionally, the success of such activities will most likely depend on the learning objective and/or the nature of the learning task. That is, I hypothesize that it is more likely that trial and error approach will be associated with satisfactory learning experiences and outcomes in the context of more creative tasks, such as the one in the study cited above. However, in the context of STEM subjects, it may not suffice.

To explore this hypothesis, I suggest we refer to the study by Williams et al. (2007). The authors used a mixed method approach to study middle school students' acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp. The authors found that the camp improved participants' physics content knowledge. However, it was also found that their scientific inquiry skills did not improve. The qualitative data collected (conversations with participating instructors) helped the researchers to identify several problems that may explain this poor result. Firstly, the authors suggest that some ER activities may not have been challenging enough for the learners to apply scientific inquiry at each step. Secondly, more to the point I intend to highlight in this section, conversations with instructors revealed that the learners were too excited over the possibility to work with robotics technology, which led to them choosing to try and fail rather than apply any systematic approach. This suggests the importance of involving teachers and instructors at the onset of designing an activity in order to develop approaches and methodologies that will help to scaffold learning processes, and to avoid situations when learners are left to their means.

This brings me to the next critical point that is pertinent to the success of almost any ER activities: teachers and instructors. I have already discussed the role teachers as enablers of authentic learning in the chapter on constructivist pedagogy and I will return to this discussion from the perspective of social constructivist approaches further in this chapter. Here, I will focus on the dimension that is more prominent in the context of constructionist approach. Namely, how constructionism and constructivism can be helpful to ensure that teachers master the technology they are to implement in their classrooms and extracurricular activities.

Teachers as learners and designers

It is important to remember that the objective behind the introduction of technology-based learning is not to replace teachers but to empower to design stimulating learning environments, as proposed by Papert. For this, it is of critical importance to provide teachers with an adequate support and sufficient degree of agency when it comes to the decisions about how a robotic application is to be integrated in their classroom.

One of the approaches I found both convincing and especially relevant in the context of the discussion about the influence of constructivist thinking, is the one proposed by Bers and colleagues (Bers, Ponte, Juelich, Viera, & Schenker, 2002). The authors emphasize the potential of constructionist approach to enable authentic learning but also recognize the challenge of integrating constructionist approaches into classroom work (i.e., how to break an activity into a sequence of steps? How to integrate it with the concepts from the curriculum? Where is more guidance necessary? etc.) To address these challenges, the authors propose a simple but powerful idea: given that teachers are learners too, and it will be their task to guide learners through the ER activities, it is sensible to allow them to experience the technology in a similar manner as their students will. To test this methodology, the authors invite a group of preservice teachers to experience using ROBOLAB and LEGO Mindstorms technology and to document their experiences throughout the project in order to facilitate self-reflection. According to the authors, the proposed methodology for teachers' training not only helps teachers to build confidence and sufficient technological fluency in respect to the technology they are to implement in their classrooms, but allows to identify more natural, activity- and classroom- situated ways, in which said technology is best integrated in the curriculum.

4.5.2 Collaborative learning

In 3.3 I discussed how group learning and collaborative activities are commonly associated with constructivist pedagogy as they are seen to provide space for learners to interact with others. Such interactions, from the point of view of radical and cognitive constructivist frameworks, trigger perturbations relative to expected results within existing knowledge scheme and lead to accommodation and assimilation processes. In the topical literature, collaboration is mentioned predominantly within two contexts: i) within the context of ER activities as enabling the development of collaborative skills, that is when ER activities are introduced with an objective to improve not only concept knowledge but "dynamical skills" of learners (collaboration as a topic) (Denis & Hubert, 2001; Kynigos, Grizioti, & Gkreka, 2018; Khanlari, 2016) ii) when collaboration (i.e. group work) is implemented as a one of the teaching scenarios (Catlin & Blamires, 2010) to enable creativity and problem-solving (collaboration as a pedagogical strategy).

While a lot of studies mention collaboration and group work in one or both of the meanings specified above, de facto few studies focus on presenting a solid theoretical foundation for collaborative work and/or focus on studying the structure and the cognitive and social processes underlying collaborative work. Goggins et al. cited in (Hong, Chew, & Sze-Meng, 2016) also point out this gap in existing research and call for more real time behavior-based studies of learners' interactions with their environment. To achieve this, the authors propose a model to determine whether learning outcomes are met by focusing precisely on the collaborative dynamics and interactions.

Another worth-mentioning example of the work that addresses this gap is an empirical study by Denis and Hubert (2001) where the authors focus specifically on investigating the structure and the processes of collaboration in educational robotic activities. According to the authors, their interest is in collaboration as a mean to design and develop common projects and improve problem solving skills. In this study, pupils aged 10 worked in two small groups of 2-4 during six periods of 80 minutes. The task of the first group was to build a program a robot with LEGO material; and the second group had to understand what was the pre-built model and to program it to move with the help of the computer. The authors deploy observation grid to code for social interactions between peers and their actions on the didactic material. For an extended overview of the results I refer readers to the original study. Here I will constrain myself to recuperating the general conclusions. Namely, the outcomes of the observations suggested that many interactions between group peers were task-focused. The learners showed an ability to work together and engage strategic competencies. The types of interactions between the learners had varied inside a group and from one group to another; in some instances, the emergence of leadership was detected. This suggested the necessity of decisions to regulate how learners interact. Finally, the researchers point out that the observations grid used focused predominantly on the cognitive dimension (aspects of problem-solving) and suggested that future studies also deploy a more specific grid to code for social dimension of interactions (e.g., roles that are centered on the climate within the group or task; learners attitudes etc.).

4.5.3 Personalisation

As discussed in 3.3, one of the principles of authentic education is recognition that every learner is different. This idea is prominent in ER, where adaptability and personalisation that robotic technology affords for is one of the most popular arguments for the introduction of such technologies in learning environments. G. Miller, Church, and Trexler (2000) suggest that robotics is a type of instructional materials that can be used to support learners of different abilities. Robots are unique comparing to text-based materials, as the same robotic material can be used to create a unique set of learning experiences for learners with different needs.

In their programmatic paper 'The Principles of Educational Robotics Applications' Catlin and Blamires (2010) suggest the following ways in which educational robotics supports personalisation:

- Self expression: ER offer tools for learners to explore ideas and express themselves creatively in the designs and codes they develop.
- Flexible use: robots can be adaptable to the needs of the teaching situation and individual learners.
- Differentiation: ER activities can be adapted to different levels of difficulty. They support struggling learners and challenge advanced students.
- Learning styles: Robots engage in multiple modal experiences (e.g., visual, audio, kin aesthetic etc.)

Some of the studies referred to in the earlier sections can also serve as an illustration of how robotic technologies allow learners to expresses themselves and their ideas creatively (e.g., RobotMusicKids), and how technology can be modified in order to fit learners' knowledge levels and needs (e.g., CocciBot). Another example of how technology can be adapted to different needs is the work by Gonzalez and colleagues (González et al., 2010) who argued for the necessity of contributions that consider different socio-cultural contexts and propose the TEACH-RI kit, developed with regard to the Colombian educational environment and grounded in the experience of the local research group.

I would like to focus more on the topic of uniqueness of learners and their experiences, and the opportunity, but also the challenge for the design of ER activities that it presents. To do so, I will forgo my classification and refer to the work that not only integrates subject-centered and socio-constructivist perspectives, but extends beyond these in an attempt to address the complexity of real-life learning in a non-dualist manner. The reason for this transgression at the expense of the structural clarity is that I believe that this work by Cho et al. (2017), setting aside its conceptual strength, also provides an important insight worth considering in the context of the discussion about personalization in ER. Drawing on Latour's actor-network theory, Cho and colleagues set off to study which human (actors) and non-human (actants) elements contribute to educational robotics activities. The team used mixed methods (video recordings and interviews with children and teachers) to analyse three second-graders' (focal subjects in a larger study of 24 children) interacting with robotic manipulatives Bee-Bots and Cubelets in the course of 8 weeks. The results of the study suggested that the dominant elements associated with each child's learning performance were different: while for two of the children exploring robotic manipulatives and other instructional materials was of great contribution, for the third child utilizing adult guidance (e.g., following a teacher's direction, asking questions and confirming ideas with a teacher) proved to be of critical importance.

Of course, we cannot generalize based on the sample of three. Despite this limitation, the importance of this study is in highlighting that learning happens in "complex networks of human, material, quasi-human/guasi-material actors and actants" (Cho et al., 2017, p. 482) and cannot be outsourced to an individual teacher, or to supporting learning material alone. Instead, a collaboration and cooperation of different bodies and forces, and sensitivity to individual learners' needs is required.

In this section I did not discuss studies where the goal is to propose a technology- and AI-driven approaches to personalization of learning by, for example, modulating the type of feedback in respect with the learner's affective state, learning stage, personality etc (Gordon et al., 2016). While these studies are both common and important for the advancement of the field, and can be said to share the principle subject-centered constructivist assumption about the importance of respecting of individuality of the learner, they are more technology-oriented, and the authors do not (explicitly) conceptualize their work in constructivist terms. That is, such studies fall outside of the scope of my overview. However, I mention this branch of ER research, even if briefly, for the more complete representation of the field.

4.5.4 Section summary

To summarize, the focus in this sub-chapter was on the group of studies that rely on subject-centered constructivist strands (i.e., cognitive constructivism, constructionism) and pedagogical approaches associated with authentic education paradigm. I discussed the importance of constructionism, understood as learning through building of artifacts that are shareable, for this branch of ER studies and classroom implementations. In this context, I highlighted the potential of trial and error and exploratory learning. However, I also indicated the limitation of these approaches and the importance of timely guidance from teachers and instructors. To the point of teachers' role, I talked about how constructionism and constructivism can be helpful for teachers' education and in establishing points of connection between a specific robotic application/activity and curriculum objectives in a more ecological, emergent manner. Further, I argued for collaborative activities and personalization as two features of authentic education that are especially prominent in ER. Here, I specified that collaboration in ER can be seen both as an objective (i.e., developing of social skills in learners) and as a pedagogical strategy. However, I also indicated that, while many empirical studies rely on collaborative pedagogical activities to be carried out, few in fact investigate the nature and the dynamics of collaborations and provide evidence based answers in respect to how these are associated with learning outcomes. Finally, I highlighted several ways in which robotic technology can enable personalization (e.g., by allowing learners to express themselves creatively, by affording for targeted adaptations etc.). I also relied on the study by Adolphson (2005) to emphasize the challenge that personalization is associated with when every learner is dependent on a unique combination of human and non-human actors and actants to reach the desired learning outcome.

4.6 Perspectives on social constructivism

As pointed out in 4.3, in contrast to the Piaget-derived constructivism and Papert's constructionism, the influence of social constructivism in the ER literature is less present. Out of the 57 publications in the sample that I reviewed, only 12 specified social constructivist theories in the theory grounding bits; all of these in reference to the works of Lev Vygotksy. Even fewer authors went beyond mere honorary mentioning and attempted to integrate social constructivist concepts in the proposed theoretical approaches to ER and empirical study designs.

The scarcity of social constructivism-inspired research in the ER is understandable given that Vygotsky never formulated a unified pedagogical framework. Rather, as I touched upon in 2.2.1, his focus in the writings that bear the most importance for the field of education was on the formulation of a theory of psychological development where the latter proceeds from interpersonal interactions and actions within a specific socio-cultural environment.

In the context of ER research, I am yet to encounter investigations that are rooted *exclusively* in social constructivism. It has been my observation that the theoretical frameworks discussed in the ER literature integrate Vygotskian concepts such as the zone of proximal development (ZPD), scaffolding and others with the concepts that are derived from Piaget, Papert and/or other approaches (e.g., socio-cognitive conflict, behaviorism, to name a few). I believe that such bricolages of paradigms can be explained by a combination of the following factors: i) Vygotsky-derived concepts are rather blurry: what Vygtosky himself understood under e.g., scaffolding, has changed throughout his life. This is to say that the lack of precision in the original definitions presents a challenge when faced with decisions how to translate these concepts into actionable methodologies (i.e., What exactly are the components of scaffolding? Who/what can provide scaffolding? What constitutes an instance of social interaction? etc.) ii) Methodologically, it is also less challenging to study intrapersonal cognitive processes and the isolated factors that underlie these than interpersonal and socio-cultural factors that define learning iii) Many socio-constructivist concepts are complementary to those derived from Piaget and Papert. That is, as I discussed in 2, subject-centered constructivist strands and social constructivism are not contradictory nor mutually-exclusive. Rather, they approach the phenomenon of learning and development at different, but not exclusive, levels. The complementarity of the two approaches is also recognized by the researchers in the field of ER. For example, Mazzoni and Benvenuti (2015), when presenting a brief account of Vygotsky's theory of development, point out that Piagetian processes of assimilation and accommodation are, among others, responsible for the incorporation of the knowledge structures that emerge in social interactions in the individual cognition. That is, in order to provide a wholesome account of learning and teaching, both intrapersonal and interpersonal dimensions have to be considered. I will speak more to the complementarity of different paradigms when I discuss individual case studies from ER in the coming sections.

In the course of the literature overview, I identified the following three perspectives/strands of ER discourse in respect to socio-constructivist influences:

- **The role of social interactions for learning and development**: Within this branch of social constructivism-inspired research, concepts such as scaffolding, zone of proximal development (ZPD) and more knowledgeable other (MKO) come forth. I will discuss how these concepts are integrated in the current ER research, and the new interpretations/extensions that these concepts receive in the field.

- **Robotic technology as a tool**: In Vygotsky's writings, the concept of technical and psychological tools are commonly reserved for material tools/artifacts and symbolic tools such as language, respectively. These tools are embedded in actions and give rise to the meaning-production processes. Thus, it is through the use of tools, individual, psychological, cultural and historical processes co-emerge and co-create each other (Daniels, 2014). Here I will discuss how in the ER research, robotic technology is conceptualized as an instance of such a tool, and address the conceptual overlap with Papert's notion of objects-to-think-with.

- **Robotic technology as a part of a semiotic system**: finally, we ought to remember that technology is not designed in a semiotic vacuum. From the perspective of social constructivism, how we conceive of and interact with technology, and the narratives we built around it, is mediated by the broader socio-cultural context. To this point, I will discuss examples of the ER research that attempt to tackle this dimension by engaging robotic technology in the explorations of the cultural narratives and values within a given group; or by studying the symbolic and iconic representations users hold about the robotic technology, and how these change with time or depending on the users' background.

I will rely on these three themes to structure the presentation of the main insights gathered in the literature overview in respect to social constructivist influences.

4.6.1 Social interactions: what are they good for?

As discussed in 2, Vygotsky-rooted social constructivism focuses on the role of social interactions for learning and development where learning is understood as preceding development. Daniels (2016) in 'Vygotsky and Pedagogy' speaks to Vygtosky's intent to propose an account of psychological development where humans are seen as 'making themselves from the outside': through acting in the world, we engage with meanings assumed within social activity and are shaped by these meaning while also shaping them in return.

In the definition of educational robotics as a field 4.1.1, I specified that learning with robotics branch is represented by robotic applications that are designed to facilitate learning through some form of social interaction (i.e., social robots). Given the primacy of social interactions and the broader socio-cultural context for the psychological development within the socio-constructivist paradigm, it is not surprising that Vygotsky's name is cited most frequently in the discussions of social robots for education and peer and tutor-based methodologies of learning (Mubin et al., 2013). In this context, concepts such as zone of proximal development and scaffolding - the two concepts proposed by Vygotsky that have had an extensive influence on the educational debates (Daniels, 2016) - are commonly discussed. One of the definitions of the ZPD suggests that it is to be understood as the distance between the actual development level as determined by independent problem solving and the level of potential development through problem solving under guidance of a more knowledgeable other (i.e., an adult or a more capable peer) (Del Rio & Alvarez, 2007). Per Del Rio and Alvarez (2007), the ZPD emphasizes openness of development to various potential trajectories. These trajectories get actualized in learning when the child "awakens" internal developmental processes in interactions with others or with his or her environment.

Zone of proximal development: show me yours I show you mine

An example of an investigation that relies on the concept of the ZPD in the context of ER is an exploratory study by Mazzoni and Benvenuti (2015). As I pointed out in the introduction to this sub-chapter, it has been my observation that, in the context of ER, socio-constructivist concepts are commonly integrated with concepts and approaches from other theories and frameworks to propose more actionable study designs. In this case, the authors rely on the socio-cognitive conflict paradigm to study how a humanoid robot (MecWilly) can act as a partner to preschool children in English learning activity. The study included two experimental conditions: child-child and child-robot. The authors' hypothesis was that social interaction (dialogue) between an artificial agent such as a robot can function as a precursor for cognitive development (i.e., can participate in negotiation of the learner's ZPD) as effectively as dialogue between humans. In this context, the Socio-cognitive conflict paradigm was used to enhance the learning by enabling situations where the child had to negotiate their ideas with the robot in order to arrive to a shared solution. According to the authors, in this scenario, the robot's reaction in the form of verbal feedback is principally based on behavioral mechanisms, while children construct knowledge, in social interaction, by the means of Piagetian assimilation and accommodation processes. The argument that the authors put forth is that, thanks to the fixed patterns of behavior programmed into the robot, the "correct" type of social interaction (i.e., that activates socio-cognitive conflict, where different points of view are presented and negotiated, and leads to the individual intrapersonal knowledge construction processes) in the form of dialogue is promoted. Thus, we see how this study integrates at least three different frameworks: behaviorism, social constructivism, cognitive constructivism, and, in addition to those, socio-cognitive conflict paradigm.

While I consider that the theoretical framework that the authors propose is a convincing example of a successful (i.e. well-reasoned and actionable) integration of the concepts that are derived from different paradigms and that pertain processes at different levels, I am somewhat sceptical in respect to the interpretation of the results of the empirical part of the study. To my point, the authors claim to have demonstrated that socio-cognitive conflict in the child-robot scenario had led to statistically significant improvement in the new words acquisition as compared to the child-child condition. However, I suspect that the improvement might be explained by the factors that were not directly considered within the experimental paradigm such as the effect of the novelty of the robotic technology. It is common for children to be fascinated by robots, and this initial excitement can be the reason for the short-term increase in motivation and engagement when compared to the child-child activity. Additionally, it may be that the robot is perceived as a tutor more than a peer; that is, children may think of it as more authoritative comparing to their peers which can also be associated with improved engagement. The authors themselves specify an additional limitation: namely, the fact that the learning gains observed may have little to do with the robot and the nature of the social interactions between the child and the robot. That is, it might be that a tablet or a virtual agent would correlate with similar learning outcomes. To the latter point, should that be the case, this would speak against the hypothesis postulating the effect of social interactions on learning, at least within the constraints of the given study. However, it does not devalue the appropriateness of the socio-constructivist concepts for the study more broadly: we can still conceptualize the robot (or any other technology) as Vygotskian tool (Daniels, 2007) that, when learners interact with it, provides scaffolding by the means of hints and feedback and thus participates in renegotiation of the learners' ZPD.

To conclude the critical remarks in respect to this study, while an in-depth investigation of the socio-cognitive conflict paradigm is outside the scope of this thesis, I would nevertheless like to raise my concern about the interpretation that this paradigm receives in the empirical study design in question. Specifically, the authors chose to implement the paradigm in the form of verbal feedback provided by the robot in the form of utterances such as "ahh, your suggestion is interesting but are we sure that it is correct? Could there be an alternative or do we think that this is the correct answer?". To me it remains unclear whether such arguably "soft" responses fall within the definition of epistemic conflict that Butera and Darnon (2010) discuss in the paper where they first propose the socio-cognitive conflict paradigm as a pedagogical tool. In other words, I am not fully convinced that utterances such as the ones cited above are sufficient in order to function as communicating a different (from the learner's) point of view.

Maybe far-fetched, but this critical remark speaks to the overall challenge when it comes to the decisions how to translate concepts and paradigms that stem from social sciences (e.g., social psychology) or social and cultural contexts-oriented frameworks such as social constructivism in to empirical designs.

More (or less) knowledgeable other

Another perspective on the importance of social interactions in ER is offered in the debates and studies of the role of teachers, parents and peers. I have already touched upon this topic in 4.5.2. Here, I will return to this conversation through the prism of the socio-constructivist concept of the More Knowledgeable Other (MKO).

As the term suggests, in its classical interpretation, MKO is someone who is understood to possess more knowledge about a particular subject than the learner (Orey, 2010). Within the traditional educational approaches, the role of the MKO is reserved for parents, teachers and more experienced peers. However, in the ER research, the concept is extended to include, alongside humans, robotic agents which are not necessarily more knowledgeable. In fact, frequently quite the contrary takes place. That said, according to some researchers, natural limitations of (social) robots can offer a potential advantage because they can facilitate relational symmetry and experiential learning (Bertel, 2016, p. 19):

> What I have found through my case studies on robot-mediated teaching and learning is, that constructive, creative, innovative and positive things can happen when children encounter robots in their frailty (because they act unexpectedly, make mistakes, fall etc. or because their morphology triggers feelings of sympathy and an urge to care) and that it is just as much the robots inadequacies as it is their abilities - its complementation of childrens spectrum of abilities - that represents the potential of robots in education.

To drive this point home, I would like to refer to the study titled CoWriter Project by the group of researchers supervised by Pierre Dillenbourg and Ana Paiva and first-authored by Alexis Jacq (Jacq, Lemaignan, Garcia, Dillenbourg, & Paiva, 2016). While this study was not originally a part of my core literature - primarily because the authors do not explicitly refer to constructivism nor constructionism, rather they ground they work in learning by teaching paradigm - I decided to include it in the overview as I find it illustrative of several important points I would like to address in the context of this thesis [13]. The study is structured around an activity where children have to help their robotic protégé (NAO robot) to improve handwriting. To elicit a strong protégé effect and enable long-term child-robot interaction, a narrative was created where a robot Clem would send handwritten letters to its friend Mimi who was away on a scientific mission. While Mimi had an excellent handwriting, Clem really struggled with his, hence he needed participants' help to improve. Narrative apart, the team also explored experimental designs and algorithms that would allow for the robot to improve at the right pace to ensure the child's continuous engagement and motivation: the robot had to demonstrate improvement not too fast otherwise the child will not have an opportunity for improving their skills, and not too slow so that the child does not loose trust in their ability to teach the robot. Additionally, the algorithms that work as a function of the child's own handwriting, allowed for the adaptation to the challenges that each individual child had with their handwriting. The data collected suggest that the participants were indeed committed to help the robot, and their belief that they were good enough to teach it helped them to overcome their initial low confidence and improve their handwriting. As I pointed out earlier, the authors do not present their research in constructivist terms. However, despite the absence of direct references, one can certainly feel constructivist influence and how constructivist concepts are implicit in this elegant work. For example, we can speak of personalization in respect to the robot's ability to adapt to individual learners' needs; of scaffolding where the robot functions as a tool and social interaction partner that enables learning; of zone of proximal development in respect to the robot's improvement rate establishing an appropriate distance between the learner's current skills level and the potential improvement they can undergo; last but not least, of more knowledgeable other where, in support to Bertel's argument about robots' limitations as a potential pedagogical advantage, the MKO is extended to include any form of social agent who/which is not necessarily an expert. Last but not least, this study speaks to my argument that subject-centered constructivist and socio-constructivist branches are complementary to each other and that they frequently meet in ER experimental designs.

To emphasize the point that, for successful learning, the social partner does not necessarily have to be more knowledgeable, I would like to refer to another study, this time again from the core literature, by Bers et al. (Bers, New, & Boudreau, 2004). While the authors similarly

[13] Also, because I really like this study.

argue for the potential of non-expert peers in promoting children's learning in ER activities, they shift focus from the discussion of the technology in the role of a peer to the discussion of how other humans can play this role. In the InterAction project, Bers and colleagues investigated family teams working together on robotic projects where the appropriate sequence of steps to follow in order to achieve the shared goals had to be decided upon jointly by the family team members. One of the main conclusions of the study was that both less advanced and more advanced partners progressed primarily as a function of the quality of interpersonal dynamics between the team members. This suggests that the *quality of social interactions* is equally or even more important for the success of collaborative ER activities than the degree of cognitive interdependence.

There are several reasons why I find this study important and useful: i) as the authors themselves suggest, this study yet again speaks to the complementary nature of the cognitive constructivist/constructionist and social constructivist branches ii) it challenges the Piagetian assumption that early childhood education ought to be developmentally appropriate [14] iii) it challenges Vygotsky's notion of the MKO as a necessary precursor for successful scaffolding and, last but not least, iv) in the light of emphasis on the importance of the quality and dynamics of social interactions for successful learning outcomes, it also invites a broader discussion how to ensure that, with the expansion of the educational technology, such quality is sustained.

The who's and what's of scaffolding

Attentive reader must have noticed by now how the concepts of ZPD, MKO and scaffolding are intimately related. While I have provided working definitions to the first two concepts, *scaffolding* up till this point was left undefined. Thus far I used it to connote the support, in the form of didactic materials and/or guidance/social interaction, provided to the learner. Daniels (2016) reviews the existing literature on the topic and summarizes how scaffolding relates to MKO and ZPD as follows:

> The term scaffolding could be taken to infer a one-way process wherein the scaffolder constructs the scaffold alone and presents it for use to the novice. Newman et al. (1989) argued that the ZPD is created through negotiation between the more advanced partner and the learner, rather than through the donation of a scaffold as some kind of prefabricated climbing frame. There is a similar emphasis on negotiation

[14] This aspect is also addressed in Charisi et al. (2015) where the authors discuss current empirical evidence from developmental psychology that suggests that developmental stages are not mapped on to age as a linear progression as originally thought by Piaget. Rather, every child follows their individual trajectory of development.

> in Tharp and Gallimore (1988b) who discussed teaching as assisted performance, in those stages of the ZPD where assistance is required. The key question here seems to be with respect to where the hints, supports, or scaffold come from. Are they produced by the more capable partner or are they negotiated? Vygotsky is unclear on this matter.

As I've touched upon in the preceding segments, in ER scaffolding is often extended to include not only humans or social robots as social interaction partners in ER activities (i.e. support in the form of social interaction), but also material artifacts, including robotic technology, that support the learning process (Chambers, Carbonaro, Rex, & Grove, 2007). To this point, it is not quite clear to me how scaffolding, understood this way, differs from Papert's notion of object-to-think[15] or Vygotskian "tool", other than scaffolding being a broader term that also, as was just specified, involves support in the form of social interaction.

Theoretical musings asides, in the coming segment I will focus on the didactic component of scaffolding in ER activities. To do so, I will discuss the pilot research study by Chambers et al. (2007) where the aim was to investigate the processes of integration of LEGO robotic technology into a mixed grades classroom composed of seven, eight and nine grade students. In this study, multiple methods of data collection were used to investigate how children work on building a robot in groups.

My motivation to talk about this study in more detail is grounded in one important aspect pertaining the pedagogical approach and methods engaged that has not surfaced in the discussion thus far, but which is of crucial importance in the context of constructivist pedagogy. Namely, the adaptability and flexibility of the scaffolding provided. If we go back to the direct citation from Daniels (2016), the distinction is made between scaffolding as fixed and scaffolding as negotiated. In the study, the latter approach was used. Namely, the team noticed that the flowcharts that the students created prior to the programming task did not translate in to the programming task itself. This suggested that the students failed to see the connection between the two tasks. To address this, the team took decision to modify the instructional strategy used: namely, the teacher started to represent the flowcharts horizontally so that they resemble the placement of the icons in the ROBOLAB program code. Such seemingly minor change helped

[15] Mikropoulos and Bellou (2013) refer to ER as "mindtools" but they also postulate it in explicit link with constructionism. Mindtools are defined by Jonassen as computer based learning environments that learners develop or modify in order to engage and facilitate critical thinking and higher order learning (2000). Mindtools act as cognitive amplifiers, intellectual partners, and reorganization tools. It is obvious that mindtools do not follow a technocentric approach; their use is not aimed at technical skills development or computer literacy. Mindtools act in a framework of meaningful learning, fostering reflective thinking, scaffolding thinking.

students to recognize the link between the flowcharts and the programming task. This almost too simple arrangement nevertheless provides additional support to the points made earlier in this thesis. That is, ER activities need to be scaffolded: for the successful learning experience to happen, it does not suffice that the learners are given unconstrained freedom to interact with technology (i.e., trivial understanding of active learning); these interactions should be supported by appropriate guidance, befitting social environment and suitable didactic approach that jointly promote learners' meaning-construction and meta-cognition processes. Further on, the evidence suggests that, at least for more complex tasks, scaffolding - while providing a framework that structures and constrains the learning activity - should also allow for sensitivity to the situated experiences of the learners and appropriate modifications/adaptations to the pedagogic and didactic approaches used.

Section summary

In the preceding sub-sections I discussed how the concepts of zone of proximal development, more knowledgeable other and scaffolding are interpreted in the ER studies. I addressed the proposition that robotic technology can function as a part of scaffolding and participate in the negotiation of the learner's ZPD by the means of: i) serving as a didactic material/mindtool that is a part of the scaffolding ii) by taking part in scaffolding by performing a role of social interaction partner where the latter can be engaged to trigger socio-cognitive conflict that leads to learners' negotiating and evaluating their original ideas, or as an (not-necessarily-more-knowledgeable) other that the learner can take care for and provide help to, as is the case within the learning by teaching paradigm. Whether in the function of a (didactic) tool (reserved typically for robotic kits) or in the role of social other (reserved for social robots), technology in this scenario participates in renegotiation of the learners' ZPD.

Following Daniels (2016), I have also discussed how scaffolding can be understood two-fold: as a fixed frame (i.e., pre-defined hints and didactic arrangements such as was the case in Mazzoni and Benvenuti (2015) or as a open to re-negotiation and adaptation in response to the situated needs of the learners as was the case of Chambers et al. (2007). While I do not wish to argue that one is necessarily better than the other - the appropriateness of each should be defined in respect to the specific learning goals and learning situations - I would like to point out that the latter hits closer to constructivist pedagogy where certain open-endedness and sensitivity to the particularities of a given learning situation is assumed.

Another important aspect in respect to the scaffolding that I would like to re-iterate here is the role of the *quality of social interactions* in contrast to the cognitive inter-dependency that was discussed in relation to the work of Bers et al. (2004). The importance of the dynamics of social interactions for the success of ER collaborative activities adds evidence to the argument I made in 4.5.2 regarding the usefulness of more studies in ER that would investigate the nature and dynamics of social interactions in collaborative group work and help to establish the critical factors associated with successful outcomes. This, in turn, could help teachers and instructors to moderate the ER activities in a more aware manner.

On a more abstracted theoretical level, in the preceding sections I also touched upon the topic of the *complementarity* of the subject-centered constructivist and socio-constructivist approaches for holistic accounts of learning and teaching processes where intrapersonal and interpersonal dimensions enable and co-shape each other.

In the coming segment I will shift the discussion toward technology as a part of a semiotic system. I will explore how robotic technology can be engaged in reflections on the cultural context and accompanying values; and how perceptions and representations of technology are, in turn, shaped by the cultural context and dominant semiotic codes, and how these codes can be renegotiated in interactions with the technology.

4.6.2 Semiotic perspective on educational robotics

To shake the established order a bit, I will begin this section by jumping head first into another case study from the core literature. We have already discussed work by Bers and colleagues in the earlier sections in respect to the quality and dynamics of social interactions as an important factor for the success of collaborative ER activities. Here, I will refer to an earlier study by the same group (Bers & Urrea, 2000). Under the name of Project Con-science, the researchers explored how participants reflected on the shared cultural and historic narratives by the means of personalizing robots. The project took place during the Jewish High Holidays when the community gathers to celebrate the Jewish New Year and the Day of Atonement. Parents and children worked together with Lego Mindstorm bricks, with a task to explore their cultural identity and to provide a context for the conversation about the meaning of values (e.g., value of giving and receiving).

Based on the data collected, the research team proposed to group the projects that the family teams came up with into three groups: 1) Projects where technology was used to represent cultural symbols in a shallow way. For example, the Lego bricks were used to recreate typical Jewish symbols without deeper exploration of the underlying values behind these symbols 2) Projects where technology was used to represent values 3) Projects where technology was used to evoke reflection and conversation. In other words, were the values were treated in a more elaborate way that sparked discussion.

Noticeably, the authors themselves ground their research in constructionism. While the element of designing and manipulating a physical object to be shared with the community is undeniably present in this study, my reason to discuss it here extends beyond that. Namely, using this project as an illustration that provides a glimpse of what *can be*, my intention is to make an argument for the potential (and importance?) of robotic activities as a way to explore and reflect on the topics beyond robotics and STEM subjects. In that, I would like to highlight another dimension that was discussed in 3.4 but that was not addressed in the discussion in this chapter thus far. Namely, the role of education in the formation of learners not only as individuals who possess certain conceptual knowledge and skills, but also as community members and citizens that share values, beliefs and cultural codes.

Robotic technology as signifier

So far, our focus has been predominantly on the aspects associated with how robotic technology is conceptualized and used in teaching and learning settings. However, robotic technology, as any other cultural artifact, also functions as a part of a semiotic system. In this segment, I will discuss how physical manifestations and roles ascribed to robotic technology, and the expectations we hold of it, are shaped in interactions between designers, researchers, users, policy makers and other stakeholders (De Graaf, Allouch, & Klamer, 2015) as well as mediated by the broader cultural environment.

One way to approach this complex discussion is through the studies of acceptability of robots and users' experiences of interactions that shape existing designs and usage protocols. Per Boczkowski (1999), in this manner, technology and users co-shape each other in a recursive manner:

> what the study of technology-in-use has ultimately shown is that technological and social elements recursively influence each other, thus becoming explanans (the circumstances that are believed to explain the event or pattern) and explanandum (the event or pattern to be explained) at different periods in the unfolding of their relationships.

This suggests that, within the socio-cultural perspective, the material and social elements related to robotic technologies are not independent of the context surrounding the processes of their design and implementation; to the contrary, these elements appear, sustain and decay as a result of situated processes of cultural construction. This also implies that what technology, for example, a robot, means is not fixed for all times and all stakeholder groups.

To illustrate this proposition, I invite the readers to consider a study by Obaid, Barendregt, Alves-Oliveira, Paiva, and Fjeld (2015) investigating how the design of educational robots as proposed by children compares against designs proposed by a group of interaction designers. The research questions that underlie this investigation were: 1) How do children's designs differ from those from adult interaction designers? 2) How are children's designs influenced by their current knowledge or robotics? To explore these, the authors relied on the creative drawing approach and moderated discussions. The 53 participants of the study were divided into 11 groups: 5 groups of interaction designers, 3 groups of children with robotics knowledge and 3 groups of children without prior formal robotics education. The data collected revealed, as predicted, that the designs proposed incorporated a range of assumptions about the role of a robotic tutor (i.e., how it should look, how much authority it is to have, its personality features etc.) that different groups hold, and that these assumptions vary significantly. While the children with no prior experiences with robots proposed designs that resembled in appearance human teachers who were clearly gendered, the designers envisioned robotic tutors more like a small or child-sized non-gendered animals or cartoon-like robots, with no clear gender attributes nor representations (i.e., color solution) that would connote gender. In turn, children with prior experience in robotics drew more machine-like looking robots which suggested increased awareness that a robot is a machine in contrast to a social agent. Additionally, they applied what they had learned about the challenges of robotic movement when designing the robots' actuators.

What are some broader conclusions that we can draw from the study? First and foremost, when designing ER activities, especially those involving social robots and some form of interaction with these robots, we should consider the expectations that the users hold in respect to what such robots can and cannot do. Specifically, some time should be allowed for the users to explore the robots in order to match the expectations the users currently hold to what a robot can realistically deliver. Additionally, it opens the discussion about how sensitive we should be to the representations that users hold about robotic technologies when working on the designs and implementation scenarios of such robots? In other words, to what extent should we rely on the current knowledge and representation structures that the stakeholders hold and/or how far can we break from these? Also, we should remember that learners are not the only ones whose expectations are concerned. ER solutions and application scenarios should consider teachers and their expectations, (false and true) assumptions and expectations in respect to robotic technology. Unfortunately, it is outside the scope of this thesis to address these topics in more detail. As a starting point, I recommend the readers consult the study by Reich-Stiebert and Eyssel

(2016).

Directions for future research

The readers will have noticed that this subsection boats much less case studies comparing to the discussion prior to that. The reason for this is simple: studies that would consider broader socio-cultural perspective in ER are yet scarce. Given the volume constraints and general orientation of the thesis, I will not speculate why that might be the case nor present critical remarks to the few case studies I used as illustrative examples. Instead, to conclude the sub-chapter on the influence of social constructivism for ER, I will sketch out a number of questions that I find relevant for the future studies:

- **21st century critical values**: While abundant number of studies in ER specify skills that are considered important in the 21st century (e.g., problem-solving, collaboration etc.) and that ER technology can help to enable, none of these studies (at least none among those that I read) addresses the topic of which *values* should be considered as important, who decides on these, and how they are already implicitly or explicitly integrated in the existing technology, technology that is yet to be developed, and accompanying educational activities. I recognize that this conversation may be more pertinent for the fields of philosophy of education, philosophy of technology, gender studies and robot ethics. However, it is also my belief that reflections on what technology can do, from the technical and didactic point of view, and what it *ought to do*, from the ethical, societal, and, if you wish, existential point of view, should not exist in complete isolation from each other, especially when it comes to educating children for the future unknown.

- **Taking authentic learning to the next level**: I have discussed how technology can enable authentic (i.e., relevant for an individual, their needs, abilities, and interests) learning. However, current social and political debates, coupled with novel approaches to education such as complexity science inspired (Davis et al., 2015), suggest we should go further than that and consider how authentic learning can be contextualized by the challenges that exist on societal and planetary level. To extent, such projects already exist in ER. For example, see C. Campbell, Boden, Dole, and Viller (2013) where elementary school students were invited to use Lego bricks to work on the Lego green city in the context of the study of sustainability. However, I believe we are yet to have more informed conversation on how authentic learning and individual meaning-making processes are to be integrated within the larger societal perspective and local and global community needs.

- **Diversifying ER** Another dimension that I believe is yet to be explored in ER is related to the fact that, as pointed out by González et al. (2010), existing technological solutions were designed in and for the use within developed economies [16]. While Gonzalez and colleagues, in their research, focus on the economic underpinning of it and work on providing cheaper solutions for developing economies, it is my believe that we ought to think about the diversity not only in the sense of economic affordability, but also from the perspective of cultural diversity. That is, more future studies should address the topic of contextualizing ER technologies for different cultural contexts as well as strive for the integration of diverse groups in the process of the design and development of robotic applications and their use scenarios.

4.7 A few words on grounded cognition approaches in educational robotics

Finally, to conclude my overview of the main trends in ER in respect to constructivism and its interpretations, in this sub-chapter I will direct the conversation back to the intrapersonal level and discuss how ER was affected by the grounded cognition theories. Before I proceed, I would like to re-iterate the point made earlier in 2.2.3 that to date no agreement exist regarding whether embodied and enacted cognition frameworks are to be considered as derivations of constructivism or as independent paradigms. The resolution of this debate is certainly not my intention here. Instead, my choice to include these approaches - regardless and in spite of their conceptual status - in the discussion is simple: the abundance of cognitive science research that supports the position that body and sensory-motor action is implicated in learning. Coupled with the proposition that ER activities are often, by definition, action- and activity oriented, to omit this topic in my overview would mean to neglect an important and significant bulk of ER-related research. That said, in this sub-chapter my objective is to illustrate how the role of sensory-motor activity is highlighted in the domain of ER. It has been my observation that in ER, the distinction between embodied and enacted cognition frameworks is blurred. I will proceed to discuss examples in reliance with the theoretical framework as authors themselves present it, and abstain from discussing conceptual differences, contradictions and overlaps in

[16]Similar point is also made by Winograd and Flores (1986) cited in (Catlin & Blamires, 2010). Specifically, authors argue that current ER applications are rooted in Western rationalistic tradition. To this point, I would like to add that, on the cognitive level, how we learn most likely is rooted in some general processes that are non (little) dependant on culture. However, the narratives we construct around learning and the problems we tackle are certainly culture-dependent.

respect to the theories of embodied cognition and enactivism. The first part of the sub-chapter will focus on the studies that explore the role of the body and body action from the perspective of the learners. The chapter with some remarks about the embodied component in teaching.

4.7.1 Body in learning

To briefly re-iterate what I outlined in 2.2.3, the theories of embodied and enactive cognition posit the biological foundation of knowledge (William, 2005). These theories have had a considerable impact on the field of education (Horn & Wilburn, 2005), also in relation to the technology-assisted learning (Bopry, 1999) and research in human-robot interaction (Dautenhahn, Ogden, & Quick, 2002; Sandini, Metta, & Vernon, 2007).

In my work, I see these theories as complimentary to that of constructionism. This complementary is implicitly suggested by Papert himself in the introduction to Mindstorms:

> [...] I could use my body to think about the gears. I could feel how gears turn by imagining by body turning. This made it possible for me to draw on my "body knowledge" to think about gear systems (Papert, 1980, p. 11).

As this citation suggests, we can extend the notion of object-to-think with to include not only technology (e.g., computer, robotic kits etc.) but learners' bodies. This idea finds support in Adolphson (2005): according to him, from an enactivist perspective, when participating in an ER activity, learners' negotiate meaning through action or doing. In this, they refer individual components of the robot to their own body functions and experiences which enables them to decompose the task in to the steps necessary to program the robot. This *coming to understand via body* is what allows Adolphson to talk about learners using their bodies in analogy with Papertian objects to think with.

It is important to point out that the divide between higher-order conceptual learning and learning as grounded in sensory-motor actions is not as strict as the theories of embodied and enacted cognition, in their original interpretations, might suggest. Empirical evidence for the blurred divide between the two kinds of knowledge also comes from the studies in ER. For example, in Francis, Khan, and Davis (2016), the researchers deploy video-observations to study learners, aged 9-10, who engage in spatial reasoning as they learn to program LEGO Mindstorms EV3 robots. The authors ground their approach in the Bruner's typology of enactive-iconic-symbolic representations. According to Bruner, the three types of representations develop sequentially. However, observing the children interacting with the technology allowed to conclude that these representations are in fact engaged simultaneously: the participants displayed subtle bodily actions as they went through on-screen iconic and symbolic manipulations. This agrees with cognitive science research that shows that many phenomena that were previously thought as purely symbolic, on the level of neural activity, also engage perceptual and sensory-motor circuits (Barsalou, 2010).

Based on these observation, the authors suggest that not only the divide between symbolic and embodied representations and knowledge may not be as clear-cut, but it also has important implications for how we think about educational settings. That is, subtle movements, such as fidgeting, are normally either dismissed or, in traditional educational institutions, even penalized. However, the persistence and the consistency of these movements throughout the data raises questions in respect to the common requirement for children to sit still during classes. This observation also speaks to the overall potential of ER activities for learning because they do not stigmatize bodily actions that, in the contexts of more traditional instructions-based learning, could be deemed as distracting or irrelevant.

Another example of how embodied and enacted cognition approaches are manifested in ER comes from Mitnik, Recabarren, Nussbaum, and Soto (2009). This study was aimed at exploring how a robotic activity can help students to improve construction and interpretation skills of graphs that represent kinematic concepts in physics such as position, velocity and acceleration. The activity was carried out by means of an interconnected robot and a set of handhelds. According to the data collected, the robotic activity led to a significant increase in graph interpreting skills as compared to the computer-simulated activity.

Let us return to Adolphson who might be helpful in providing explanation for the success of robotic activities in comparison to the computer-simulated. According to him, embodied activities hold tremendous potential as they allow to explore concepts in meso space as opposed to traditional approaches where the focus is primarily on the micro space (i.e., the level of interactions that can be affected without much moving such as book/notebook, desk or computer). Moves within meso, understood as an intermediate space that allows for interactions through choices of position, and macro space (implies areas where information can only be obtained through successive moves), allows the users to embody relationships between distance, velocity, time, proportions and others that form the core of STEM subjects.

This section presented only a marginal fraction of all research on the relation between conceptual learning and embodied activities in ER. However, I hope that these examples allowed to shed light on the importance of this topic for the field.

4.7.2 Body in teaching

In 3 I defined pedagogy as a broader umbrella term that encompasses teaching and learning. In prior sections I also discussed the importance of teachers' support and guidance, as a form of scaffolding, for the success of ER activities. Here I would like to specify, however briefly, another dimension that needs to be considered in respect to teaching and the influence it takes on the learners. Namely, the role of bodily modality (e.g., gestures, gaze control, non-verbal signalling of concepts and emotional states etc.) for teaching. In this regard, I propose to divide existing research in ER into three broader categories: i) studies that focus on how the non-verbal components outlined above affect learning. These are especially prominent when it comes to learning with robotics, where non-verbal communication should be considered in the design of social robots as tutors or peers. ii) Studies that compare virtual representations of a tutor character with robotic embodiment with reference to social presence, learning gains, learners' enjoyment etc e.g., (A. Jones, Castellano, & Bull, 2014). iii) Studies that investigate the haptic dimension (e.g., touch) in social human-robot interactions e.g. (Tanaka et al., 2015).

Though important for the ER, these studies are commonly narrowly-focused and are not conceptually associated with constructivism. That is, I will not review them in this thesis.

This segment concludes my overview of the ER in respect to constructivism as an epistemic and pedagogical framework. I will present the overall summary of the chapter and my suggestions for the future studies in ER in the coming chapter.

Chapter 5

Constructivism in Educational Robotics: Summary and Discussion

5.1 Interpretations of constructivism in educational robotics

5.1.1 Summarizing main insights

In the second chapter of the thesis I spoke about constructivism incorporating at least six different branches: radical constructivism, cognitive constructivism, second-order cybernetics, enactivism and embodied cognition, social constructivism and operational constructivism. I argued that, among the six branches, radical constructivism, cognitive constructivism and the theories of embodied and enacted cognition, have had the most significant impact on the educational philosophy and teaching and learning sciences. Respect for individual learner's history and the general orientation toward nurturing of individual potential within Authentic Education paradigm can be traced back to radical and cognitive constructivism frameworks with their focus on the intrapersonal knowledge-construing processes as grounded in prior experiences and existing knowledge scheme of the learner. With this paradigmatic shift, the learner's body is no longer seen as an obstacle on the way toward some sort of external objective knowledge. Following enactivist and embodied cognition turn in cognitive sciences, in authentic education, learning is now recognized not as driven exclusively by higher-order cognitive processes that are accessible for linguistic articulation, but also as an embodied activity that relies on sensory-motor action.

Social constructivism comes to the fore in Democratic citizen education paradigm where the role of educators shifts from unraveling individual potential toward helping learners to develop also as personalities and as citizens. Learners are now recast as a part of the collective that is classroom and their local and global community. By interacting and co-depending on the relationships with other humans, learners develop recognition of the partiality of their worldview. Learning, from this perspective, is seen as a fundamentally social process where knowledge networks are no longer confined to cognitive processes within individual minds, but are historically, culturally and politically shaped.

The results of my critical overview of educational robotics literature suggest that, in this field, constructivist influences further narrow down and are rooted primarily in Piaget-derived cognitive constructivism and its spin-off - constructionism - that was put forth by Seymour Papert. Papert was also largely responsible for the foundation of the field of educational robotics as such.

In 2 I discussed how constructivism as a framework of philosophy can be interpreted at different levels: as a pragmatic orientation, as an epistemological orientation and, finally, as a metaphysical orientation. No agreement exists in respect to which of these levels are of relevance for education: while some authors, myself included, posit that conversations about education should embrace at least two of these (practical and epistemological) dimensions, others insist that constructivism is only of use to education if understood narrowly in relation to the cognitive processes that underpin learning. Regardless of whose side the truth is on in these debates (or, to remain true to constructivist spirit, whose position will prove to be more viable), when casting an eye at the field of ER at large, one thing can be said with confidence: the transition from the level of theory and reflection to the level of (educational) praxis is indeed accompanied by weakening of the radicalness of the constructivist argument (Terhart, 2003). If we look at the educational robotics publications, we'll notice that authors, willingly or inadvertently, commonly choose to structure their work around cognitive constructivism and constructionism as pertaining individual learning, rather than discuss more "fuzzy" aspects associated with cultural and social environment or, what's even more complicated, questions regarding what are we to teach, to whom and why, or, god forbid, how any of it relates to the ontological status of reality.

Given that the roots of the field are so intimately associated with subject-centered constructivist movement, it is not surprising that constructivism and constructionism in ER research are commonly used to anticipate the research proposals and to argue for the inclusion of ER activities in intra- and extra-curricular studies. Following though not uncontested but yet considerable, success of constructivist pedagogy in modern education, constructivism in ER functions as a stand-in for authentic, learner-centered and future skills-oriented educational praxis where the latter is made so by the very virtue of robotic technology affording for hands-on operations by users. While such connotations are not necessarily wrong or untrue, the ubiquitous usage of the term 'constructivism' in ER publications has lead, in my opinion, to the semantic devaluation of this concept. That is, in many publications constructivism is reduced to any instance of hands-on learning (while other important human and non-human factors that also support constructivist pedagogy are disregarded); and it remains unclear what referring to constructivism de facto adds to the research that the authors of these studies conduct.

Fortunately, proportionally large number of research in ER goes beyond such "casual", simplified interpretation of constructivism. In 4.5 I discussed studies that can be considered as genuinely informed by radical and cognitive constructivism and constructionism and engage ideas such as trial and error learning, exploratory learning, personalization, collaboration and others - all notions that are common within authentic education - either as pedagogical strategies and/or as objects for the investigation (e.g., how pedagogical strategy such as group work contributes to learning outcomes). While not entirely contradictions- and challenges-free, these studies nevertheless attempt at providing grounded definitions to constructivist jargon used and strive to follow through in empirical designs.

While the ontological/metaphysical orientation in ER is missing entirely (most likely, for good reasons), though fewer in numbers, there are nevertheless studies that take more social constructivist-direction and touch upon the role of technology not only as an epistemic tool or object-to-think-with, but also as a signifier that can function in a network of other signifiers to connote certain values, established cultural narratives and dominant cultural codes. As such, it can be used both as a means to reflect upon these values, narratives and codes, or to construe/shape new ones in instances of interactions between the users and technology. However, studies that touch upon these topics are scarce [1].

That said, strong social constructivist influence is also traced in ER studies that address the role of social interactions in and for learning. As I discussed in 4.6, it is manifested in the following ways: i) in the studies that rely on the Vygotskian concepts of scaffolding, zone of proximal development and more knowledgeable other to explore whether and how robotic technology (e.g., social robots) can take on the role of providing social scaffolding for the learner and participate in the negotiation of their zone of proximal development. Here, arguments for the modification of the concept of MKO are made. According to the existing evidence, for successful learning, it does not necessitate that the interaction partner is necessarily more knowledgeable or skilled than the learner. To the contrary, the intrinsic limitations of existing robotic devices

[1] Here, I also leave room for the possibility that it might be that my selection criteria resulted in the pool of literature that is generally oriented toward cognitive constructivism and constructionism. It might be that these debates are more prominent in the field of philosophy of technology, ethics and cultural studies and not so much in ER.

may present a pedagogical advantage as they allow to establish the effect when the learners feel compelled and intrinsically motivated to "help" the robots to improve and by doing that they improve their own skills.

I was left with the impression that the conversations and studies oriented toward the role of robotic technology as a social partner further blur the divide between subject-centered and social constructivism. That is, while these studies rely on social constructivist terminology for the conceptualization of empirical designs and findings, they commonly integrate concepts and processes that are derived from cognitive constructivism, such as cognitive conflict, accommodation/assimilation, and others. In addition, the general orientation in these studies is still toward enabling individual learners' potential and growth. In other words, social constructivist concepts in ER seem to be integrated within authentic learning paradigm. The conversations about ways in which robotic technology can be engaged in shaping learners also as persons and citizen (i.e., how technology can contribute to the formation of learners' belief and value systems in a more directed way) are yet to be had. At least, within my literature pool - even though there are studies that address the topic of values such as, for example, by Bers and Urrea (2000) - I have not come across projects where social robots would be used in the role of a social dialogue partner for the purpose of engaging learners in the conversation about shared values and believes. I assume that this gap in research can be largely attributed to the state of the art of the technology. Simply put, it might be that robots are yet not "smart" enough for this type of complex interaction scenarios. Whether they necessarily *should* be engaged for this purpose is open for a debate.

One exception to the observation that educational robotics is rarely engaged in the broader conversations about the values and the future we are to strive for are projects where the learning task itself is conceptualized not in terms of the individual learners' preferences or interests, or curricular concepts, but in terms of the local and global needs of the community. For instance, educational robotics activities where participants are invited to build a smart city out of LEGO bricks or to explore robotics-driven green energy solutions etc. In these projects, robotic technology is used again as a tool to explore certain topic (learning by robotics) rather than a social dialogue partner.

Last but not least, in respect to social constructivist interpretations, in ER the conversations about the role of social interaction in learning settings are also had from the perspective of how other humans (classroom peers, teachers, parents) mediate educational robotics activities. This is the point where the divide between subject-centered constructivist and social constructivist frameworks is the hardest to draw. In 3 I spoke about Perkins' criticism in respect to the terminological confusion where one and the same activity, such as group work, can be conceptualized as cognitive-constructivist (i.e., interacting with others as triggering cognitive conflict and subsequent processes of accommodation or assimilation) or as social-constructivist (i.e., interactions with others provide necessary scaffolding and allow one to jointly participate in the creation of shared meaning-structures). ER is certainly not immune to this ”terminological confusion disease”: indeed, as I discussed in 4, collaborative activities and group work in ER are more frequently than not associated with constructionism and overall authentic education stance. However rarely, they are also spoken of and studied through the prism of social constructivist terms. That is, not from the point of view of how social interactions affect cognitive processes within an individual mind but how, for example, the dynamics and nature of social interactions in the group allows for the successful project completion more so than the cognitive inter-dependence by the team members.

I must admit that, in spite of (maybe even because of?) all the literature I studied in the course of my research, I myself remain somewhat confused when it comes to deciding what constitutes a social constructivist interpretation when applied to many collaborative interaction scenarios where educational robotics is involved. On the one hand, this again speaks more not to my negligence but rather to the overall challenge of transitioning from the level of theory to the level of application. Vygotsky himself never clearly postulated what should be considered as a unit of social interaction, or what exactly scaffolding means, or how exactly teachers are to help to renegotiate learners' ZPD. That said, contrary to Perkins' critical stance toward terminological confusion, I choose to remain optimistic more than critical or frustrated. I believe that it might be that such confusion can in fact be interpreted positively as an argument for the integration of subject-centered and social-constructivist frameworks and for the bridging of the artificial divide between individual and social. I am quite confident that in real life interactions, individual and social are co-emergent and co-determined. And - instead of insisting on artificially dividing them - we should seek conceptual frameworks and empirical methodologies that allow for integration of individual and social dimensions in a manner that is respectful to the complexity of the real world interactions but is also empirically consistent and sound. I will speak more to this in the coming paragraphs.

Getting back to the (relative) safety and coziness of the authentic education paradigm, while the recognition of the embodied component in learning within this paradigm goes hand in hand with the overall radical and cognitive constructivist orientation (Davis et al., 2015), it has been my observation that in educational robotics, research that is grounded in embodied and enacted cognition frameworks stands separately from the rest of the constructivism-inspired literature.

I discussed why it might be so elsewhere in the thesis. Here I would like to re-iterate two points: i) though some authors differentiate between embodied and enacted cognition frameworks in theory, I was left with the impression that, in empirical designs, the two frameworks collapse into each other. At least based on the literature that I read, it would be hard for me to clearly identify what in ER research belongs under embodied cognition framework and what belongs under enacted cognition framework ii) these two frameworks in ER commonly stand for the general orientation toward the study of the role that sensory-motor action plays in tackling tasks and concepts during educational robotic activities. Following Begg (1999), I would say that such orientation is rather enactivist in that it investigates, in contrast to learning *from* action [2], learning *in* action. Namely, if in constructionist approaches the emphasis is on the learners building a tangible artifact and, in the process, building new knowledge structures, in enactivism-grounded studies in ER, the researchers focus on the details of sensory-motor activity of the learners as underpinning higher-order cognitive processes. If we remember, in (Francis et al., 2016), Francis and colleagues found that enactive, iconic and symbolic representations are engaged not sequentially but simultaneously.

Unfortunately, given that my principle interest was on studying ER literature where direct references to constructivism and constructionism are made, embodied and enacted cognition research are represented in my thesis only marginally. I am certain that the literature on the topic is vast, and there are more dimensions to it that I could ever touch upon here. However, I'd like to hope that the few publications that I did discuss have proved useful to make the case that educational robotic activities can indeed enable - if not active - but more *enactive* learning. Contrary to more traditional instructional approaches where learners are expected to sit still and listen to the teacher, educational robotics activities invite learners to move around and engage their bodies in less restricted manner. However, as I also specified elsewhere in the thesis, we are yet to evaluate how such enactive learning compares with more traditional instructional approaches in respect to meeting the established learning intentions (Catlin, 2016).

5.1.2 Call me by... any name

Finally, to conclude the presentation of the overall results of my literature survey, I would like to touch upon one more insight I had when studying the literature. Namely, I noticed that, in addition to the studies that refer to constructivism but have little to do with constructivism (what I referred to as "casual constructivism"), the field is also represented by publications that

[2] Begg equates this with embodied cognition approaches when I see it rather as a constructionist proposition. Again, this speaks not to one of us being wrong but to the challenge to distinguish between different frameworks: we can conceptualize the same activity from different theoretical perspectives)

do not rely on constructivist pedagogy but that can, nevertheless, be said to be constructivist in spirit and in principles. In 4.6.1 I discussed Jacq et al. (2016) as an example of such studies.

Some might suggest that this trend speaks in favor of the contra-constructivist critique positing that constructivism has not offered educational sciences anything new that expert educators wouldn't know all along. In the context of ER, this critique can be paraphrased as: one does not need to engage in constructivist parlance to conduct excellent empirical investigations of teaching and learning processes. My personal position on this is not as radical. To me it seems inaccurate to proclaim constructivism redundant. To the contrary - while I believe that, knowing what we know today, it is indeed possible to move past constructivism in empirical studies of teaching and learning - constructivism as a movement, or as a paradigmatic shift in the way we conceive learning and knowing, was necessary to lay the foundation, first of all, for the work of Papert that gave birth to the field of ER, and, as a consequence, for the research we conduct today. I believe that it is largely due to the constructivist wave in the 70s and 80s that today we come into the field of ER with almost ubiquitous understanding of knowledge as not objective an pre-given but as construed, personally or inter-personally. Given this shared foundation, we can now skim constructivist concepts and (false) dualisms and propose new theories that would be informed, on the one hand, by the novel theoretical approaches such as complexity science and, on the other hand, by what we learn from observing and studying real-world interactions between the users and robotic technology.

Also, we should not forget that our relationship with technology is not one-sided: not only we come into the classrooms with some ideas about pedagogy and didactics in respect to how we can apply robotic technology for our purposes. Our pedagogical approaches and the manner we think about education is in turn shaped by what we learn by interacting and watching others interact with technology. In other words, as Bers et al. (2002) suggest, technology offers us space to reflect back on educational praxis: on how we understand knowledge creation, what are the appropriate ways to assess learners' development, how to best tie curricular objectives with ER practices etc.

If asked today, at the final stages of this laborious and at times frustrating process of working on this thesis, *what is* the value of constructivism for educational robotics, my answer would be as follows: I believe that this value is primarily in making what's implicit and intuitive in "good teaching" and "efficient learning" explicit. I believe that - despite all the contradictions, dualisms, terminological confusions - by articulating and attempting to investigate empirically processes at different levels, constructivism is useful in that it helps educators and researchers to approach their work in an informed manner and to remain aware in respect to the range of possible strategies they can take when addressing different learners in different classrooms and with different educational aims.

This concludes the broader discussion of the results of my critical survey of the constructivism-related literature in educational robotics domain. This chapter will conclude with some suggestions for the future empirical studies and my intuitions regarding the future of the field.

5.2 Suggestions for future studies

Instead of re-iterating through the critical points I discussed in Chapter 4, here I will present my observations in a more positive manner as suggestions for the future studies. These suggestions will be broken into three groups: i) suggestions in respect to the concepts use and theory grounding ii) suggestions regarding methodological approach iii) suggestion in respect to pedagogy (i.e., scaffolding of educational robotics activities). Notice that all of these suggestions are given with constructivist perspective in mind; some of these suggestions can be, but not necessarily are, valid for the studies in the field that do not assume constructivist orientation.

5.2.1 Theory grounding and concepts use

Avoid taking constructivism as a term in vain: before introducing constructivism and/or constructionism in the theory-grounding sections, my recommendation to the authors is to think through how exactly their proposed theoretical framework or empirical study integrates constructivist concepts, or what are the constructivist pedagogical moments in their design of an educational activity. If the answer converges only to inviting the learners to build and/or program a robotic artifact, while other human and non-human factors that are correlated with the process of such building are not considered or bracketed out as irrelevant, I would recommend against conceptualizing it as constructivist learning. Alternatively, if the objective of the publication does not pertain teaching and learning processes (for example, when the main goal is to describe technological features of a robotic application), one can specify that they operate within constructivist framework but do not address associated aspects in the current paper. An example for this approach is Arlegui, Menegatti, Moro, and Pina (2008).

Define your constructivism: considering that constructivism, as I discussed extensively in this thesis, is not a unified framework, it is important to remain aware as to which constructivist strand and associated concepts are of relevance for the work that the authors conduct. Here, I would recommend against the use of formulations and wordings that may suggest that the kind of constructivism practiced by the authors *is THE* constructivism. Instead, simple formulations such as "In this work, we abide by the following definition of constructivism..." should already be helpful in order to prevent further terminological confusion.

Dealing with ambivalent concepts: I discussed that constructivism poses several challenges when transitioning from the level of theory to practice, be it in the form of pedagogical activity or an empirical study. Primarily, the reason is twofold: i) many constructivist terms, such as ZPD or scaffolding, are lacking precise definitions ii) no agreed upon rule-book or user manual exists in respect to how we are ought to approach constructivism-inspired pedagogical moments such as, for example, "dialogic learning" or "conscientization". Every teacher will interpret it differently depending on a number of factors. This ambivalence needn't necessarily be detrimental. However, I believe that, for the purpose of consistency and transparency, it is important for the researcher to specify what they mean by the constructivist terms that are open to multiple interpretations, such collaboration, personalization, scaffolding etc.

Clearly postulate the learning intentions behind an ER activity and how you intend to evaluate whether these intentions were met. Given that the evidence of the usefulness of ER activities, also in how they compare to more traditional approaches, is still lacking, it is important for the authors to define not only the structure of an ER activity and the features of the technology they are to use, but also what are the learning objectives or, in the words of Catlin (2016), *intentions* this activity is intended to meet, and how this is to be assessed or evaluated.

5.2.2 Topics of research and methodology

Extensive documentation: As I discussed on a number of examples, the success of educational robotics activities depends on a range of human and non-human factors. To date, the empirical data on these are scare. This is why, irrespective of the target of the study, I believe it is useful to collect and document not only quantitative data but observations and shared experiences of teachers and learners when interacting with the technology. This should assist in the identification of the challenges that teachers and learners have, as well as the critical moments where more scaffolding might be necessary.

Hypotheses generation based on the observations from the field: in connection to the point discussed above, I believe it is important to allow for the generation of hypotheses based on the close observations and detailed documentation of ER learning activities.

Evaluation of educational robotics activities against other approaches: Much has been said here and elsewhere about the need for further empirical studies that would provide evidence for the success of educational robotics activities. Not only that, but I believe we also need more studies that would evaluate educational robotics activities against more traditional instructional approaches, or against other technology-based learning scenarios. That is, it does not suffice to establish that learners concept-knowledge or social skills improve as a result of participating in an educational robotics activity. Additionally, we are to gather more evidence how the learning outcomes and users' experiences compare to that of the control group where different type of educational activity was used (for example, where learners watched and discussed a film, or if they were read a lecture).

Mapping different teaching/learning strategies of structuring ER activities to desired learning outcomes and competencies: similarly, more data are needed to determine which type of learning approach is more appropriate for which type of task or skill we want learners to improve. Denis and Hubert (2001) offer a useful schema to differentiate between different kinds of teaching/learning approaches to match these with specific learning intentions and competencies we want to develop in learners: creation, exploration, practice, imitation, reception, experimentation. Each of these is more suitable for developing different competencies, e.g., creation is more fit for dynamic competencies and not so much for the specific (domain-related) competencies. I discussed this in 4.5 on the example of the RoboMusicKids project (Bærendsen et al., 2009), where creation and exploration were engaged for the learners to have their first-time experience of composing a musical piece. More studies that would provide evidence for the appropriate mapping of strategies and learning intentions are necessary.

More data on the affective component of teaching and learning in ER: while in broader conversations about education and teaching and learning, epistemic and social emotions have been recognized as instrumental for learning (Schutz, Pekrun, & Phye, 2007), in educational robotics studies touching upon this topic are relatively scarce. Commonly, the affective component in these studies is interpreted through learners' motivation where the latter is typically measured by questionnaires. I believe, more studies targeting emotional dynamics in educational robotics activity can be useful for the more thorough and accurate understanding of how users engage with technology in learning.

Further socio-cultural orientation and diversification: in 4.6 I discussed how studies that would be situated within the democratic citizen education paradigm are scarce. Even when social constructivist concepts are introduced, the general orientation is still predominantly on the individual learner and on supporting the development of concepts knowledge and skills such as problem-solving, collaboration, computational thinking etc, while the normative and cultural development is rarely addressed explicitly. We are yet to propose conceptual and methodological frameworks that would allow for more targeted exploration of the latter dimension. As examples of the two directions that can be further discussed and investigated are: i) culturally-embedded diversification of robotic technologies: what does it mean? How can it look in practice? ii) Technologies as assisting learners' development as persons and citizens: should we and, if yes, how should we use robotic technology for this purpose?

5.2.3 Pedagogy

Flexible scaffolding: In 4.6 I discussed how scaffolding can be understood as fixed or as open to negotiation and modification. While I understand that, for the purpose of empirical studies, it can be important to have the type of social and didactic support provided to the learners fixed, from the pedagogical perspective, it is valuable to remain sensitive to the ongoing dynamics of learning and to be willing to change the strategy in response to manifested needs of the learners and the challenges that they face.

Seek to integrate stakeholders in the decisions regarding how ER activities are to be tied into the curricular objectives. To this point, I discussed how constructionism and the idea of teachers as learners can be useful to empower teachers and to allow for the identification of organic ways how educational robotics activities can be connected to the learning objectives.

Chapter 6

Conclusions

Constructivism is a term used extensively in social sciences, cognitive science and philosophy and it is applied to a wide range of topics, including metaphysical status of reality, epistemology, cognitive processes underlying learning and development, and others. Many of these topics are of direct relevance for educational philosophy and teaching and learning sciences.

Constructivism-inspired conversations in education have evolved around the core constructivist proposition that learning relies on interpretative structures, prior history, situatedness and the overall active role of cognizing agents in construing knowledge. Meanwhile - depending on whether positioned within cognitive constructivism, radical constructivism, social constructivism, theories of embodied and enacted cognition or other constructivist strands - authors disagree on a number of issues, among which are: whether learning originates from within the structures of the individual mind, or from within the social domain that the mind operates in; whether knowledge is necessarily reliant on higher-order cognitive processes, or it can also be represented in sensory-motor and perceptual circuits, and others.

When it comes to the evaluation of the overall usefulness of constructivism for educational sciences, similarly, positions vary from enthusiastic to extremely pessimistic. As example to the latter, authors like Terhart (2003) posit that constructivism is nothing but a fluke and that it did not bring anything new to the table that experienced educators would not know all along.

Such heterogeneity of views, internal contradictions and unresolved disputes, nevertheless, have not prevented constructivist ideas from being integrated within a number of contemporary educational paradigms put forward in response to traditional approaches to education. In 3.3 I discussed how within Authentic Education paradigm, radical and cognitive constructivism, coupled with the ideas originating from embodied and enacted cognition frameworks, have contributed to several critical pedagogic moments. Among these are: recognition of the current knowledge scheme and abilities of the learner, the shift in understanding of the role of teachers from training to guiding and enabling of individual potential, emphasis on learning about learning (i.e., importance of meta-cognitive skills), importance of collaborations and group work as an environment where learners can test their ideas and negotiate meanings, and others. Within Democratic Citizen Education paradigm, the emphasis shifts from casting learners as individuals to conceptualizing them as a part of a collective that is classroom, school and local and global communities. From this point of view, teachers ought to not only support learners in acquiring concepts and skills as prescribed by curriculum, but to enable the development of learners as personalities and as citizens. Some of the key pedagogical moments within this paradigm are: participation (i.e., enabling understanding of one's role in the dynamics of social processes), conscientization (i.e., helping learners to recognize privileges and partialities), dialogic learning, reciprocal learning, and others that I addressed in 3.4.

The constructivist wave has also absorbed educational robotics, a sub-domain of technology-based learning where robotic technology, such as robotic kits and social robots, is used to facilitate teaching and learning. Constructivism, constructionism, alongside activity based learning, inquiry based learning, problem-based learning, project based learning, design-based learning - methodologies that share common roots with constructivism - are routinely referred to in the theory grounding segments of the ER scientific publications. While it is hard to over-estimate the popularity of constructivism in educational robotics, it is nevertheless not so obvious - especially considering the heterogeneity of interpretations that I discussed above - what different authors mean when they refer to constructivism. To answer this question, I studied a corpus of 57 scientific publications in ER dated 2000-2018. As a result, I identified 4 larger groups of studies based on the depth (shallow vs. informed) and emphases (subject-centered constructivism and associated concepts vs. social constructivism vs. embodied and enactive cognition theories) of interpretations of constructivism in these studies: i) Casual constructivism ii) Informed constructivism iii) Perspectives on Social constructivism and iv) Grounded cognition theories in ER.

In relation to the first group of publications, I discussed how, in these, constructivist pedagogy is commonly reduced to any instances of hands-on manipulations of robotic technology. While such manipulations may not be problematic or unhelpful - to the contrary, they could even lead to successful learning outcomes - I argued that, in itself, they do not suffice for us to label them constructivist as they do not consider other human and non-human factors that contribute to teaching and learning processes. To this point, I asserted that such unfounded references to constructivism, where also no attempts to follow through in empirical designs and theoretical proposals are made, should be avoided as they lead to further devaluation of the term.

The second group of publications is the most extensive. Here constructivism is interpreted primarily through the prism of authentic education paradigm and subject-centered constructivist strands (radical constructivism and cognitive constructivism, with the most frequently cited authors being Piaget, Papert and Resnick), and the robotic applications used predominantly belonging to learning robotics and learning by robotics branches of educational robotics. I discussed how in this group of studies, Papert's constructionism and pedagogical methodologies such as trial and error learning and exploratory learning come forth. I also indicated the limitations of these approaches and the importance of appropriate and flexible (open to change in response to learners' needs and the dynamics of learning activities) support provided by teachers/instructors. Furthermore, I spoke about usefulness of constructionism and constructivism in empowering teachers to integrate robotic technology into classroom work. I also touched upon the role of collaborative activities and of personalization - two critical pedagogical moments within authentic education paradigm - that are also widely applied within educational robotics as pedagogical strategies and, in case of collaboration, as learning objective (i.e., development of social skills necessary for collaborations). However, I also specified the challenge regarding the structuring and evaluation of these approaches as little empirical studies to date exists that would provide data in respect to the nature and dynamics of collaborations and the complex experiences of learners in respect to human and non-human factors that contribute to their success in educational robotics activities.

In the context of the discussion of the third group of studies (Perspectives on social constructivism), I addressed the complementarity of subject-centered constructivist approaches and that of social constructivism as manifested in educational robotics. I discussed that, in educational robotics research, Vygtosky's concepts such as zone of proximal development, scaffolding, more knowledgeable other are commonly integrated within general authentic education orientation. That is, the focus in these studies is still predominantly (but not exclusively) on the individual learner and unravelling of their individual potential. I also pointed out that research that relies on social constructivism, in synthesis with subject-centered constructivist approaches, is less common in comparison to the number of investigations that are grounded exclusively in subject-centered constructivist frameworks. On the topic of social constructivist influences, I discussed how robotic technology from within this perspective can be interpreted as a tool that mediates learning, as a social partner that scaffolds learning by participating in some form of social interaction with the learner and, finally, as a signifier that is shaped by cultural codes and narratives and also shapes these back through the interactions between users and technology.

While some studies in this group addressed the topic of values and believes and how technology can be used to reflect on these, such studies are relatively rare. I speculated that future research in ER may address this topic, as well as the topic of diversifying robotic technology and interaction scenarios for different cultural and social groups. In connection with the democratic citizen education paradigm, I left open the question whether and how social robots as peers or tutors should participate in the formation of learners as persons and citizens.

To conclude the overview of the four groups, I discussed how studies rooted in enactivist and embodied cognition frameworks stand separately from the main block of ER literature where direct references to constructivism are made. This may be explained by the fact that, in constructivist debates, there is no agreement on whether grounded cognition theories should be considered as a part of constructivist movement, or they should be regarded separately on their own terms. In the context of ER, it may also be explained by the shift of emphasis from the study of learning as driven by higher-order cognitive processes or by social interactions, to more targeted investigations that focus on the sensory-motor action during educational robotics activities. Importantly, these studies suggest that embodied level of representations during ER activities is not parallel or sequential to that of iconic and symbolic levels, but that these three levels co-exist simultaneously and support each other. These findings add further evidence to the argument that the divide between different levels represented by different constructivist branches (embodied, intrapersonal cognitive, interpersonal social) is artificial: in real-life teaching and learning, all three levels co-exist and enable each other.

When presenting the results of the critical survey of ER literature I identified a number of false assumptions, challenges and gaps in research. Despite these, my personal view in respect to the role of constructivism for ER diverges from that of Perkins and Terhart. While I agree that, indeed, certain terminological confusion is common to the field (i.e., the same activity can be conceptualized in cognitive constructivist or social constructivist terms), I believe that this speaks not to the ignorance of the authors but to the complementarity of these frameworks and calls for their further integration in theoretical proposals and empirical designs.

I discussed that today it is indeed possible to conduct excellent research that is constructivist in spirit and in principles without necessarily relying on constructivist jargon. However, I am fairly confident in my assumption that - for this to happen - constructivism and constructionism had to play a critical role. It is my belief that these approaches were instrumental for establishing the foundation of the field of educational robotics where learning is almost ubiquitously understood as an open-ended process that relies on learners actively engaging with their environment and interacting socially with their peers and more knowledgeable others - the realization that is yet to be as widely accepted in more traditional learning environments.

I postulated that my objective in this thesis was not to provide arguments for nor against further integration of such technology in extra- and intra-curricular activities. That said, in my discussions I have touched upon the features and affordances of educational robotics that, in my opinion, present the potential worth further exploring. I side with Bers et al. (2002) in positing that one of these features is that - by allowing users (teachers and learners alike) to interact with the technology - it also opens up space for reflections on the assumptions we hold about teaching and learning. These reflections, in turn, can and do lead us to changing and improving our practices. In other words, not only we design and implement robotic applications in agreement with the views that we hold about learning and education at large. But the technology we design also shapes our views by actualizing new ways of engaging with the learning material and with our peers.

To the latter point - while remaining optimistic and sensitive in respect to the potential that robotic technology holds - we shouldn't forget that technology holds power to determine what knowledge is and how it is processed (Noss & Pachler, 1999). This is to say that, in our chase for more sophisticated technological solutions, we should remember that teaching and learning is far from being only a "cognitive" matter. In real life, education is intimately intertwined with complex interpersonal dimensions such as trust, care and vulnerability and, because and thanks to these, it is and it shall remain a fundamentally human enterprise.

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